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THE IMPACTS OF SITE FORMATION PROCESSES ON EXCAVATION METHODOLOGY: THE STUDY OF A WORLD WAR II B-24 CRASH SITE IN MUNSTER, GERMANY

By

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THE IMPACTS OF SITE FORMATION PROCESSES ON EXCAVATION METHODOLOGY: THE STUDY OF A WORLD WAR II B-24 CRASH SITE IN MUNSTER, GERMANY

Alicia J. Lawson, M.A.

University of Nebraska, 2023

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Academic partnerships between universities and the Defense POW/MIA Accounting Agency (DPAA) are a recent development to provide top research universities resources to assist in recovering and identifying MIA service members since World War II. A University of Nebraska – Lincoln (UNL)/DPAA Partner excavation revisited a WWII B-24H crash site in Münster, Germany in the summer of 2022. B-24H [redacted] crashed into three agricultural fields on 23 March 1945. Utilizing quantitative and qualitative data collected on the incident-related and archaeological osseous remains and artifacts recovered from the fields and the fields' land use history, this thesis focuses on analyzing the site formation processes affecting the site and associated material, such as pedoturbation, trampling, plowing, and scavenging. The main methods of analysis are GIS spatial analysis and statistical analysis using Wilcoxon rank-sum and Kruskal-Wallis tests. Before now, the presence and effects of formation processes in WWII aircraft crash sites has remained largely understudied. Special emphasis is placed on comparing the dry-screening and low-pressure wet-screening recovery methods employed during the UNL excavation to discover the significance each had on the type and amounts of material collected. DPAA prefers its organic recovery teams to utilize wet screening as they believe it is quicker and increases osseous remains recovery. They are currently

attempting to transition academic partners to use wet screening as well. However, this thesis concludes that low-pressure wet-screening recovery methods should only be used when high fragmentation rates of possible human remains less than 2.5 cm in length are expected at this or other similar crash sites.

**Please note this thesis contains Department of Defense proprietary information, which has been redacted due to the on-going nature of this DPAA investigation for the protection of the family members and individuals involved in the case.

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I would first like to acknowledge and thank the U.S. service members who have fought and given their lives for our country and our future. Their sacrifices and courage in the face of hardship and suffering exceed what most of us will even have to endure, in part because of their actions. In particular, I would like to recognize the nine airmen aboard B-24H [redacted]. Through my own research, I feel I formed a connection with them as I learned about them, their lives, and the loved ones they left behind. I would also like to acknowledge two other service members, my grandfather Robert Schuetz, who was a B-29 flight engineer and fought in the South Pacific in WWII, and my great-uncle, FSGT Rodney Lawson, a career Army soldier who fought in the Korean War and was killed in action in Vietnam in 1968. Both of these men serve as my continued inspiration for my research into twentieth-century conflicts and MIA service member recovery and identification.

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CHAPTER 1: INTRODUCTION

Over 82,000 U.S. service members are missing in action (MIA) since the attack on Pearl Harbor on 7 December 1941 marked the entrance of the U.S. into World War II. Approximately 72,000 of these missing personnel served during WWII with 22,000 being lost in the Europe/Mediterranean Theater (Defense POW/MIA Accounting Agency [DPAA] 2023**)**. The Defense POW/MIA Accounting Agency is the current iteration of the federal government and U.S. military's multiple groups dedicated to the recovery, identification, and repatriation efforts of these service members over the past 150 years. In the past decade, academic institutions began partnering with DPAA, directing the capabilities and advantages of top research universities toward fulfilling DPAA's mission of providing the fullest possible accounting for MIA personnel from past conflicts to the families and the nation. In return, these partnerships provide educational and research opportunities to students, faculty, and staff. With these new partnerships and novel field team compositions, a review of the current recovery strategies for representative field sites is needed to determine cost and time effective tactics.

This thesis is an inquiry into the site formation processes affecting a WWII B-24 crash site, assessing their impacts on the artifacts, material evidence, and osteological material recovered while analyzing the recovery strategies used to excavate these types of sites. The site in question is designated [redacted] by DPAA and is the crash site of B-24H [redacted], which received a direct hit by anti-aircraft fire over its bombing target in Münster, Germany on 23 March 1945 and crashed into a nearby farm. There were nine U.S. Army Air Force (USAAF) airmen aboard the aircraft. Three crew members survived the incident and were taken as prisoners of war (POW). Five crew members remains were recovered from the site and later identified after the war while one airman remains unaccounted for. Site [redacted] is spread across three agricultural fields (Plots 7, 133, and 113) with the main concentration of incident-related material being in a current horse pasture, Plot 113. The site has been the focus of three investigative and recovery missions since 2016. In September 2016, a DPAA team was sent to locate the crash site and assess its potential to contain remnants of aircraft wreckage (ACW) and related human remains, mainly through a surface search and systematic metal detector survey. A DPAA recovery team began excavating in Spring 2019, focusing on the areas with the highest density ACW.

From 17 June to 19 July 2022, a University of Nebraska–Lincoln (UNL)/DPAA Partner excavation revisited the site with the goal of excavating it to its fullest extent through a perimeter excavation around the 2019 recovery team's completed excavation area within Plot 113. The UNL team consisted of Dr. William R. Belcher, the Lead Archaeologist; six forensic anthropology graduate students, including the author; and five upper-level undergraduate anthropology and forensic students. Taking advantage of this educational opportunity, the excavation doubled as a field school teaching the students basic archaeological field methods, such as how to create site maps, use simple mechanical transits and GPS units, set up excavation grids, and, through this thesis' research, perform simple field-based artifact analysis.

The excavation's goal was to recover all possible human remains and probative material evidence still at the B-24 crash site in hopes of identifying the remaining MIA crew member. This thesis' research was performed secondarily to these efforts, but the results from this analysis will provide recommendations on improved methods for future excavations at comparable crash sites. The two main research questions examined by the author are:

(1) What are the site formation processes affecting Site [redacted], the associated archaeological artifacts, the incident-related material evidence, and possible osseous remains; and,

(2) How does the use of dry- versus wet-screening methods affect the material recovered, in which quantities it is recovered, and the screening efficiency of an academic partnership team comprised mostly of graduate and undergraduate students?

These research questions are answered through a combination of quantitative and qualitative analysis based primarily on the data collected by the author during the 2022 UNL excavation. Spatial analysis using ArcGIS Pro determines the distribution of archaeological and incident-related materials throughout Plot 113. It is also used to compare the samples of collected materials from the dry- and wet-screening stations. The spatial analyses results' significance is determined using non-parametric statistical testing, specifically the Wilcoxon rank-sum and Kruskal-Wallis tests. To determine the effects of the volume of sediment screened by station compared to each station's quantity of recovered materials, the author used an experiment for excavation unit N504-508/E514-516 in which the number of buckets screened per station was recorded. The results of both the spatial and statistical testing will then be interpreted based on the effects of the site formation processes present at the site, identified through qualitative analysis of the archaeological material recovered and knowledge of German agricultural practices and environmental factors in Münster.

The site formation processes of WWII aircraft crash sites remain largely understudied by both DPAA and non-DPAA personnel. Because of this, the broader range of archaeological and geological studies on site formation processes as they impact archaeological deposits are reviewed and applied to this specific site type. This author believes a thorough understanding of these factors will better inform expected preservation rates and materials' behaviors within the sediment matrix to determine the best excavation methodology for team efficiency and ensuring a site's excavation to its fullest extent.[1] Furthermore, academic partners have only recently become an increasingly prominent and relied-upon resource for excavating such sites. DPAA has had to revise and implement their standard operating procedures for such teams with little analysis into the practicalities of these procedures. DPAA Standard Operating Procedures (SOPs) are more akin to the excavation methods of cultural resource management than a traditional academic archaeological excavation; the excavations are often goal oriented to extract possible human remains and probative material evidence from the site sediments. Because of this, the academic archaeologist partners must often adapt to a new style of excavation unlike anything they have done previously. This has resulted in slightly dissimilar excavation methodologies between DPAA recovery teams and academic partnerships. DPAA is currently attempting to merge these two different SOPs and to determine the capabilities of academic partnership teams when applying DPAA recovery standards.

[1] A site's "fullest extent" is defined by DPAA to be its geographic, archaeological, and stratigraphic extent, or to "the extent that the probability of subsequent recovery of additional [human] remains from that location is minimal" (SOP 2.0: *Recovery Scene Processing* 2018:9, 45)

One significant distinction between DPAA recovery teams and academic partnerships recovery strategies is the screening method used. DPAA has become more focused on the use of wet-screening rather than dry-screening sediment during its own recovery teams' excavations, mainly due to the belief that wet screening is quicker and allows for a greater recovery of material evidence and osseous remains. For example, the 2019 DPAA excavation of Site [redacted] wet screened all sediment except the top-most vegetation-heavy stratigraphic unit. However, there has been some hesitation to implement wet-screening operations for academic partner missions due to the increasing logistics, set-up, expense, and experience required for a large-scale DPAA-style wet-screening station. The UNL 2022 excavation of Site [redacted] was the first time an academic partner used a low-flow wet-screening system, in part as an experiment to see if such teams can successfully carry out these kinds of operations. Because UNL also dry screened, this created a unique opportunity to compare the two recovery strategies and their efficiency for academic partners within this thesis.

This thesis discovered multiple site formation processes were present, including those of environmental and human origin that impacted the site area before and after the crash incident. The two deposits, the first being the pre-incident (and to some extent post-incident) archaeological materials and the second being all incident-related materials, have been affected by these processes in unique, divergent ways, requiring two separate excavation strategies. Using ACW and non-human remains as proxies for probative material evidence and possible human remains, this thesis concludes that wet screening allows for a more complete recovery of osseous remains less than 2.5 cm in length but is comparable to dry screening regarding material evidence recovery and time spent screening. Most importantly, only with a thorough grasp on expected modifications to the incident-related materials by formation processes can the best excavation methodology be determined for an aircraft crash site.

A Note on Historical Archaeology in Germany

Münsterland German archaeological research has been largely focused on the medieval period and earlier. Only in the late twentieth century does the term "postmedieval archaeology," covering a similar period as U.S. historical archaeology, begin to emerge in Germany, and it is a field of study with minimal inquiry before the 2000s. Most archaeology performed by Germans into this postmedieval era focuses on either the sixteenth and seventeenth centuries as a continuation of medieval archaeology or the twentieth century's conflicts, including WWII and the Cold War. As a result, German archaeological sites and material culture dating to the late eighteenth and nineteenth centuries are underrepresented in the number of excavations performed and academic literature (Mehler 2018). Unfortunately, this is the main depositional period for the archaeological artifacts recovered at Site [redacted], which has made locating sources referencing the precise period and region within Germany difficult due to their scarcity. This is compounded by the fact that most archaeological research is published in German, further limiting the number of accessible sources for non-specialists. These factors have resulted in the source material for the discussion of recovered artifacts in Chapter 5 being either a general overview of them covering a wide geographic or temporal context or studies focused on a relatively close geographic context but a slightly earlier period.

Moreover, this thesis is a significant contribution to archaeology for the city of Münster and the surrounding area (collectively referred to as Münsterland) because the dearth of documentation on Münsterland farming practices during the postmedieval period in relation to the archaeological record. Although the main excavation goal for Site [redacted] is the recovery of MIA service member remains, throughout this mission, the UNL team also collected a substantial quantity of non-incident-related archaeological materials, which reflect the farming activities and material culture from an average postmedieval farmstead in Münster. These materials are also analyzed for the cultural depositional behaviors that have resulted in their presence within the horse pasture and the identification of site formation processes impacting them after they have entered the archaeological context.

Site Formation Processes

Archaeologists need to consider the site formation processes acting upon a site prior to making inferences and conclusions based on the archaeological record. Although objects move from the systematic to archaeological contexts primarily because of cultural activities, artifacts exist within a sediment matrix that is acted upon by a variety of other cultural and noncultural processes that affect the artifacts' forms and locations in the time between deposition and recovery from excavation (Wandsnider 1987:157). Cultural processes are ones that transform the artifacts and deposit through human behavior while noncultural processes are ones where the main agents of change are environmental factors, such as fauna, water, and sediment formation (Holliday 2004:261). As summarized by Schiffer (1983:678), both these processes can modify objects formally, spatially, quantitatively, and relationally. Moreover, the archaeological record reflects the systematic transformations by these processes, adding, subtracting, and modifying assemblages, to create patterns irrelated to the behavior of the individuals responsible for the initial deposition (Wandsnider 1987:158).

Schiffer (1996[1987]) is a seminal work for the importance of site formation processes and their impacts upon the archaeological record. His book synthesized and built off the scholarship on formation processes while specifying how to identify their presence within the archaeological record. Schiffer discussed cultural formation processes, including the depositional, reclamation and reuse, and cultural disturbance processes, as well as environmental formation processes affecting the artifact, site, and region, such as decay, pedoturbation, and climatic processes. His book's final section is a guide of how to identify these processes by the traces they leave in the archaeological record and how to construct archaeological inferences from the disturbed record.

The two main works for environmental formation processes, specifically pedoturbation and soil formation, are Wood and Johnson (1978) and Holliday (2004). The article "A Survey of Disturbance Processes in Archaeological Site Formation" explored the impacts of pedoturbation processes on the archaeological record (Wood and Johnson 1978). Pedoturbation is defined as the biological, chemical, or physical mixing of soils or sediment, which often disturbs deposited artifacts, creating identifiable patterns; however, the processes' effects are not mutually exclusive and can be compounded (Wood and Johnson 1978:317). As all pedoturbation processes result broadly in either the creation of sediment horizons or the combination of sediment particles from separate horizons, Wood and Johnson (1978) argued the processes can be identified through which of these two results are visible within the deposit. They examined nine widespread processes within their article–faunalturbation, floralturbation, cryoturbation, graviturbation, agrilliturbation, aeroturbation, aquaturbation, crystalturbation, and seismiturbation–which will be considered in Chapter 5 for their potential presence at Site [redacted].

Soils in Archaeological Research is a study of soil formation and how soils and sediments more broadly reflect the environmental factors that influence their formation, including climate, organisms, parent material, and time (Holliday 2004). Holliday considered the applications of pedology and soil geomorphology, defined as the study of how soils form over time, to be especially important for archaeology, a juxtaposition to earlier works that had primarily focused on humans' effects on sediments. Particularly pertinent to this thesis is his discussions on soil genesis and soil derivation from parent material regarding the creation and relationships between the stratigraphic layers at Site [redacted]. Other important topics are the environmental processes that influence soil formation and how to extrapolate soil behavior as indicators of various noncultural site formation processes at a site, especially pedoturbation ones. Holliday finally touches briefly on the impact of cultural site formation processes on soil behavior, including land use and cultivation.

Wandsnider (1987:151) notes the two general methods for the study of site formation processes depend on whether the effects are well-known. For those that are understood, testing can be performed directly on the archaeological record and its deposits to validate previous conclusions; however, for lesser-known processes, experimentation within a modern, controlled setting is necessary to gain a baseline understanding before the conclusions are applied to archaeological materials. This is especially true for cultural formation processes in which a main factor is human behavior, allowing for quantifiable measures of human, and thus the external forces, impacts on the materials under study. Moreover, cultural formation processes' inherent nature of being the result of human behavior makes them fall further within the purview of anthropology than noncultural processes, most of which fall under the fields of geology and ecology. Therefore, archaeological experiments represent a good source of information of the cultural formation processes' impacts on Site [redacted]. Multiple experimental studies are used in this thesis to better understand the effects of plowing and trampling on the site.

Plowzone Archaeology

Historically, archaeologists were unsure how to analyze materials collected from the plowzone stratum, so the materials were often ignored or discounted as useless when answering the main research questions of a study. However, this presented a problem because plowzone archaeological deposits constitute the largest subsection of the archaeological record globally (Dunnell and Simek 1995). To learn more about the effect of plowing on archaeological sites and materials, archaeologists began to record site survey findings and perform experimental research to gain understanding of these effects in the 1970s. Major topics archaeologists focused on were the patterns and extent of horizontal and vertical displacement of materials by plowing, the mechanical damage and fragmentation of materials due to plowing, and the impact object size had on these patterns.

Artifacts. Roper (1976) performed one of the first experiments into plowzone archaeology in which she tracked the movement of biface tool fragments to examine their lateral displacement post-breakage. She found most fragments were displaced parallel to the direction of plowing. She concluded plowing was one of the main sources of lateral displacement at the site (Roper 1976:374). Frink (1984) conducted another early study into plowing's effects on artifact size and distribution, also using lithic artifacts. He recognized the potential presence of a "size effect" in which larger artifacts are more likely to be brought to the surface due to plowing, creating an overrepresentation of larger artifacts on the surface compared to their total population within an assemblage. In particular, he noted that length and thickness rather than weight were impactful characteristics with this sorting. Moreover, he suggested it could be possible to infer artifact density and total population subsurface based on the number of artifacts located on the surface (Frink 1984). Other studies have shown that while it is possible to locate specific features or sites through surface artifact concentrations from site surveys, the accuracy of using artifacts on the surface to estimate total artifact assemblage is questionable (Newcomb et al. 2017; Odell and Cowan 1987).

Odell and Cowan (1987) focused on quantifying the degree of artifact dispersion over time and increasing plow passes, building off Frink's research (1984). Their conclusions supported Frink's size effect and the importance of length and width over thickness and weight in determining the appearance of larger artifacts on the surface. Moreover, they discovered multiple plowing events were necessary for the size effect to be present. They also found the amount of an artifact's displacement is not related to an artifact's size but rather a relationship exists between the duration of plowing and an increase in artifacts' parallel and perpendicular displacements. Also, plowing causes a generally random distribution of materials (Odell and Cowan 1987).

Dunnell and Simek (1995) examined the mechanical damage to artifacts caused by physical contact with plowing implements and the built-up pressure within the sediment during plowing, and how artifact fragment size can be used to infer temporal inclusion into the plowzone. Their study demonstrated artifacts generally reach an equilibrium size with size reduction exponentially decreasing after each repeated plowing. They noted that fragile material classes are more susceptible to this size reduction until they reach a stable size. Additionally, they hypothesized that larger fragments within the plowzone represent artifacts more recently incorporated into the plowzone that have yet to reach the equilibrium size (Dunnell and Simek 1995).

Osseous Remains. Less plowzone literature is dedicated to the examination of how plowing impacts osseous remains, but a few studies have confirmed that bone is similarly affected by plowing when compared to other archaeological materials. Lyman and others (1987) analyzed the length of deer and other similarly sized diaphysis fragments throughout one plowzone and five sub-plowzone strata at a 2,000-year-old archaeological site on the Cuirve River in Missouri that had been plowed for the last 120 years. The authors found 81.4 percent of the plowzone fragments were less than or equal to 4.5 cm compared to only 60 percent in the sub-plowzone layer (Lyman et al. 1987:494-495). This implies bone is similarly subjected to the size reduction process from plowing seen in Dunnell and Simek (1995) and the equilibrium size for deer long bones impacted by plowing is under 4.5 cm, demonstrating that osseous material reaches a stable size over time because of plowing. It also suggests their conclusion on the temporal incorporation of larger artifact fragments could be applicable to bone as well.

Newcomb and others (2017) performed a study on the horizontal movement of dry pig bones buried entirely within and partially within the plowzone to simulate the effect of plowing on a juvenile human burial. They used 10 juvenile pig skeletons buried at 15 cm below surface (cmbs) and 22 cmbs, which were differentially impacted by various numbers of plow passes. For the pig skeletons buried completely within the plowzone, the maximum horizontal displacement of the skeletal material was 12 m in the direction of plowing and 4 m perpendicular to plowing direction after 10 passes. For the pig skeleton partially buried in the underlying stratigraphic unit, the maximum displacement was only 5 m by 3 m for the same number of passes (Newcomb et al. 2017:69). While the relationship between the number of plow passes and the dispersal parallel and perpendicular to the plow direction were significant for both burial depths, the amount of dispersal was much greater for the 15 cmbs burial completely within the plowzone. Furthermore, their conclusions indicate that subsurface fragments can be dispersed at greater lengths than surface fragments (Newcomb et al. 2017). Although the movement of skeletal material was probably greater due to use of whole bones rather than fragments, this study highlights the great potential for horizontal movement by osseous material due to plowing.

Trampling Studies

Like plowing, trampling of the sediment matrix also impacts the size and movement of the archaeological record. The effects to both these properties are determined by sediment penetrability, trampling intensity, artifact depth within the matrix, and inherent properties of that specific material. Penetrability is a measure of the ground surface’s compactness or resistance to applied force (Schiffer 1996:126). It is important to remember a matrix's penetrability can change over time depending on a variety of factors, including moisture content and vegetation.

Gifford-Gonzalez and others (1985) compared the horizontal and vertical displacement of lithic debitage caused by human trampling in a sandy substrate and a loam, sandy silt substrate. At the loam site, the researchers found after two hours of repeated trampling, two people caused more horizontal than vertical dispersal with 94 percent of pieces remaining on the surface. The unconsolidated sandy substrate demonstrated higher penetrability with most artifact fragments penetrating to a depth of 3 to 8 cm. The authors also noted a difference in the vertical distribution of artifacts originally trampled on the surface compared to artifacts already incorporated into the sediment matrix. Regarding the mechanical damage to the artifacts, it varied depending on substrate penetrability and artifact size with the loam site suffering higher rates of damage to artifacts less than 2 cm while more edge-damage was seen on artifacts greater than 2 cm at the sandy site (Gifford-Gonzalez et al. 1985).

Wilk and Schiffer (1979) synthesized archaeological surveys of 17 vacant lots in Tucson, Arizona, drawing conclusions about multiple activity patterns, including refuse disposal, storage, adult and children's uses of the space, camping, and use of paths through the lot. One main conclusion the studies' authors drew was the identification of the "fringe effect," relating to the horizontal movement of artifacts on the low penetrability surface due to trampling. Objects trampled in compact, high trampling zones move laterally to and collect in nearby low trampling zones, such as along walls, fences, or the edges of paths (Wilk and Schiffer 1979:533). This implies artifacts' spatial distribution is in part influenced by trampling behavior, which does not result in the dispersion but rather the concentration of artifacts within portions of a site.

CHAPTER 2: LATE WORLD WAR II ALLIED BOMBING

The historical and geographic context surrounding the 23 March 1945 crash incident as well as the history of the agricultural fields the site is located within are important in understanding the cultural and archaeological settings. The historical background regarding the military activities in the European Theater that led up to the 23 March bombing mission and the eyewitness accounts of B-24H [redacted]'s crash is discussed in this chapter. Furthermore, the recovery efforts for unaccounted for service members were extensive both post-war and have continued into the twenty-first century. This chapter reviews the U.S. military's efforts to locate and identify missing service members specifically in Münsterland after WWII. Modern efforts made by DPAA to account for the one remaining MIA crew member aboard B-24H [redacted] are also detailed for context on past inquiries at Site [redacted]. Finally, it is necessary to review the land use history for Plots 7, 133, and 113, which is based primarily on conversations with the families who have farmed these fields for decades. All of these activities are important aspects for the site formation of Site [redacted].

Historical Context

Although the scope of this thesis is holistic in nature, encompassing centuries of varied land use and agricultural activity represented in the archaeological record, the crash of B-24H [redacted] on 23 March 1945 into these fields is a defining single catastrophic event. The potential for recovering U.S. MIA service member remains is the sole reason for the archaeological excavations at this site. Because this remained the focus of the UNL excavation, with this research being performed secondarily, it is important to place the 23 March 1945 air crash within its historical context. This section will provide contextual information, moving from a broad operations overview to individual perspectives, on the Allied military operations that occurred leading up to and during the 23 March 1945 bombing mission to Münster.

Figure 2.1. Location of Münster in Nordrhein-Westfalen, Federal Republic of Germany (Search and Recovery Report 2022:Figure 1).

Allied Forces Crossing the Rhine and the Preparatory Bombing of Germany

WWII was the first, and some argue only, major conflict since the invention of the airplane to utilize high altitude precision bombing as a primary military strategy. The Casablanca Conference in January 1943 decided the British would focus their efforts on night bombing of targets while USAAF would attack Germany by day. Control of the skies was vital for Allied success because the destruction of Germany's industrial and, thus economic, systems through sustained and constant aerial bombardment was considered necessary for the eventual defeat of Nazi Germany (Freeman 1970:212). The devastation of specific industry and service centers would allow for the invasion and gains by Allied armies on land, therefore before major campaigns, there would be concentrated efforts to destroy important targets to limit German capacity for armed resistance (Simpson 2023). Often, targets would need to be bombed multiple times over a period of weeks or months to prevent repair work or due to only partial destruction in past attacks (Freedman 1970:212).

By 10 March 1945, German forces on the western front had retreated across the Rhine River, considered one of Germany's final natural defenses against invasions. However, significant losses and the chaotic nature of the German retreat, particularly in the south due to the Saar-Palatinate offensive, led to the massive disorganization and limited fighting capabilities of the German divisions along the Rhine's east bank (Churchill 1953). To take advantage of this, Allied forces planned their next offensive to cross the Rhine on 23 March. The main efforts aimed to encircle and capture the Ruhr, an industrial region spanning 50 miles along the Rhine and 60 miles deep. The Ruhr Valley is located in North Rhine-Westphalia and is a large population center, encompassing

Figure 2.2. Allied troop movements from February 8 to March 22 prior to crossing the Rhine and then after the March 23 crossing through April 2. Note Münster in the top middle of the map (Winston 1953:Crossing the Rhine).

cities such as Dortmund and Essen (Figure 2.2). Prewar it produced 65 percent of Germany's crude steel and 56 percent of its coal. Now, it was Nazi Germany's only remaining major source of power, and capturing it would deeply cripple what remained of Nazi Germany (MacDonald 1993:294). Two offensives were planned, to the north and south areas of the Rhine, with an eventual link up to the east of the Ruhr region.

The U.S. First and Third Armies oversaw the crossing in the south. General George Patton had ordered all forces be ready to cross by 21 March, and the actual invasion began at 2200 hours on 22 March as assaults started near Oppenheim and Nierstein to establish bridgeheads. The U.S. First Army had captured the Remagen Bridge on 7 March and had already established their bridgehead there. Within a few days, the U.S. Army had successfully secured the region, and were making inroads to the surrounding areas (MacDonald 1993:220).

The main Allied effort was with the Twenty-First Army Group's crossings in the North on 23 March, codenamed *Operation Plunder*. It is considered the most elaborate river crossing operation of the time, rivaling the D-Day invasion of Normandy in number of troops involved; build-up of supplies, transport, and special equipment; amount of supporting firepower; and intricacy of deception plans (MacDonald 1993:318). Approximately 1,250,000 men intended to cross, with 256 tons of supplies, such as ammunition and engineer stores (MacDonald 1993:297). The airborne attack was codenamed *Operation Varsity*, which supported the river crossings by parachuting behind German lines on 24 March (MacDonald 1993:325). The Allied advances in both the North and South Rhine were so definitively successful the two forces linked up east of

Hamm by 2 April, signaling the collapse of Nazi Germany's western front (Churchill 1953:417).

Allied Air Force Operations Leading Up to Operation Plunder. The Allied Air Forces began a heavy bombing program the last week of February 1945 that continued through March in preparation for the assault across the Rhine. The program was designated "Interdiction of Northwest Germany" and was aimed at sealing off the Ruhr from the rest of Germany by destroying the transportation infrastructure along an arc extending from Bremen to Koblenz. West of this line, targets were communication centers, rail yards, and industrial areas (MacDonald 1993:321). The action began with *Operation Clarion* from 22-23 February (Freeman 1970:211). In March alone, the Eighth Air Force's B-17 Flying Fortresses and B-24 Liberators operated 26 days, flying a total of 30,358 sorties, their record high, and dropping their largest tonnage of bombs in a month during WWII (Freeman 1970:212). In the two weeks leading up to the invasion alone, heavy bombers from the Royal Air Force and USAAF dropped nearly 50,000 tons of bombs (Churchill 1953:411). The assault on such a restricted region, combined with the fact that many of these targets had been hit repeatedly over the last three years, was devastating to Nazi Germany. Churchill's assessment of the Allied Air Forces efforts by 23 March claimed, "continuing raids by our heavy bombers had reduced the German oil output to a critical point, ruined many of their airfields, and so heavily damaged their factories and transportation systems as to bring them almost to a standstill" (Churchill 1953:408).

USAAF [redacted]th Bombardment Group (Heavy)

B-24H [redacted] was assigned to the [redacted]th Bombardment Squadron ([redacted]th BS) of the [redacted]th Bombardment Group ([redacted]th BG) based out of Tibenham, England. The [redacted]th BG was activated in April 1943, entering combat in December 1943. It flew 280 missions during the war, with the last being 25 April 1945 (Birsic 1947). There were four bombardment squadrons within [redacted]th BG: [redacted]th BS, [redacted]st BS, [redacted]nd BS, and [redacted]rd BS. The [redacted]th BG was a part of the Second Combat Wing of the Second Air Division of the Eighth Air Force. The [redacted]th BG flew B-24 Liberators, one of three types of heavy bombers used by the USAAF throughout WWII, the others being the B-17 Flying Fortress and the B-29 Superfortress. Heavy bombers were designated as such because they could carry the largest payloads and had the longest ranges of all planes in use. The Eighth Air Force's bombardment groups based out of England since Spring 1942 were tasked with the daylight bombing of Nazi-occupied Europe (Eighth Air Force Historical Society 2023).

Bombing Missions to Münster, Germany

Münsterland was a major industrial target for the Allies. Its marshalling yards, which are places where trains are assembled and often loaded with goods, played an important role in the transportation of troops and supplies throughout northwestern Germany. It is one of the larger towns located just north of the Ruhr region within the area west of the Bremen-Koblenz line. Because of its importance, Münster was well defended by anti-aircraft installations, making its marshalling yards a dangerous and difficult to navigate target (Case Study: CIL [redacted] 2021). The Münster marshalling yards targeted by the 23 March 1945 mission were subjected to 19 bomb missions by the Eighth Air Force alone, the first occurring in November 1943. Four of these missions were within the month of March 1945, the last being on 23 March. The [redacted]th BG participated in five of these missions to Münster, dropping an approximate total of 297 tons of bombs on the city, making it the group's seventh most heavily bombed target of the war (Birsic 1947).

Figure 2.3. Aerial photograph of Münster during a bombing mission to marshalling yard, which is located under the smoke cloud in the middle of the image. White dots in the surrounding landscape are bomb craters. Most likely taken during a [redacted]th BG mission to Münster on 17 March or 23 March 1945. Top of image is northwest. (Birsic 1947).

23 March 1943 Bomb Mission to Münster, Germany

Eighth Air Force's Mission 908 on 23 March 1943 attacked 10 rail targets in West and Central Germany, consisting of 1,240 heavy bombers successfully dropping their payloads (Carter and Mueller 1991:605-606). Over 160 B-24 Liberators were assigned to target the Münster marshalling yards, including 22 B-24s from the [redacted]th BG (Case Study: CIL [redacted] 2021). The [redacted]th BG mission report recorded 22 aircraft taking off, with 21 of them bombing the target with 500 GP bombs. Only one aircraft was lost from the [redacted]th BG, and the report concluded that the results of bombing were good (Birsic 1947).

Accounts of the B-24H [redacted] *Aircraft Crash Incident*. Multiple accounts of B-24H [redacted]'s crash have been recorded over the decades, including airmen from other planes participating in the bombing run in the Missing Air Crew Report [redacted] (MACR [redacted]), eyewitnesses on the ground questioned by investigators after WWII and in modern times, and the surviving crew members' own reports in the six KIA crew members' Individual Decreased Personnel Files (IDPFs).

A MACR was completed for each air crew that failed to return to base after a mission and included any pertinent information, such as the names of those aboard the plane, target location, eyewitness accounts from other airmen, and last known locations of the aircraft. IDPFs were created for each service member declared MIA in WWII and is a main source of information on the service member's loss event and all attempts to locate and identify their remains. All six crew members from B-24H [redacted] killed in action have their own IDPFs, which contain the individual's medical and dental records and all correspondence between different sections of the military and government as well as between the military and the individual's family members. They also have copies of the American Graves Registration Commission's (AGRC) report for the 1946 investigation into those declared MIA in Münsterland and the cemetery in Münster where all Americans were interred by German soldiers during the war. Eyewitness accounts by those who witnessed the crash and later events on the ground as well as the surviving crew members' accounts of the incident and their initial capture as POWs are in them as well. Also included in IDPFs of those crew members identified after the war is the analysis of the unknown servicemember's remains (X-File) later correlated with and identified as that individual and the final disposition of the remains. The MACR and

IDPFs are valuable primary documents for understanding the historical events of the incident.

As expected, many contradictions exist between all these accounts due to the traumatic nature of the event and confusion over the details as time passes. However, an accurate reconstruction of the incident is still possible. The bombing formation approached Münster's marshalling yards from the east, with a course of 290º from Gütersloh, Germany (REF: Missing Air Crew Report [MACR] [redacted], dtd 26 March 1945). At approximately 1130 hours, B-24H [redacted] received a direct hit by anti-aircraft fire while over the target just after it dropped its payload. The plane maintained its direction and altitude of 24,000 feet for another minute before entering a spin toward the ground (Case Study: CIL [redacted] 2021). The airman eyewitness from another aircraft reported in the MACR that the plane's rudder and horizontal stabilizer came off, causing this loss of control (REF: MACR [redacted], dtd 26 March 1945).

The three surviving crew members provided their own accounts of the crash via letters to the War Department after the war, which were added to the deceased crew members' IDPFs. The nose turret gunner[2] had escaped the nose turret as the plane began to lose control but lost consciousness from the lack of oxygen, sliding out of the aircraft. After regaining consciousness while falling, he released his parachute. He was quickly captured once on the ground and did not see the aircraft after it crashed (Case Study: CIL [redacted] 2021; REF: Individual Deceased Personnel File [IDPF] [redacted]). The navigator

[2] There was no bombardier aboard this aircraft. After their initial operations in 1943, the [redacted]th BG would have either a nose turret gunner or a bombardier aboard each aircraft for missions. Lead aircrafts would fly with a full crew, but all other aircrafts on the mission would have their nose turret gunner in charge of releasing their own bombs when the lead aircraft bombardier dropped theirs (Simpson and Simpson 2021).

reported he assisted the nose turret gunner through the nose gear doors and bailed out himself when the plane was at 8,000 feet.[3] After landing, he saw the aircraft on its belly in an open field next to a highway in the northwest area of Münster with part of the right wing and right vertical stabilizer and rudder off. The German soldiers who interviewed him after his capture showed him the tail gunner's identification tags and the waist gunner's pin, both of which they found in the aircraft wreckage (Case Study: CIL [redacted] 2021; REF: IDPF [redacted]). The radio operator was the only other survivor. He bailed out but did not see anyone else leave the aircraft and hypothesized the centrifugal force of the plane's spiral to the ground prevented other crew members from bailing out themselves. He did not see the wreckage after landing. The Germans who captured him stated they found only two sets of remains in the aircraft, but he thought they were lying to him to learn more information about the other crew members. He believed all six unaccounted for crew members were likely still within the aircraft when it crashed and all six sets of remains were found in the wreckage (Case Study: CIL [redacted] 2021; REF: IDPF [redacted]; REF: IDPF [redacted]).

Multiple eyewitnesses on the ground provided accounts of the crash as well as the immediate events after the crash. The landowner of Plot 113 during WWII, [redacted], was interviewed by AGRC investigators in 1946. He stated three sets of remains were removed from the wreckage by German soldiers and another two were found near the crash site. He reported another body was also found some distance away

[3] The navigator and nose gunner's positions in a B-24H were closest to one another in the front of the plane. Both were supposed to bail out of the nose gear doors in emergencies (see Figure 2.5)

from the site, but no other residents' historical accounts mention this set of remains (Case Study: CIL [redacted] 2021).

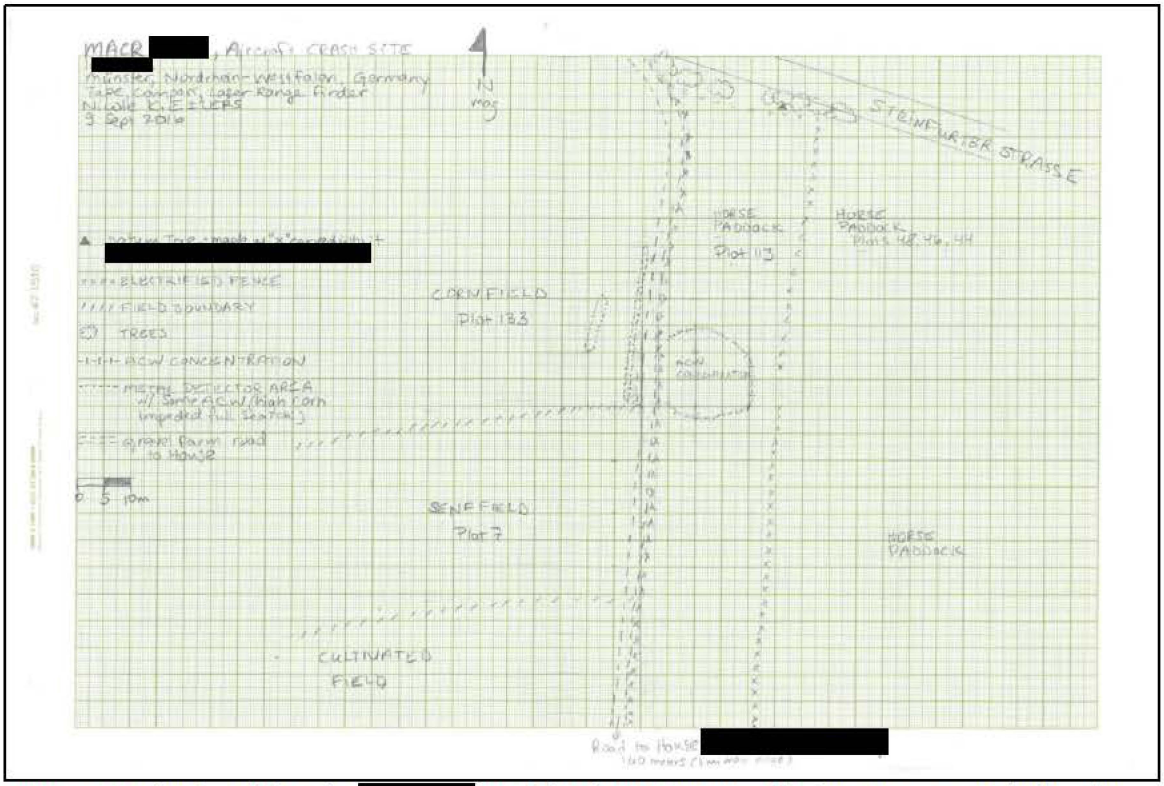

Figure 2.4. Site sketch for Site [redacted] made by the DPAA Investigation Team. Note the location of Plots 133 and 7 in the center-left portion of the map and Plot 113 in the center-right portion. Wasserweg Road bisects the map vertically in the center with the left vertical line (Excavation Proposal: CIL [redacted] 2016:Figure 2).

The surviving eyewitness [redacted] (hereafter Herr [redacted]) is the current landowner of Plot 113, the son of [redacted]. He was 13 years old at the time of the incident and witnessed the crash from his family's bunker in their barn. He was interviewed first by DPAA in 2016 and again by the author in June 2022. Herr [redacted] remembers the aircraft first crashed into their neighbor's field, before bouncing across Wasserweg Road, the dirt road dividing the two properties, and coming to rest on its belly in Plot 113 approximately 200 m from their farmhouse. There were no bombs onboard because B-24H [redacted] had released their payload before being hit by anti-aircraft fire, so the aircraft did not explode at any time. He believed it was largely intact at this point but caught fire upon impact. It rested mostly on top of the ground with no impact crater created. He reported four sets of remains were found in the wreckage–three were in the front and one in the tail section. Herr [redacted] remembers seeing two men in the cockpit who could not escape because of the fire. The only "whole" set of remains in the plane was the one recovered from the tail. The others were burned due to the fire. He reiterated his father's statement that one man jumped out of the plane, and his body was found a few hundred meters away from the crash. Once the fire stopped and German soldiers were able to access the plane, they laid the recovered remains along the Wasserweg Road until they were buried at the Haus Spital Cemetery a few days later.

The aircraft itself most likely broke in two during the crash according to Herr [redacted]'s account, separating the tail from the front half behind the wings. B-24s were susceptible to breaking in this area due to their design. The plane's nose and wings with the four engines came to rest a few meters beyond Plot 113's fence line, the cockpit being torn apart, and the broken tail section resting further behind ([redacted], personal communication 2022; Report of Investigation: CIL [redacted] 2016). The aircraft wreckage and its materials belonged to the state. The German soldiers did not allow the landowners to get close to the aircraft. It was a few weeks before the large pieces were taken away from the field. The family and their neighbors collected the small parts that remained. Herr [redacted] does not know what his father did with the pieces he took, but a 97-year-old neighbor told the UNL 2022 excavation team he repaired his motorcycle with salvaged parts from the crash site when he returned home in November 1945 ([redacted], personal communication 2022; [redacted], personal communication 2022). There were some reports that the remaining fuselage parts were buried in a nearby bomb crater, though these remain elusive from modern inquiries (Interim Search and Recovery Report: CIL [redacted] 2019).

German Report. The German military kept detailed records on Allied aircraft crashes, containing information like witness accounts, type of aircraft, number of remains found and burial locations, and names of POWs captured. Both the IDPFs of the six crew members killed in the crash and DPAA historical reports reference the German report for this aircraft written on 28 March 1945. Identification tags of one of the waist gunners were recorded as found at the crash site along with the identified crash site being located on the [redacted] property (Case Narrative: CIL [redacted] 2016). The report states the aircraft was shot down by anti-aircraft fire and caught on fire upon impact; however, the aircraft is mistakenly identified as a British Lancaster 683, which had a similar twin tail configuration to B-24s. The report denotes the aircraft was 99 percent destroyed, creating a plausible reason why it was misidentified. Five deceased crew members were recovered from the wreckage. Five men were taken prisoner by the Germans; however, it was presumed by the U.S. military that these men represented the survivors of both this aircraft and another lost approximately 6 km northeast of the crash site on the same day (Case Summary: CIL [redacted] 2021; Case Narrative: CIL [redacted] 2016).

Post-War Efforts for Recovery and Identification of Remains

AGRC Investigation in March 1946

AGRC, U.S. Quartermaster Corps, was tasked with searching for and recovering the remains of missing servicemembers in the European Theater. This often involved performing area searches to locate isolated burials and aircraft crash sites in Europe, disinterring their remains to identify them at identification centers around Europe and/or re-interring the remains in established U.S. military cemeteries. An AGRC team investigated Münsterland in March 1946. They reported locating a B-24 wreckage found on the [redacted] property and correlated it with B-24H [redacted] based on the four machine guns' serial numbers found at the site matching the ones listed in MACR [redacted] (REF: IDPF [redacted]).

The AGRC team also exhumed 41 sets of remains from the Haus Spital Cemetery, which were eventually all identified as American service members associated with the multiple U.S. aircraft losses in Münsterland. All U.S. service members were buried by the German military at this cemetery throughout the war in a total of 26 marked graves with bodies buried individually or in common graves. AGRC was unable to recover any German military records for the cemetery as they were taken by the German Army in

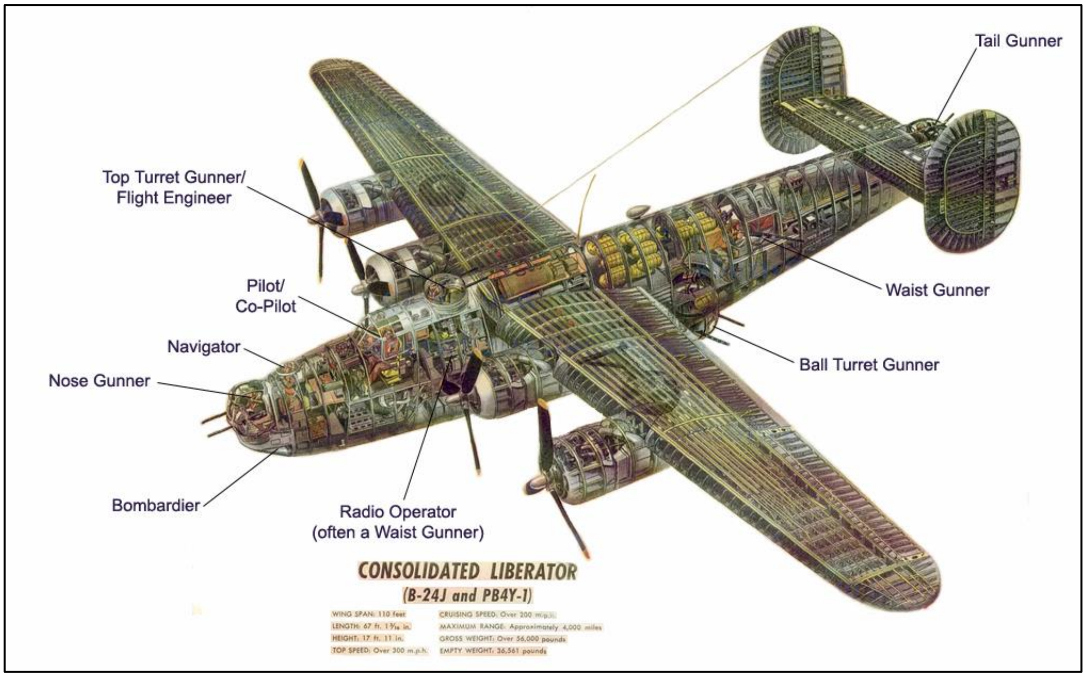

Figure 2.5. Position of crew members in a B-24J, which had no major differences in crew positions from B-24Hs. The crew aboard B-24H [redacted] included two waist gunners as well as a radio operator (Weber 2023).

April 1945 when they retreated from the area and were in a Russian-occupied zone as of March 1946 (Case Study: CIL [redacted] 2021; REF: IDPF [redacted]).

Identification of the Five Recovered B-24H [redacted] Crew Members

Three members of the crew were specified as being disinterred from two boxes found within Grave 11 at the Haus Spital Cemetery. One box contained the remains of the pilot, identified by his identification tags, and the top turret gunner, identified through dental records (REF: IDPF [redacted]; REF: IDPF [redacted]). The other box disinterred from Grave 11 contained the remains of one of the aircraft's waist gunners, who was also identified through the comparison of dental records (REF: IDPF [redacted]). All three sets of remains were described as "mangled" and burned, with only small portions of bone and decomposed flesh recovered (REF: IDPF [redacted]s; RED: IDPF [redacted]). Based on the location of the pilot and top turret gunner's stations in the front half of the plane, it is likely their remains were two of the three recovered from the front half of the aircraft in the wreckage (Figure 2.5). This is further supported by the reports of their remains exhibiting thermal alteration due to the ensuing fire in this location after the crash.

There is greater confusion surrounding the location and disinterment of the other waist gunner and the tail gunner. AGRC's records state they were recovered at a cemetery in Münster but do not identify the cemetery. All 41 remains disinterred from the Haus Spital Cemetery were sent to the U.S. military cemetery at Neuville for identification while these two crew members' remains were sent to the U.S. cemetery at Margraten instead.[4] Moreover, they were not identified in the AGRC report as coming

[4] For information on the movement of unidentified remains by AGRC post-war between American cemeteries for identification purposes, see "Utilization of GIS in Tracking Disinterment and Movement of

from a specific grave at the Haus Spital Cemetery. This means it is possible they were exhumed from a different cemetery in Münster (Case Study: CIL [redacted] 2021). Other reports indicate their bodies might have remained unburied until March 1946, which is why they were not reported as coming from the Haus Spital graves (REF: IDPF [redacted]). The tail gunner was identified through clothing marks while reports did not specify how the waist gunner was identified (REF: IDPF [redacted]; REF: IDPF [redacted]). The tail gunner's remains were described as "complete" in the identification report and based off the tail gunner's position in the bomber's tail, it is likely his remains were the ones described as being located in the tail wreckage after the crash by the eyewitness (REF: IDPF [redacted]; [redacted], personal communication 2022). It is unknown which waist gunner was recovered from the aircraft wreckage versus the one most likely found a few hundred meters from the wreckage; however, it is probable the waist gunner identified from Grave 11 was the one recovered from the wreckage itself in the front portion of the aircraft because of the description of thermal alteration to his remains as well as the fact he was buried in the same grave as the two crew members most likely recovered from that location.

Modern Efforts for Recovery and Identification of the Remaining MIA Service Member's Remains.

DPAA has undertaken multiple investigations into the 23 March 1945 crash and the unrecovered service member's case. The two main field investigations occurred on the site in 2016 and 2019. An overview of these two missions as well as DPAA's

Unknown US WWII Dead: Foundations for a Geospatial Approach to Addressing Commingled Remains" by E. N. Axelrod (2022).

justification for excavating the crash site based off their research and the conclusions drawn from their investigations is important for understanding the methodology of the UNL excavation.

DPAA Investigation Team Mission in September 2016

DPAA Investigation Teams (ITs) are generally the first field investigators for cases. DPAA sends ITs to locations to conduct field investigations, including interviewing eyewitnesses and local residents, conducting research in regional archives, identifying potential sites for excavation, and performing site surveys (DPAA Partner Field Orientation Manual 2022). An IT was sent to Münster in September 2016 with the intent to investigate cases in Münsterland and a primary focus on B-24H [redacted]'s case. Their mission goals involved conducting archival research into relevant burial records, records pertaining to the loss incident, and cadaster maps to locate the property ownership of the crash site during WWII and currently; identifying and interviewing potential witnesses and researchers with information on the loss incident; locating and correlating the crash site of B-24H [redacted]; conducting a site survey of the crash site; and collecting data on other air losses and missions in the area for DPAA records (Report of Investigation: CIL [redacted] 2016).

They successfully completed these goals, including conducting extensive research at local archives into cemetery records and historical records pertaining to the 23 March 1945 crash incident and other losses in the area, identifying the crash site across Plots 113, 133, and 7 through witness information and historical aerial imagery (Figure 2.6), and conducting a site survey of the plots (Report of Investigation: CIL [redacted] 2016). Using a combination of a systematic metal detector survey of Plots 7 and 113 and a pedestrian survey through 133, the IT was further able to locate a concentration of ACW in Plot 113 that was of archaeological significance for future excavations (Site Survey Form: CIL [redacted] 2016).

Figure 2.6. Post-incident aerial imagery indicating the location of possible anomalies at Site [redacted] (Interim Search and Recovery Report: CIL [redacted] 2019:Figure 3).

Justification for Excavation of Site [redacted]

Based on all research conducted by DPAA historians and the IT, DPAA concluded excavating the crash site offers the best chance for recovering the unidentified service member's remains. The unaccounted-for crew member was reported by the surviving navigator to be in the plane while it was descending (REF: IDPF [redacted]). There is no evidence suggesting his remains were removed from the crash site or buried with the other crew members. There is also no evidence claiming he was able to bail-out prior to the crash. Both eyewitness accounts and the German report indicate only five sets of remains were found at the crash site and later buried (Case Narrative: CIL [redacted] 2016). Moreover, even though three other B-24s crashed within a 25 km radius of Site [redacted], all those aircrafts' crew members are accounted for, and there currently are no unknown remains associated with the Haus Spital Cemetery nor any other cemeteries or isolated burial sites in Münster (Excavation Proposal: CIL [redacted] 2016). All 41 sets of disinterred remains from the Haus Spital Cemetery were identified in the years following the war, supporting the theory that the unaccounted-for crew member is still at the crash site. Due to the partial and mangled nature of the identified deceased crew members' remains, it is considered probable additional portions of their remains and the remains of the unidentified crew member are located at the crash site.

[redacted]*: Excavation of Site* [redacted] *by DPAA Recovery Team in 2019*

From 19 April to 17 May 2019, Mission [redacted][5] excavated approximately 448 m^2 of Plots 133 and Plot 113. The approximately 25-person recovery team included both

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[5] The mission number for the 2019 excavation is [redacted], referring to the fiscal year [redacted], this being the [redacted] DPAA field mission scheduled that year, and the country designation of [redacted] for Deutschland, or Germany.

DPAA personnel and short-term individual augmentees, who generally are military personnel assigned to the mission. Prior to excavating, the team conducted a systematic metal detection survey of Plots 113 and 133 to assess where the highest concentrations of ACW and incident-related materials were located to direct the location of the initial excavation area within the plots. The team ended up excavating a sizable rectangular area within the western edge of Plot 113 and a 4-m-x-12-m area in Plot 133 on the opposite western edge along Wasserweg Road. They recovered possible osseous remains, possible material evidence, and possible life-support evidence, which was sent to the DPAA Offutt Laboratory for further forensic analysis. The excavation was suspended by the Lead Archaeologist on 17 May due to the end of the mission, but he recommended further excavation of Plot 113 to the north, south, and east of the area the 2019 team excavated and in Plot 133 (Interim Search and Recovery Report: CIL [redacted] 2019).

Land Use History of Site [redacted]

Land Use History of Plots 7 and 133

The city of Münster owns both plots but a tenant farmer has leased them for decades. They were leased by the current tenant's father before him. Plot 7 has been alternatively used as a horse pasture and cultivated field. For example, during 2016, it was a mustard field. Plot 133 had always been a cultivated field, rotating crops of grains, maize, potatoes, and cabbage (Report of Investigation: CIL [redacted] 2016). Both fields were plowed regularly following the 23 March 1945 crash incident (Site Survey Form: CIL [redacted] 2016).

Land Use History of Plot 113

Most information in this section comes from the conversations between the author and Plot 113's current landowners, Herr [redacted] and his wife [redacted] (hereafter Frau [redacted]). This family has lived on this farm for at least two generations, which includes much of the twentieth century. However, the existing farmhouse itself dates to the seventeenth century, and it is likely the land was worked in some fashion even before this. Not much is known about Plot 113's land use before the [redacted] family acquired the property. They always had it as part of their farm in which they both cultivated crops and raised livestock. The [redacted] indicated Plot 113 was primarily a pasture for their livestock and rarely plowed by both them and Herr [redacted]'s parents before them. During the war and for two years after, the plot laid fallow before being worked again due to state mandates. Both before and after the incident, the family raised cows, pigs, and hens on their farm that used the field. Around 1964-1965, they owned approximately 70 cows and transitioned the farm to solely be a cattle operation, using the pasture for grazing. From 1972 to 1992, it became a pig farm. In February 1993, [redacted] reopened their farm as a horse stable, and Plot 113 became a horse pasture.[6] Because the fields have primarily been used for livestock, the vegetation grown on them consisted mostly of grasses regularly mowed to make hay and other feed for the animals raised on the farm at that time ([redacted], personal communication 2022). The vegetation regenerates itself, though the landowners' son-in-law [redacted] indicated it has been seeded in the past if necessary ([redacted], personal communication 2022). Due to the rapidly expanding Münster city boundaries, the land will be developed by the city in the near future, which presented an

[6] All animals mentioned were represented in the faunal osseous remains recovered during the 2022 excavation.

extra concern for the excavation of the crash site before this occurs ([redacted], personal communication 2022**)**.

Wasserweg Road and Highway B54 Changes Since Incident

Wasserweg Road is the residential road bisecting the crash site, dividing Plots 7 and 133 from Plot 113. This is the road B-24H [redacted] probably bounced across upon impact before coming to rest in Plot 113. It is primarily used by residents of the area and has not been greatly altered since WWII. The one exception is the addition of utility lines, including a fiber-optic cable that run along the east side of the road, and presented an extra concern while excavating units in Plot 113 directly adjacent to the road. Road construction and maintenance over the years has likely impacted the border zone of Plot 113 and the materials within this area. State Highway 54 was present in 1945, but it expanded to the four-lane highway of today in 1969. The city used a portion of the northern edge of the fields to expand the highway, altering how the crash site's location looks relative to the highway's boundaries today compared to historical imagery of the site ([redacted], personal communication 2022**)**. The highway expansion probably did not impact Site [redacted] in any way.

CHAPTER 3: METHODOLOGY

Chapter 3 provides a review of the pertinent information on DPAA's archaeological excavation methodology as described in DPAA's Standard Operating Procedures 2.0: *Recovery Scene Processing* (SOP 2.0: *Recovery Scene Processing* 2018). This lays a foundation upon which the comparisons and recommendations of the screening methods occur. Furthermore, excavation methods have a direct impact on which site formation processes can be identified and on how and which data were collected by the author for spatial and statistical analysis. The limitations of the quantitative data based on the archaeological and incident-related assemblages recovered by the UNL excavation team affected which statistical and spatial analyses were performed as well. The selection and benefits of the experiments and testing implemented are also discussed.

Archaeological Methods

Determining where and how to excavate a site can have some of the most significant impacts on the materials recovered. Often, at aircraft crash sites, the debris will be scattered across a large area ("debris field"), and it is up to the investigators to identify areas with the highest chance for recovering possible human remains using pedestrian surveys or remote sensing methods. Moreover, the excavation methods used at a site will govern which materials are recovered and their quantities. Because of these considerations, special attention is paid to the DPAA 2016 and 2019 teams' relocation of the crash site, the 2019 team's decision of where to begin excavating, and the screening methods and station set-ups used by the 2019 and 2022 excavation teams.

DPAA Investigation Team Site Survey

As previously mentioned, the IT initially located the crash site, including the large concentration of ACW in Plot 113. From 9-10 September, the 2016 team conducted a site survey to make two assessments: (1) were these three plots the correct location of the B-24H [redacted] crash and (2) would archaeological excavation yield any incident-related probative materials that would lead to an identification, such as human remains and material evidence. Probative evidence can be defined as items that contribute direct or circumstantial support toward the identification of an individual. Some examples of probative material evidence include personal items like a watch or ring, identification media like ID tags or ID bracelets, and data plates linked to specific aircrafts (DPAA Partner Field Orientation Manual 2022). Non-probative material evidence can be considered ACW or other incident-related materials with no investigative value.

The IT performed a systematic metal detector survey in Plots 113 and 7, covering an area approximately 70 m by 60 m. The team excavated any metal signatures within 10 cm of the surface to ascertain if they were aircraft-related materials or metal objects that had been discarded into the field through cultivation and agricultural use. The IT located a concentration of ACW in Plot 113 approximately 15 m by 15 m in size. They also conducted a visual survey in Plot 133, which was planted with mature maize at that time, impeding a metal detector survey. The team found plexiglass, .50 caliber ammunition, and possible ACW on the surface in this plot, all incident-related material (Site Survey Form: CIL [redacted] 2016). Based on witness accounts and wartime aerial imagery, the IT recommended Plot 113 be the focus of future recovery operations/excavations.

DPAA [redacted] Recovery Team Excavation

The 2019 excavation was conducted using the procedures and guidelines outline in SOP 2.0 under the direction of Dr. Clive Vella, the team's Lead Archaeologist. Two key archaeological methods they used in the context of this thesis were the initial metal detector survey and the wet- and dry-screening stations setup and operation.

Initial Metal Detector Survey. The team first completed another metal detector survey before excavating to determine the areas where the team should focus their efforts based on ACW and evidence concentrations. They focused primarily on Plot 113 but extended the survey further west across Wasserweg Road into Plot 133, which was unplanted at the time, and into the horse pasture east of Plot 113. Like the previous IT, the recovery team, excavated all metal signatures to determine whether incident-related materials were present. The team reidentified the high ACW concentration in Plot 113 the IT located in 2016. They also discovered that while there were some metal signatures in the other two fields, there was a significant decrease in incident-related materials and found only small ACW in them (Interim and Recovery Report: CIL [redacted] 2019). Based on the results of this survey, Vella decided to focus efforts along the western edge of Plot 113 because of possible life-support equipment found. The grid origin[7] was set at MGRS [redacted] using the WGS-84 horizontal datum and a Garmin GPSmap 79s receiver tracking eight satellites with an estimated positional error of ± 3 m at an elevation of [redacted] m above mean sea level. A grid of 4-x-4-m units was established.

[7] Grid origin is set at N500/E500 according to DPAA procedure to avoid having units with negative number designations.

Different sized units were used along the edge of the pasture and Wasserweg Road to avoid excavating into the road and damaging underlying service cables.

Excavation and Screening Operations. The sediment was excavated through a combination of hand tools and an 8-ton mechanical excavator (Interim and Recovery Report: CIL [redacted] 2019). For much of the mission, the topsoil, identified as Stratigraphic Unit 1 (SU 1) or the root mass, and the subsoil were kept separate with the topsoil being dry screened while the subsoil was wet screened. This is a normal request as many farmers do not want the nutrient rich top layer to be mixed with the subsoil during the excavation. Plot 113's landowners, however, did relax this requirement toward the end of this investigation and throughout the UNL excavation. The excavation reports and field notes do not contain much detail about the dry-screening station, expect to say it was located about 12 m south of the grid origin (Interim and Recovery Report: CIL [redacted]

Figure 3.1. Image of the wet-screening station from the 2019 excavation in the foreground with the dry-screening station is in the left background and the Plot 113 excavation area in the right background. View is northwest (Interim and Recovery Report: CIL [redacted] 2019:Figure 8).

[redacted] 2019). The wet-screening station was a more extensive operation, consisting of two elevated wet-screening platforms with a 16,000-liter pool under it to collect the sediment and water (Figure 3.1). The water was then cycled through three 5,000-liter pools before being fed by two water pumps up to the platform again. A fourth 5,000-liter pool was also used for overflow when the screened sediment was being removed from the other pools. With no other easily accessible water source, the landowner's water supply was used to replenish the pools. Even through it was a closed system, 2,000 to 4,000 liters of water was replenished daily due to water loss from sediment removal. The mechanical excavator was also used for this removal process (Interim and Recovery Report: CIL [redacted] 2019).

UNL [redacted] *Excavation Archaeological Methods*

Mission [redacted][8] excavation's main objective was to excavate a 2- to 4-m perimeter around the area excavated by the 2019 recovery team in Plot 113 (Figure 3.2). This perimeter is termed the "2-4 Meter Evidence-Free Margin" in the DPAA Partner Field Orientation Manual (2022). It is a customary rule to ensure all units yielding any probative material are surrounded by at least 2 to 4 m of excavated units that do not contain probative evidence. Only once this evidence-free margin is complete and all information points to a low likelihood of finding any additional evidence at the site can DPAA determine an excavation has reached its reasonable limits and close it from further investigation or excavation (DPAA Partner Field Orientation Manual 2022).

The IT and 2019 excavation used an oak tree between State Highway 54 and the

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[8] [redacted] is the mission designation for the UNL/DPAA Partner excavation. It was initially slated to occur in the [redacted] fiscal year.

northern fence line of Plot 113 as their site datum. The UNL team started by re-locating this tree, which had been marked with a carved and spray-painted "x" into its southside. They also re-established the grid origin and the four exterior corners of the 2019 recovery

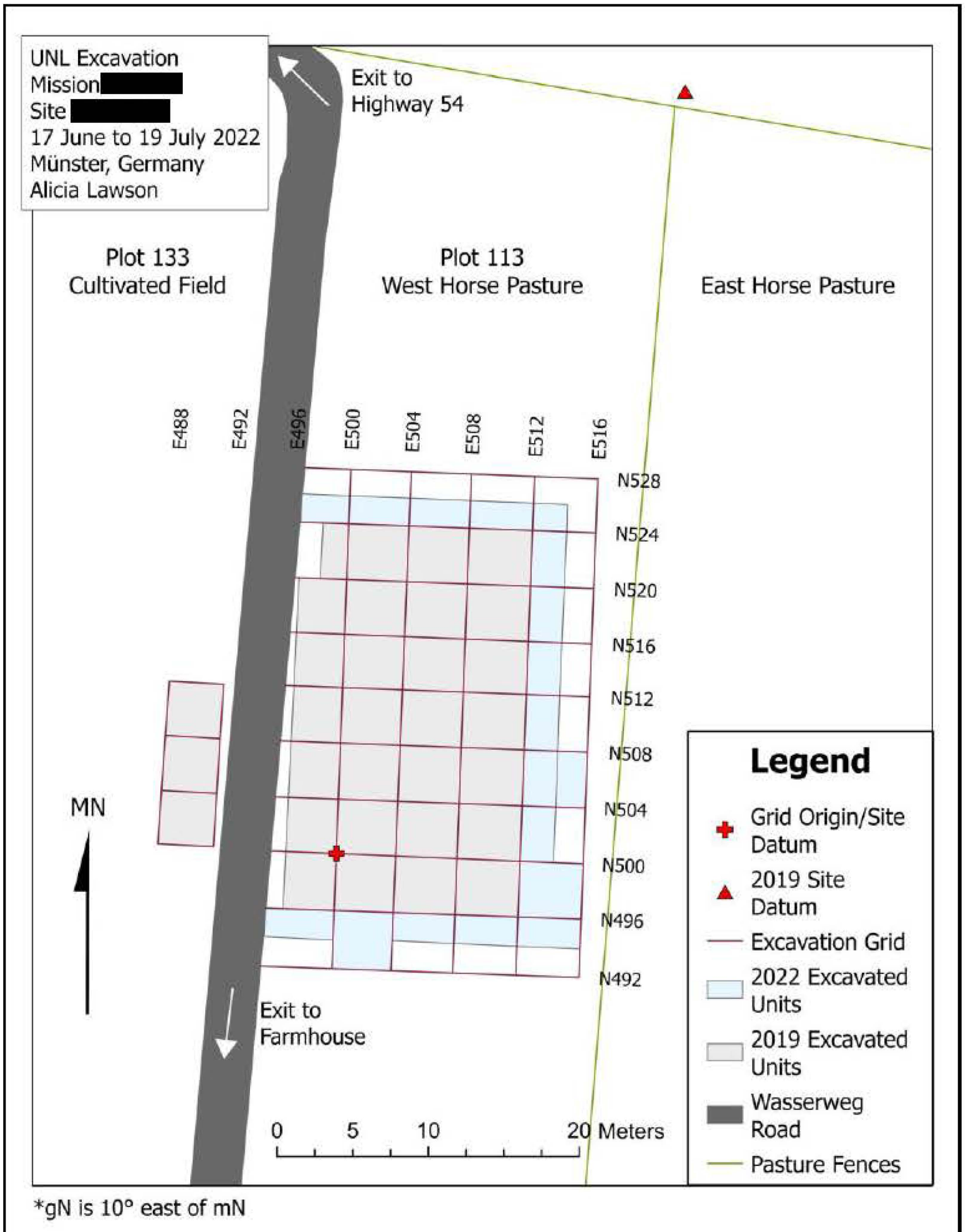

Figure 3.2. Site map for Site [redacted]. Units are designated by the two northings and two eastings which delineate their four borders.

team's excavated area using five metal rods placed in these locations by the 2019 team before closing the site. Rather than continuing to use the oak tree as the site datum, the UNL team established the grid origin as their site datum (N500/E500).

The site had been planted with a long grass used to make hay, which was mowed by the landowners prior to the team's arrival. The team cleared the remaining hay from the excavation area before establishing the first 4-x-4-m unit (N492-496/E500-504). They added more units to the grid periodically as the excavation progressed, moving in a counter-clockwise direction around the area excavated in 2019. The first unit was 4-x-4-m, but the following ones were 2-x-4-m units because no probative evidence had been found in each preceding one. The one exception to this trend was N496-500/E512-516, which was the only other 4-x-4-m unit, due to the fact the landowner's son-in-law mistakenly dug the entire square with the excavator before realizing it was intended to be a 2-x-4-m unit. The only other units that varied in size were N524-526/E512-514, N524-526/497.8, and N494-496/E496.7-500. The former was a 2-x-2-m corner unit and the latter two marked the most western extents of the UNL excavation because of Wasserweg Road.

Units N492-496/E500-504 and N494-496/E504-508 were excavated manually using shovels and picks. All other units' sediments were excavated by a Wacker-Neuson ET-16 mechanical excavator, operated by Dr. Belcher and Herr [redacted].[9] Unit walls and floors were hand cleaned with hand picks, shovels, and trowels to ensure units

[9] According to SOP 2.0, the use of a mechanical excavator can be "cost effective and efficient." Annex F (Mechanical Excavation) particularly notes its usefulness when excavating a larger swath of area to a shallow depth, which the UNL excavation qualifies under (SOP 2.0: *Recovery Scene Processing* 2018:42). The UNL excavation was across an area 20 m by 32 m with an average depth of only 37 cmbs.

were excavated to their fullest extent and to obtain clean profiles for documentation. Excavated sediments were placed next to each unit and tagged before being carried to screening stations using two-gallon buckets. Prior to closing excavation units, both the unit floor and the ground where the unit's sediment was placed were scanned using a metal detector to ensure all incident-related materials had been recovered. All materials recovered from a unit were given the same vertical provenience designation based on the lowest point of excavation in that unit (e.g., all recovered materials for N492-496/E500-504 had a vertical designation of 0-40 cmbs).

There were three stratigraphic units present in Plot 113 (Figure 3.3). Stratigraphic Unit 1 (SU 1) is characterized by a brown (7.5YR 4/2) sandy silt matrix containing a concentrated root mass for the pasture's vegetation. Stratigraphic Unit 2 (SU 2) is a mottled brown (10YR 4/3) silty sand matrix and is a plowzone with high artifact concentration and yielding almost all incident-related materials. SU 2 could also be considered a cultivated A or Ap horizon (Holliday 2004:266). Stratigraphic Unit 3 (SU 3) is a yellowish brown (10YR 5/4) silty sand matrix considered incident-sterile glacial till

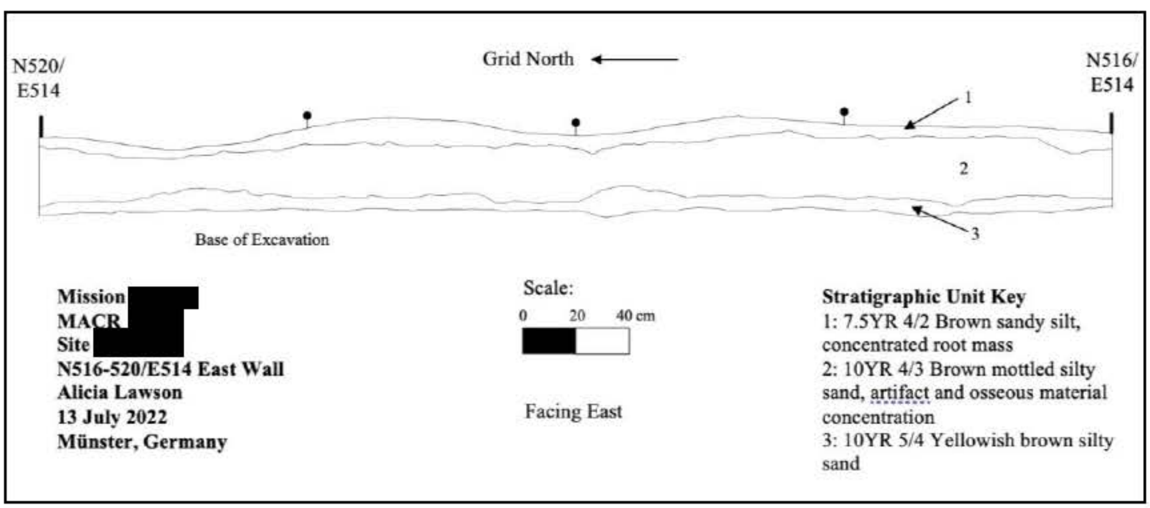

Figure 3.3. Section Drawing of E512-516/E514 (facing east).

sediment, marking the Site [redacted]'s vertical limits. Almost no incident-related materials and other artifacts were collected from SU 3, and the few that were recovered for this layer most likely were embedded into it due to the force of the aircraft's impact in the field. No eyewitness accounts mention the presence of a crash crater, which is reflected in the observed stratigraphic composition of the site. Most likely, the aircraft collided with the ground at a low enough angle to cause the aircraft to bounce along the surface while preventing a crash crater from forming.

Dry-Screening Station Set-Up and Operation. The dry-screening station was established south of the excavation area. It consisted of four wooden A-frames supporting a metal rod that had six one-fourth inch wire screens hanging from it. Typically, two people would work on the same screen, so a total of 12 people could dry screen at one time, but only rarely were 12 people dry-screening at once. Usually, five to seven people would be on dry screens, especially after the wet-screening station became operational. Hand picks and trowels were used to break up clumps of sediment as well as any root masses. All sediment was removed from the root masses before the grass was discarded during the screening process. Archaeological and incident-related artifacts were collected in buckets while possible osseous remains were placed in the evidence bags made for each unit. As the screened sediment built up underneath the screening station, the mechanical excavator was used to remove it and place it out of the way.

Wet-Screening Station Set-Up and Operation. The team began wet screening on 3 July 2022. Although they experienced little difficulty dry screening the sediment before this, Dr. Belcher decided to begin wet screening to see if its inclusion could increase the speed at which the team screened units. N504-508/E512-514 was the first unit to be screened using a mixture of both wet and dry screening. All units after it were wet screened to some extent.

The set-up was a modified version of previous DPAA wet-screening stations, albeit a low-flow system (Figure 3.4). It used a water pump that moved water at a low pressure into hoses used to direct the water onto the screens. The water was then collected in a 5,000-liter pool under the screens before flowing into another 5,000-liter pool where it was then re-cycled through the pump. The water pressure was no higher than a regular garden hose. It was a closed system that required daily water replenishment as it was lost from sediment removal from the pools. Four screening stations, using the same one-fourth inch wire screens, were set up, so only a maximum of four people could wet screen at one time. Usually, three to four team members would wet screen at once. The team would rotate who was wet or dry screening throughout the day. Generally, one

Figure 3.4. Wet-screening station for the [redacted] excavation. View is northwest (Photographed by W.R. Belcher, DSC_0203.jpg).

shift consisting of three people wet screened in the morning (from 0900 or 0930 to 1200 hours), and two shifts of four people each would divide the afternoon (from 1300 to 1800 hours).

One hour each day was dedicated to removing the sediment build-up from the first collection pool. Two team members would enter the pool to scoop the sediment into buckets, which were then passed down a bucket line to a closed excavation unit, where it was deposited. The removed sediment was first deposited in N492-496/E500-504, and the team continued to deposit it into units, moving in a counter-clockwise direction as preceding units were filled up.

Quantitative Data Collection

The primary data for this thesis was collected during the UNL excavation. It consists of both qualitative and quantitative data. While the majority of the quantitative data is based on the types and amounts of incident-related and archaeological materials recovered, the qualitative data were gathered through conversations with the landowners, eyewitness accounts of the crash, and the author's own research into the incident. These qualitative data have been partially discussed in Chapter 2 when reviewing the incident and land-use history and will be further analyzed within the section on site formation processes in Chapter 5.

The author was responsible for processing all artifacts, archaeological and incident-related, collected by unit, sorting them into six categories: porcelain, earthenware, glass, ACW, oxidized metal, bricks/shingles, and miscellaneous objects. ACW and oxidized metal were separated because most of the B-24 metal was aluminum, which had corroded due to the aircraft fire and ensuing exposure to the elements for almost eight decades, giving it a whiteish-green appearance. The other metal found in Plot 113 was largely iron or steel farming implements, nails, and bolts that had been deposited into the field and were rusted. When in doubt, a hand-held metal detector was used to determine if an object was metallic. The team recovered burned chunks of silica from the sediment, probably created by the aircraft fire, which caused confusion due to its similar color and appearance to metal.

Other common types of ACW recovered were Bakelite fragments, metal from ammunition feeds, .50 caliber ammunition, wiring and parts from the instrument panels, Lift-the-Dot snaps, navigator protractor fragments, and plexiglass. The ammunition was collected in a separate bucket throughout the excavation and was turned over to the Unexploded Ordnance and Disposal Unit of the Münster Fire Department for disposal. It was not included as part of the recovered ACW weight. The miscellaneous objects included both random archaeological materials that were not prevalent enough for their own category like graphite pencils, but also the more important artifacts that were segregated out for the LWL Museum – Archäologie für Westfalen archaeologists (LWL Museums). These included clay pipe bowl and stem fragments, porcelain and metal figurines and toys, lead textile seals, and coins.

Once all artifact types were sorted, each was weighted in grams to gain a quantitative measure of their prevalence for the spatial and statistical analysis. In addition, the wet- and dry-screen collected artifacts were kept separate throughout this process to facilitate comparisons between the two methods.

For the osteological material recovered, it was examined first by Dr. Belcher for a human or non-human determination. The osteological material data used in this thesis consists solely of material designated as non-human remains (NHR). For this analysis, all NHR fragments from each unit were separated into three size categories: small (<2.5 cm), medium (2.5-5 cm), and large (>5 cm). Size was determined by the length of the longest axis of the fragment. These size categories were chosen arbitrarily based on the NHR fragments' sizes seen from the first few excavated units. One consequence of these designations is 86 percent of all fragments ended up being categorized as small. However, as will be discussed in Chapter 5, this size categorization and the vast number of small fragments, gains an interesting facet when one applies expected site formation processes to these data. For every unit, the number of fragments in each category was recorded along with the total weight of all fragments in grams. Like with the artifacts, all NHR fragments collected through wet and dry screening were kept separate for comparison purposes.

Table 3.1. Dry-screened artifact category weights (g) by excavation unit. Units N492-496/E500-504 through N500-504/E512-514 were solely dry screened. N524-526/EE508-512 was mostly dry screened.

Excavation Unit	cmbs	ACW	Glass	Porcelain	Earthenware	Metal	Brick/ Shingles	Misc.
N494-496/ E496.7-500	0-60	149	285	102	159	865	780	13
N492-496/ E500-504	0-40	326	984	380	403	851	1098	31
N494-496/ E504-508	0-35	179	684	395	311	466	890	31
N494-496/ E508-512	0-30	50	349	271	277	584	632	45
N494-496/ E512-516	0-30	7	473	186	357	596	1021	79
N496-500/ E512-516	0-35	124	116	451	661	968	1890	43
N500-504/ E512-514	0-40	193	403	169	361	672	1126	75
N504-508/ E512-514	0-30	265	364	276	167	764	950	62
N504-508/ E514-516	0-45	290	387	207	226	451	734	6
N508-512/ E512-514	0-40	218	368	125	233	498	939	4

N512-516/ E512-514	0-40	89	300	150	150	638	730	26
N516-520/ E512-514	0-35	18	336	127	138	361	695	8
N520-524/ E512-514	0-40	56	376	149	265	504	963	12
N524-526/ E512-514	0-30	5	187	123	125	213	379	4
N524-526/ E508-512	0-35	29	584	341	286	752	1616	12
N524-526/ E504-508	0-40	14	249	161	224	626	812	71
N524-526/ E500-504	0-28	45	167	87	89	160	423	7
N524-526/ E497.8-500	0-30	10	181	82	96	214	679	11

Table 3.2. Wet-screened artifact category weights (g) by excavation unit. Units N492-496/E500-504 through N500-504/E512-514 were not wet screened at all. N524-526/EE508-512 was only minimally wet screened.

Excavation Unit	cmbs	ACW	Glass	Porcelain	Earthenware	Metal	Brick/ Shingles	Misc.
N494-496/ E496.7-500	0-60	49	124	48	88	274	144	N/A
N492-496/ E500-504	0-40	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N494-496/ E504-508	0-35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N494-496/ E508-512	0-30	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N494-496/ E512-516	0-30	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N496-500/ E512-516	0-35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N500-504/ E512-514	0-40	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N504-508/ E512-514	0-30	78	146	26	78	183	300	25
N504-508/ E514-516	0-45	120	230	120	242	259	555	7
N508-512/ E512-514	0-40	233	208	122	129	129	346	11
N512-516/ E512-514	0-40	68	170	100	75	290	334	6
N516-520/ E512-514	0-35	34	181	95	165	158	457	6
N520-524/ E512-514	0-40	7	128	104	76	145	245	2
N524-526/ E512-514	0-30	7	163	68	62	60	269	15
N524-526/ E508-512	0-35	N/A	4	9	14	N/A	13	N/A
N524-526/	0-40	6	220	120	157	156	292	10

E504-508								
N524-526/ E500-504	0-28	12	156	109	134	211	463	12
N524-526/ E497.8-500	0-30	7	177	62	57	153	238	7

Table 3.3. Dry-screened NHR fragments by number and total weight (g) by excavation unit. Units N492-496/E500-504 through N500-504/E512-514 were solely dry screened. N524-526/EE508-512 was mostly dry screened.

Excavation Unit	**cmbs**	**Small Fragments Number (<2.5 cm)**	**Medium Fragments Number (2.5-5 cm)**	**Large Fragments Number (>5 cm)**	**Weight (g)**
N494-496/ E496.7-500	0-60	39	2	0	29
N492-496/ E500-504	0-40	40	7	1	43
N494-496/ E504-508	0-35	97	16	5	152
N494-496/ E508-512	0-30	60	7	2	64
N494-496/ E512-516	0-30	55	12	3	88
N496-500/ E512-516	0-35	161	35	2	188
N500-504/ E512-514	0-40	105	10	0	73
N504-508/ E512-514	0-30	89	12	2	97
N504-508/ E514-516	0-45	30	7	1	35
N508-512/ E512-514	0-40	47	7	1	59
N512-516/ E512-514	0-40	65	3	1	34
N516-520/ E512-514	0-35	40	7	0	40
N520-524/ E512-514	0-40	79	12	1	80
N524-526/ E512-514	0-30	21	2	0	14
N524-526/ E508-512	0-35	114	19	4	152
N524-526/ E504-508	0-40	38	10	2	147
N524-526/ E500-504	0-28	6	2	0	25
N524-526/ E497.8-500	0-30	12	2	1	25

Table 3.4. Wet-screened NHR fragments by number and total weight (g) by excavation unit. Units N492-496/E500-504 through N500-504/E512-514 were not wet screened at all. N524-526/EE508-512 was only minimally wet screened.

Excavation Unit	cmbs	Small Fragments Number (<2.5 cm)	Medium Fragments Number (2.5-5 cm)	Large Fragments Number (>5 cm)	Weight (g)
N494-496/ E496.7-500	0-60	4	1	0	<1
N492-496/ E500-504	0-40	N/A	N/A	N/A	N/A
N494-496/ E504-508	0-35	N/A	N/A	N/A	N/A
N494-496/ E508-512	0-30	N/A	N/A	N/A	N/A
N494-496/ E512-516	0-30	N/A	N/A	N/A	N/A
N496-500/ E512-516	0-35	N/A	N/A	N/A	N/A
N500-504/ E512-514	0-40	N/A	N/A	N/A	N/A
N504-508/ E512-514	0-30	21	0	0	7
N504-508/ E514-516	0-45	71	7	1	64
N508-512/ E512-514	0-40	51	10	0	37
N512-516/ E512-514	0-40	48	2	1	56
N516-520/ E512-514	0-35	89	1	0	33
N520-524/ E512-514	0-40	59	9	0	60
N524-526/ E512-514	0-30	50	3	1	38
N524-526/ E508-512	0-35	N/A	N/A	N/A	N/A
N524-526/ E504-508	0-40	24	8	0	39
N524-526/ E500-504	0-28	35	1	0	12
N524-526/ E497.8-500	0-30	10	4	0	16

Volume Experiment with Unit N504-508/E514-516

The spatial and statistical analysis comparing recovered assemblages from units both wet and dry screened do not consider the recovery rates with respect to the total volume of sediment screened by each station. Central components of DPAA's argument favoring wet screening concern increased volume of sediment processed per unit time and enhanced recovery of materials of interest because the water and cleaning increases the visibility of probative evidence in the screens. Volume is a necessary factor when considering these two arguments, which are the hypotheses for the following experiment. Because of this, an experiment was conducted throughout the screening of unit N504-508/E514-516 (0-45 cmbs) to allow the volume of sediment screened by each station to be estimated based on the number of buckets the team screened. The experiment was conducted from 4-6 July with the majority being screened on 5 July. Throughout the excavation two-gallon buckets were used to transport excavated sediment to the screening stations. For this experiment, each bucket was filled three-fourths of the way full (approximately 1.5 gallons (gal) per bucket). The author oversaw counting and filling buckets for these three days to ensure the experiment’s accuracy and consistency. Eight buckets were designated for the wet-screening station and 18 were designated for the dry-screening station, keeping them constant for the entire experiment. The author collected the empty buckets from one screening station and tallied the number being filled for that round before filling them. Only after all were filled would they be carried back over to the screening station. Wet-screening and dry-screening buckets would not be filled at the same time to prevent confusion.

The grams per gallon (g/gal) for each artifact category based on the weight of the artifacts collected by the two screening stations was calculated through a series of steps (see the formulas listed below for reference). First, the number of buckets processed by the wet- and dry-screening stations was multiplied by 1.5 gal, the volume of sediment in each bucket, to get total volume of sediment processed by each station. The weight (g) of artifacts collected for each artifact category and station was then divided by the total volume of sediment processed by that station. A similar process was followed for the NHR fragments data. The number of small, medium, large, and total fragments collected by each station were divided by the total volume of sediment processed by that station to get the number of fragments per gallon (number/gal) recovered. Then, the weight (g) of the total number of NHR fragments recovered by each station was divided by the total volume of sediment processed for that station to calculate the g/gal of NHR recovered.

Number of buckets x 1.5 gal = Total volume of sediment processed by screening station

Weight (g) of artifacts ÷ Total volume of sediment = Weight (g) of artifact collected/gal screened

Number of NHR fragments ÷ Total volume of sediment = Number of NHR fragments collected/gal screened

Spatial Analysis Methodology

The [redacted] site map made by Vella for the Interim Search and Recovery Report (CIL [redacted] 2019) was used to georeference the site and to guide the digitization process in ArcGIS Pro (ERSI ArcGIS Pro: Release 3.0.0). All data were imported on top of this digitized base map to create the various maps used for the spatial analysis of artifact and osseous material's distributions. Two reference points, the [redacted] site datum and the [redacted] site datum, were used in the georeference process. One main problem encountered while completing this was the lack of other known GPS coordinates for the site. The two datum points' MGRS coordinates were converted into their equivalent degrees-minutes-seconds coordinates and the WGS-84 projection was used, which was the GPS's set horizontal mapping datum when initially taking the coordinates in the field. The map elements, including Wasserweg Road, the excavation grid, the [redacted] site datum, the [redacted] site datum/grid origin, and the fence line, were digitized using Vella's then georeferenced site map into polygon, line, and point shapefiles.

The artifact and osteological material quantitative data from the UNL excavation were imported into ArcGIS Pro in a TXT format and joined to the shapefiles of the 2022 excavated units with the key being each unit's grid coordinates (e.g., N504-508/E512-514). This means the data can be spatially displayed in relation to the unit from which the recovered materials came by connecting it to the shapefile. The data manipulations performed for the spatial and statistical analysis involved taking the base data collected in the field, described above in Tables 3.1-3.4, to determine new values, such as total NHR fragment number for each unit from adding up all small, medium, and large fragment numbers.

Wet-Screening versus Dry-Screening Material Recovery and Distribution Choropleth Maps

Choropleth maps are used to compare the recovery and distribution of archaeological and osteological materials based on the wet- and dry-screening populations. Equal frequency classifications facilitate comparisons within a population, such as the total weight of an artifact collected by each unit. This classification system also allows for a relative quantity comparison within and between populations. This is done through the classifications of low, medium, and high concentrations of each artifact by excavation unit for each screening method and comparing the relative classification of the units and their distribution to each other and the other screening method. This also negates the volume problem when comparing screening methods across all excavated units. Furthermore, only 2-x-4-m units are included in these maps to standardize the unit dimensions and volumes as best possible. This was done to prevent either the increase in total sediment amount from larger units or the decrease in amount from smaller units from impacting the analysis and obtain a better comparison due to consistent underlying variables. A choropleth map was chosen for this series because it is the thematic map most closely associated with area, and there is a close association between the data and the area of each excavated unit. The same colors, layout, and visual hierarchy are utilized for these maps to facilitate comparisons between wet and dry screening within the same and between different recovered material categories.

Total NHR Fragments and ACW Distribution Graduated Symbols Maps

These maps examine the total number of NHR fragments and total weight of ACW recovered from each unit, combining the data from wet- and dry-screening stations. The Jenk’s natural breaks classification strategy was used as it identifies the best divisions for the desired classes by increasing the differences between classes and decreasing differences within them. For the NHR fragments map, four classes were used to divide all 18 excavated units. For the ACW distribution map, three classes were used to divide the 13 2-x-4-m units. The 2-x-4-m units were chosen to standardize unit size and facilitate comparison to the dry- and wet-screening concentration maps. Only three classes were created to compensate for the loss of the five irregularly shaped units from consideration. A graduated symbols map was chosen to display the class information for each unit because of the connection between larger symbols used for larger numbers of fragments. To ensure readability, each class’s symbol size was assigned a different color with the color intensity increasing with consecutively larger classes as well.

Statistical Analysis

The two main statistical tests used were the Wilcoxon rank-sum test (also called the Mann-Whitney U-Test) and the Kruskal-Wallis test. Both are nonparametric rank tests that analyze the probability of two or more samples deriving from the same population based on the samples' distributions and location of both medians. The corresponding parametric tests, the independent t-test and one-way analysis of variance test, use the samples' means, but both medians and means are measures of central tendency. Both can be used to describe populations and samples derived from said populations; however, a mean can be distorted by the extreme or outlier values within the data unlike medians, which is why even though parametric tests could be considered more rigorous, they are not recommended for samples with non-Gaussian distributions. Moreover, Bridge and Sawilowsky (1999) demonstrate that the Wilcoxon rank-sum test lost little statistical power compared to an independent t-test should the sample's population turn out to be normally distributed while holding significant power advantages for skewed or heavy tailed population distributions. These advantages also favor the Wilcoxon rank-sum test when the analysis contains smaller sample sizes.

Table 3.5. The null or directional hypothesis for all statistical tests used.

Statistical Test	**Null (H_0) or Directional (H_D) Hypothesis**
Two-tailed Wilcoxon rank-sum	H_0: the medians of the two samples are equal
Kendall's tau	H_0: the two samples are not correlated
One-tailed Wilcoxon rank-sum	H_D: sample A's median shift is less than sample B's
Kruskal-Wallis	H_0: the medians of all samples are equal
Eta-squared	H_0: all samples are from the same population
Pairwise Wilcoxon rank-sum	H_0: the medians of the two samples are equal

The statistical analysis can be split into two overarching categories. The first involved one- and two-tailed Wilcoxon rank-sum tests to analyze whether there was a significant difference between the recovery rates of all artifact categories and NHR between the wet- and dry-screening stations, and which station had the positive directional median shift. The second used the Kruskal-Wallis and the pairwise Wilcoxon rank-sum tests to determine whether there was a significant difference between the distribution classes identified in the spatial analysis across the excavation units for ACW and NHR. Following anthropological statistical standards, a significant p-value of 0.05 was used for all tests. All statistical analysis was completed using RStudio (R Core Team 2021:v.4.1.2).

Methodology for the Wilcoxon Rank-Sum Test Analysis of Screening Station Recovery

Before discussing the statistical process, there are a few considerations to review concerning the data used in the wet- and dry-screening samples. Although the volume of sediment screened by each station is not numerically considered in this analysis, only data from 2-x-4-m units are included to standardize the underlying variable of unit size. Including both smaller and larger units would unnecessarily introduce outliers and impact the results. Furthermore, only 2-x-4-m units that were screened for the majority by both stations are used, which excludes N524-526/E508-512 from this analysis because it was almost entirely dry screened. Due to these constraints, the samples for both stations are comprised of the eight 2-x-4-m units both wet and dry screened. This is an unusually small sample size for this type of statistical analysis, but because of the above considerations, these eight units will offer the most consistent and valid results.

The Wilcoxon rank-sum test has multiple assumptions the data must satisfy before use, including data are measured on at least an ordinal scale and chosen randomly. Furthermore, both samples must have a continuous distribution, be independent from one another, and have equal variance (Fogarty 2019:161-162; Taegar and Kuhnt 2014:110).

Non-Gaussian distribution could almost be assumed due to the small sample sizes, but visual inspection of the data in boxplot formats confirmed this. One flaw with statistical tests usually used to determine the nature of a sample's distribution, such as the Shapiro-Wilk test, is they often return Type II errors when analyzing small samples, so they were not considered. Levene's test for homogeny of variance, which can be used to analyze variance for two or more samples of non-Gaussian distribution, also confirmed equal variance between samples (National Institute of Standards and Technology 2012).

For all samples that met these assumptions, first a two-tailed Wilcoxon rank-sum test was performed to determine if that artifact or NHR category's recovery samples distributions are different. The null hypothesis is the medians of each sample are equal (i.e., both samples' distributions are equal, meaning they come from the same population). The alternative hypothesis is the medians of each sample are not equal (i.e., the shift or difference in their distributions' locations is not equal to zero, meaning they come from different populations; Fogarty 2019:161-162).

Because a two-tailed test can only determine if the two populations are different and not how they are different, a one-tailed Wilcoxon rank-sum test can be used to determine whether one is larger or smaller than the other. In this case, a directional hypothesis states whether the true location of the median shift is greater than or less than zero depending on if one is examining the positive or negative tail of the sample's distribution. For all categories that rejected the two-tailed Wilcoxon rank-sum null hypothesis, the one-tailed test was computed to determine the direction of the median shift.

One main problem with rank tests occurs when ties are present within the data. Rank tests focus not on the value of the observations but their rank, which is based off their position when listed lowest to highest according to their value. The sums of the samples' ranks are then calculated to determine the likelihood they come from the same distribution. Ties, defined as two observations with the same value, are problematic because two observations cannot be of the same rank, meaning mid-ranks must be assigned to them. R automatically averages tied observations' ranks when running a Wilcoxon rank-sum test; however, this mid-rank means R cannot compute an exact p-value and returns an approximate p-value instead (Taeger and Kuhnt 2014:111; Ford 2017). R will still return an approximate p-value when ties occur in a test of less than 50 observations but with a warning message. Only three categories examined for this analysis contained tied observations, which are annotated in the results section.

Another important thing to note is the wilcox.test() function in R returns both a test statistic (*W*) and a p-value. However, the *W* value returned by R is actually the Mann-Whitney *U* test statistic, which is derived from the Wilcoxon rank-sum test statistic *W*, defined as the sum of the combined sample's ranks, and is not equivalent (Taeger and Kuhnt 2014:113). The Mann-Whitney *U* is used when reporting the results for clarity.

To measure the association between the dry-screened and wet-screened samples, the Kendall's rank correlation coefficient test, or Kendall's tau, was used. The measure of association can also be thought of as measuring the strength of relationship between variables, so while Wilcoxon rank-sum tests determine the presence of a relationship between the two samples, the Kendall's tau test will determine how strong that relationship is. Kendall's tau was chosen over a Spearman's rank correlation coefficient test because of the small sample size and the presence of ties in the data. Two assumptions for Kendall's tau are that samples are measured on an ordinal or continuous scale and are monotonic (Laerd Statistics 2018). The null hypothesis being tested is the samples are independent, or not correlated (τ = 0). The alternative hypothesis is the samples are correlated (τ ≠ 0). The value of τ can range from -1, meaning there is a perfect negative relationship between the two samples, and 1, meaning there is a perfect positive relationship between the two samples. Table 3.6 contains how relationship strength will be determined for all other values in this range.

Table 3.6. Definitions of the levels of a relationship's strength based on the Kendall's tau value (±).

τ value	**Strength of Relationship**
0.01 – 0.19	Very weak
0.2 – 0.39	Weak
0.4 – 0.59	Moderate
0.6 – 0.79	Strong
0.8 – 0.99	Very strong

Methodology for the Kruskal-Wallis Test Analysis for ACW and NHR Distribution

The Kruskal-Wallis test is the nonparametric equivalent of the one-way analysis of variance test and an extension of the Wilcoxon rank-sum test. The main difference in the Wilcoxon rank-sum and Kruskal-Wallis tests assumptions is the latter is designed to compare the medians of three or more independent samples. As such, the same procedure to confirm all assumptions was used. The tests also use the same theory of ranking each observation to compare the medians of all groups. The Kruskal-Wallis' null hypothesis is all samples have equal medians, and the alternative hypothesis is the samples' medians are not equal (Sullivan 2023; Taeger and Kuhnt 2014:117). The one caveat to this statistical test is it can only identify that there is a difference between the samples' distributions but is not capable of computing how the samples' distributions are different.

The pairwise Wilcoxon rank-sum test in R can then be used to compute the pairwise comparisons between group levels with corrections to determine if there is a significant difference between individual pairings from the original group of samples being examined (R Documentation 2023a).

Tomczak and Tomczak (2014) recommend using an eta-squared test to determine an effect size for the Kruskal-Wallis test. The eta-squared estimate is calculated using the *H*-statistic given by the Kruskal-Wallis test, and its possible values range from 0 to 1. If this estimate is multiplied by 100, it indicates the percentage of variance in the dependent ordinal or above variable explained by the independent nominal variable (Tomczak and Tomczak 2014:24). The accepted values to determine small, moderate, or large effect are 0.01 – <0.06 for a small effect, 0.06 – <0.14 for a moderate effect, and >0.14 for a large effect (R Documentation 2023b).

The samples used for this analysis are based off the classes computed by ArcGIS Pro concerning ACW and NHR distributions throughout the site as depicted in the relevant spatial maps. The aim of this statistical analysis is to determine if the classes classified by the Jenk’s natural breaks classification scheme are significantly different from one another. ACW and NHR were focused on because they can be considered proxies for probative material evidence and human remains. Moreover, if a significant difference exists between the concentration of ACW across the site, it could indicate where further excavation efforts should be focused. As for the distribution of NHR, whether significant differences exist between classes, their location throughout the site potentially lends value to the site’s deposition analysis, specifically the traditional fertilization techniques used on Plot 113 while it was cultivated for crop production.

CHAPTER 4: RESULTS

The N504-508/E514-516 volume experiment as well as the spatial and statistical analysis of artifact and NHR fragment distributions are presented in this chapter. Preliminary conclusions are provided to offer some clarity for conflicting statistical results based off the sample compositions. Furthermore, connections reflected in the statistical and spatial analysis results are highlighted.

Volume Experiment Results for Unit N504-508/E514-516

A total of 460 buckets were screened with the dry-screening station completing 269 and the wet-screening station completing 191 (Table 4.1). On 4 July, only 12 buckets (10 were dry screened and 2 were wet screened) were processed because the unit was started right before the end of the day. On 5 July, the team completed 293 buckets. On this day, three team members were working on cleaning unit walls and floors the entire day. Because of this, four people worked at the wet-screening station, and only four to five people worked at the dry-screening station, giving roughly equal workforces per station. Interestingly, this is reflected in the almost identical number of buckets screened by each station that day: 148 by the dry-screening station and 145 by the wet-screening one. It is important to note most of SU 2 was screened on 5 July, which is the stratigraphic unit that contained most recovered artifacts. On 6 July, the wet-screening station had three to four people at a time, completing 44 buckets, while the dry-screening one had five to seven, completing 111 buckets. The unit was completed around 1345 hours and the sediment screened this last day was mostly the root mass in SU 1, which was much easier to dry screen, and the sediment from the unit's wall and floor.

Regarding the rate of screening, it is important to remember two people at the dry-screening station would usually work on one screen together while the wet-screening station was set up to allow only one person per screen. Based on 5 July, this translates to one person being able to wet screen one screenful, or 1.5 gal of sediment or one bucket, in the same amount of time it would take two people to dry screen two screenfuls. This means, for SU 2 and SU 3 sediments, one person could screen the same volume of sediment in approximately the same period of time.

Table 4.1. Number of buckets screened for N504-508/E514-516.

Day	Number of Buckets Wet Screened	Number of Buckets Dry Screened	Total Number of Buckets Screened
July 4	2	10	12
July 5	145	148	293
July 6	44	111	155
Total	191	269	460

Converting the number of buckets to volume measurement reveals a similar pattern. The difference in sediment volume processed between the stations on 5 July was only 4.5 gal when both stations had roughly equal manpower and majority of the sediment was a loose silty sand matrix. Comparatively, there was a 100.5-gal difference on 6 July when the dry-screening station had a few more workers and most of the matrix screened that day was the concentrated root mass from SU 1. Overall, 58.5 percent of the sediment from N504-508/E514-516 was processed by the dry-screening station and 41.5

Table 4.2. Volume (gal) of sediment screened by each station and total volume screened broken down by day and overall for N504-508/E514-516.

Day	Volume of Sediment Wet Screened	Volume of Sediment Dry Screened	Total Volume of Sediment Screened
July 4	3	15	18
July 5	217.5	222	439.5
July 6	66	166.5	232.5
Total	286.5	403.5	690

percent by the wet-screening station, a total difference in volume being 117 gal (Table 4.2).

Considering the quantity of materials collected, the dry-screening station collected more for each artifact category except for earthenware and miscellaneous objects (Table 4.3). For these two categories, the difference between the two totals is small (earthenware) or almost none (miscellaneous objects) whereas the dry-screened sample is approximately one-third the times larger for all other artifact categories. The number of NHR fragments and the total NHR weight offer a different result entirely (Table 4.4). Interestingly, the number of medium and large fragments collected by both screening stations is the same, with the difference in total fragment numbers and weights being affected by small NHR fragments recovery. Over two times the number of small fragments were collected by the wet-screening station than the dry-screening one, with fragment number equaling 71 and 30 respectively.

Table 4.3. Weight (g) of amount collected for each artifact category for N504-508/E514-516.

Screening Type	ACW	Glass	Porcelain	Earthenware	Metal	Bricks/ Shingles	Misc.
Dry Screening	290	387	207	226	451	734	6
Wet Screening	120	230	120	242	259	555	7

Table 4.4. Both number of NHR fragments by size category and total weight (g) of NHR for N504-508/E514-516.

Screening Type	Number of Small Fragments	Number of Medium Fragments	Number of Large Fragments	Total Number of Fragments	Total Fragment Weight (g)
Dry Screening	30	7	1	38	35
Wet Screening	71	7	1	79	64

Finally, comparing the differences in g/gal of each artifact category, the stations recovered within 0.3 g/gal of each other for all of them (Tables 4.5). The largest difference was between the ACW g/gal collected. The weight of miscellaneous objects recovered by the gallon is close to zero and indistinguishable between the stations. A larger quantity per gallon was recovered by the dry-screening station for ACW, glass, porcelain, and oxidized metal. Regarding NHR, one of the principal juxtapositions for this experiment is the differential number of small fragments recovered by the wet-screening station compared to the dry-screening one (Table 4.6). Although the recovery rates of medium and large fragments (number/gal) are equal or almost equal for both screening stations, the difference in the screening methods is evident in small fragment recovery rates. For dry screening, it was less than 0.10 number/gal while it was 0.25 number/gal for wet screening. This translates to a small fragment being recovered approximately every three screens for wet screening and every nine screens for dry screening.[10]

Table 4.5. g/gal of amount collected for each artifact category for N504-508/E514-516.

Screening Type	ACW	Glass	Porcelain	Earthenware	Metal	Bricks/ Shingles	Misc.
Dry Screening	0.72	0.96	0.51	0.56	1.12	1.82	0.01
Wet Screening	0.42	0.80	0.42	0.84	0.90	1.94	0.02

Table 4.6. Number/gal of NHR amount collected for each size category and total number of NHR fragments for N504-508/E514-516. Also, g/gal for weight of total NHR amount collected.

Screening Type	Small Fragments	Medium Fragments	Large Fragments	Total Fragments	Total Weight
Dry Screening	0.07	0.02	0.002	0.09	0.09
Wet Screening	0.25	0.02	0.003	0.28	0.22

Results of Wet- Versus Dry-Screening Recovery and Distribution Analysis

Artifact Categories

[10] Remember, 1.5 gal of sediment, or one bucket, would be screened at one time.

Spatial Analysis. Two patterns are represented in the GIS-generated maps comparing the aggregate weights of artifact materials recovered from the wet- and dry-screening stations. The ACW map (Figure 4.1) reflects a high concentration of ACW recovered by both screening methods along the eastern side of the UNL excavation between N500-516/E512-516. The location of this concentration reflects both the author's own note of much ACW being recovered within these units, including fragments of the navigator's protractor and the instrument board, as well as Vella's reports of majority of incident-related materials being located on the northeastern edge of the [redacted] excavation area (Interim Search and Recovery Report: CIL [redacted] 2019). There is a noticeable low concentration on the UNL excavation's northern 2-x-4-m units for both

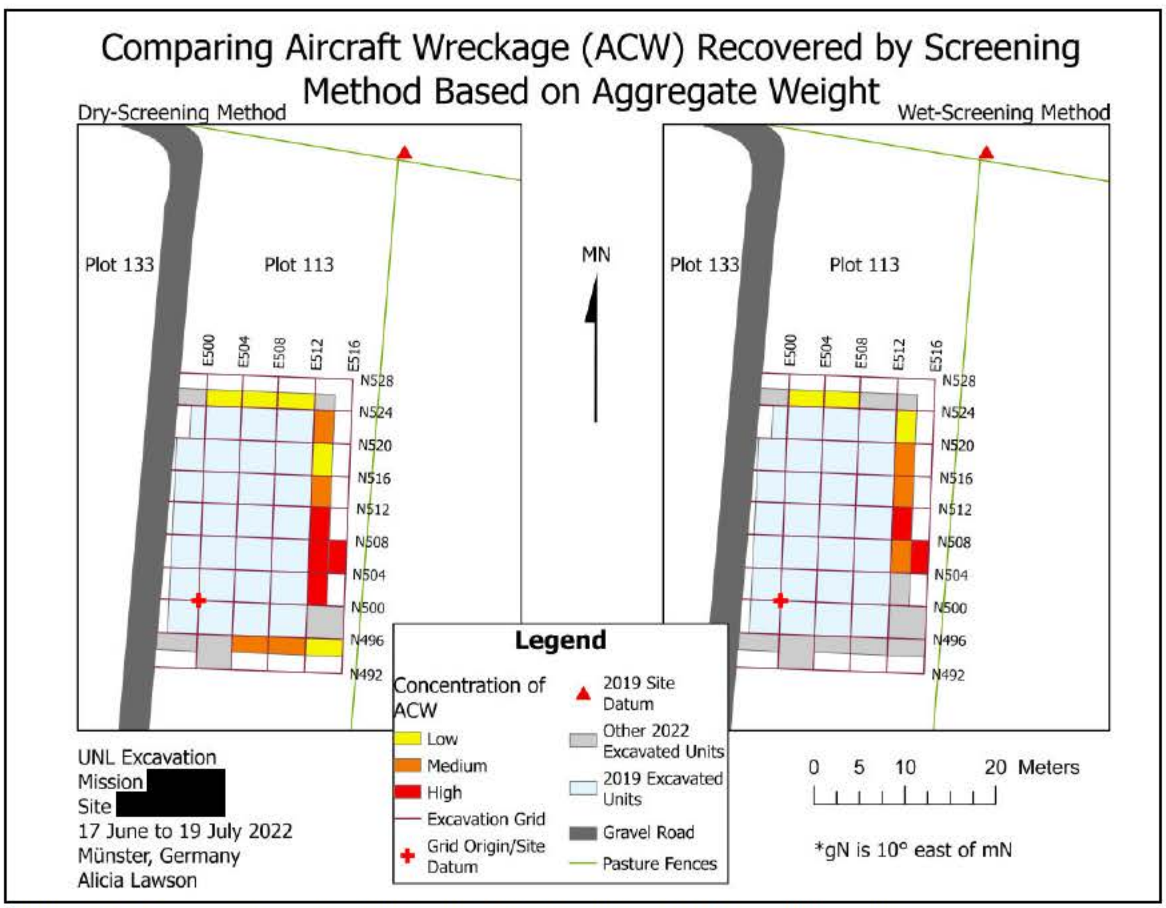

Figure 4.1. Concentration distribution of ACW throughout UNL excavation units.

screening methods, possibly indicating the team reached the northern extent of the ACW distribution in Plot 113.

The other artifact categories (glass, porcelain, earthenware, oxidized metal, bricks/shingles, and miscellaneous objects) exhibit the other pattern represented in this series of GIS choropleth maps. The glass and bricks/shingles maps are provided as representatives of this pattern (Figures 4.2 and 4.3). There are two primary commonalities that define this pattern. First, there seems to be a tradeoff between the screening methods for which unit has various concentration levels. In units that have high concentrations for one screening method, the other screening method for the same unit will generally be classified with lower concentration level. The other main trend seen in

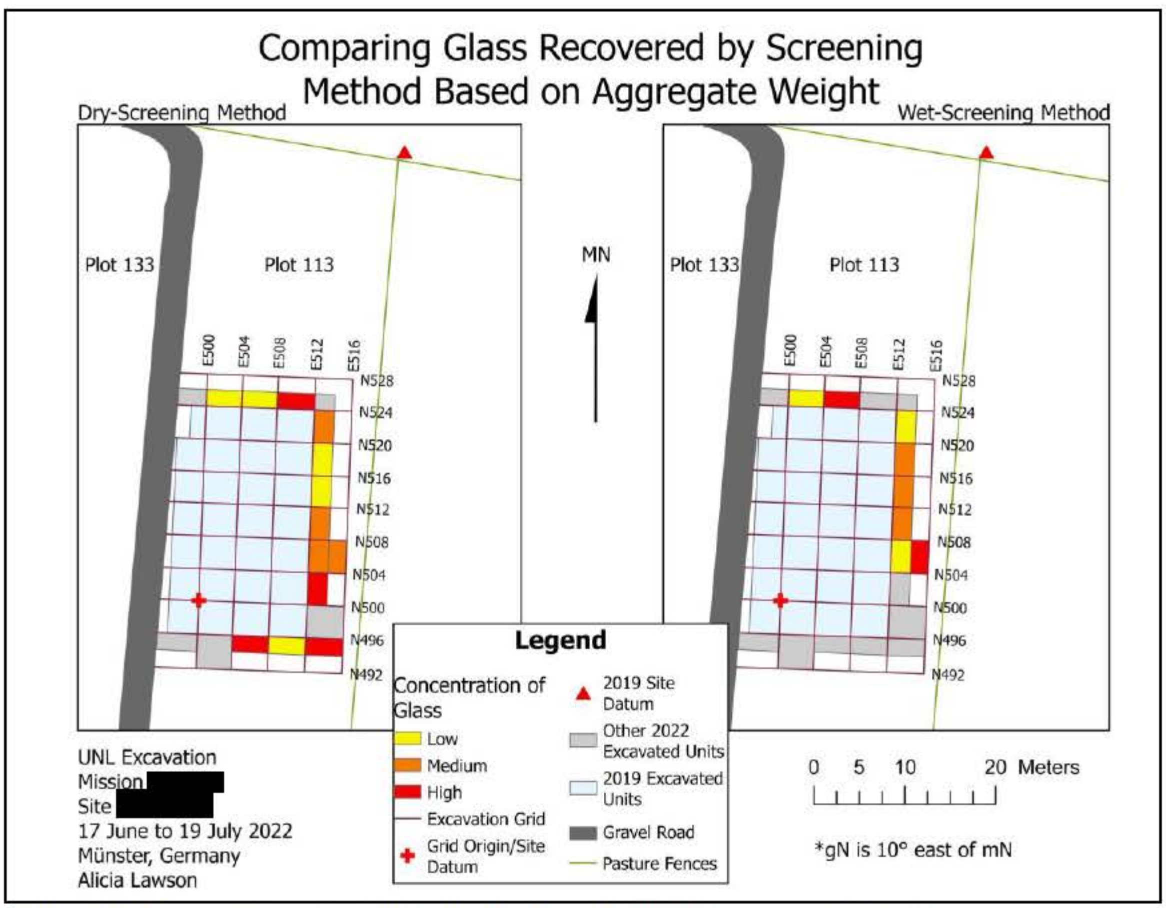

Figure 4.2. Concentration distribution of glass throughout UNL excavation units.

this pattern is a tendency for the dry-screening station's higher concentration levels to be assigned to units primarily or solely dry screened. This is especially clear in Figure 4.2 for units N494-496/E504-5508, N494-496/E512-516, and N524-526/E508-512, which were all exclusively or almost exclusively dry screened, are all classified as high concentration units for the glass dry-screening station map. One can assume both characteristics reflect the fact that there is a finite number of artifacts contained within each unit. If a relatively larger quantity of an artifact was recovered by one screening station, it is expected the other would often recover a corresponding lesser quantity. In the case of only one screening method being applied for that unit, that unit's finite artifact

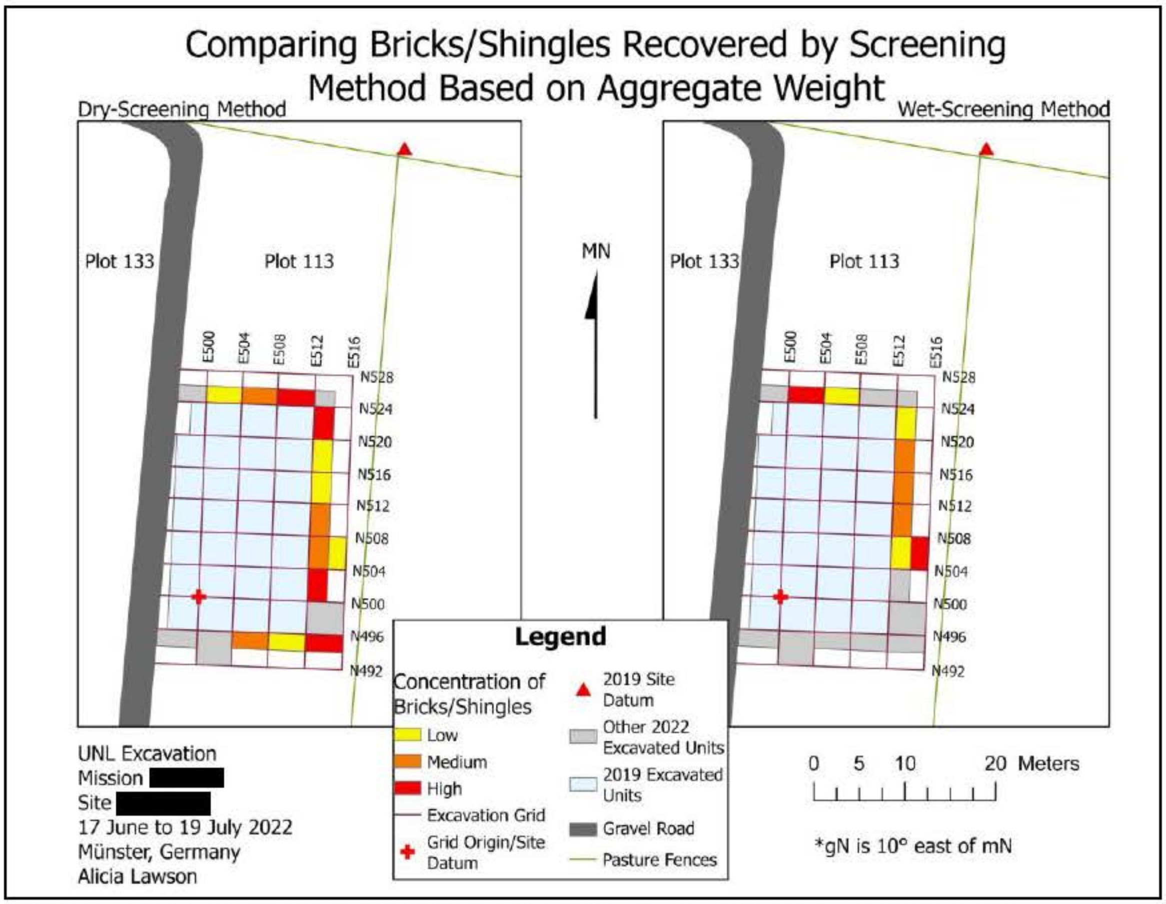

Figure 4.3. Concentration distribution of bricks/shingles throughout UNL excavation units.

quantity will not be divided between the two recovery methods. The bias of primarily dry-screened units toward a higher concentration classification is a notable factor when interpreting these results and is the reason for their exclusion from the dry-screening samples statistically analyzed below.

Wilcoxon-Rank Sum Statistical Analysis. Out of the seven artifact categories, only ACW ($p = 0.28$), earthenware ($p = 0.08$), and miscellaneous objects ($p = 0.37$) retain the null hypothesis that the two samples come from the same population for the two-tailed Wilcoxon rank-sum test. Glass ($p < 0.01$), porcelain ($p = 0.01$), oxidized metal ($p < 0.01$), and bricks/shingles (($p < 0.01$) all rejected the null hypothesis (Table 4.7). The rejection of the null hypothesis means the alternative hypothesis that the two samples are significantly different, or they derive from separate populations, is accepted.

Table 4.7. Results of the two-tailed Wilcoxon rank-sum test and the Kendall's correlation coefficient test. * indicates approximate p-value due to ties present in the data. Dry-screening sample median (Mnd_{DS}), wet-screening sample median (Mnd_{WS}).

Artifact Category	**Medians**	**Mann-Whitney *U*, p-value**	**Kendall's τ, p-value**
ACW	$Mnd_{DS} = 72.5$ $Mnd_{WS} = 51$	$U = 43$ $p = 0.28$	$\tau = 0.64$ $p = 0.03$
Glass	$Mnd_{DS} = 350$ $Mnd_{WS} = 149.5$	$U = 59$ $p < 0.01$	$\tau = 0.07$ $p = 0.9$
Porcelain	$Mnd_{DS} = 149.5$ $Mnd_{WS} = 106.5$	$U = 57$ $p = 0.01$*	$\tau = 0.18$ $p = 0.53$*
Earthenware	$Mnd_{DS} = 195.5$ $Mnd_{WS} = 131.5$	$U = 49$ $p = 0.08$	$\tau = -0.07$ $p = 0.9$
Metal	$Mnd_{DS} = 501$ $Mnd_{WS} = 170.5$	$U = 60$ $p < 0.01$	$\tau = 0.07$ $p = 0.9$
Bricks/Shingles	$Mnd_{DS} = 773$ $Mnd_{WS} = 340$	$U = 61$ $p < 0.01$	$\tau = -0.57$ $p = 0.06$
Misc.	$Mnd_{DS} = 10$ $Mnd_{WS} = 8.5$	$U = 41$ $p = 0.37$*	$\tau = 0.04$ $p = 0.9$*

Kendall's tau tests were performed for each category as a measure of association with τ representing the strength and direction of the relationship. The null hypothesis is the two samples are not correlated. Only the ACW and bricks/shingles categories' samples rejected the null hypothesis of independence, meaning the samples are correlated with one another. The $\tau = 0.64$ for ACW indicates a strong positive relationship between the two samples while the $\tau = -0.57$ for bricks/shingles indicates a moderate negative relationship. This means the ranks of both screening methods samples increase together for ACW. This reflects the spatial analysis pattern of high concentrations of ACW being recovered by both methods for the same units (see Figure 4.1). Regarding bricks/shingles, this moderate negative relationship follows the tradeoff characteristic for artifact quantity recovered by screening methods identified within the second pattern discussed previously (see Figure 4.3).

The Kendall's tau ($\tau = -0.07$, $p = 0.9$) indicates only a very weak negative relationship was found between earthenware's wet- and dry-screening samples. It is interesting earthenware failed to reject the null hypothesis of no correlation between samples, which contradicts the Wilcoxon rank-sum null hypothesis. It is important to note the Wilcoxon rank-sum $p = 0.08$ for earthenware is close to $p < 0.05$ threshold of statistical significance. This closeness could explain the contradictory nature of earthenware's two test results. The miscellaneous objects category indicates a very weak positive relationship ($\tau = 0.03$, $p = 0.9$) and similarly failed to reject the Kendall's tau null hypothesis even though it also retained the Wilcoxon rank-sum null hypothesis. This contradiction could be explained by the multiple ties that exist between the samples. The ties' effect could further be exasperated by the small sample sizes, contributing to this incongruity. Another explanation would be the fact that the UNL excavation recovered very little miscellaneous objects for each unit. For some objects, whether they were considered miscellaneous depended on if Dr. Belcher or the author could identify them, making it a catchall category rather than one with a strict definition for the artifacts included.

For glass ($\tau = 0.07$, $p = 0.9$), porcelain ($\tau = 0.18$, $p = 0.53$), and oxidized metal ($\tau = -0.07$, $p = 0.9$), all retain the Kendall's tau null hypothesis that they are not correlated, which follows their acceptance of the Wilcoxon rank-sum alternative hypothesis of samples originating from different populations. Glass and porcelain have only very weak positive relationships while oxidized metal has an equivalently weak negative relationship to glass. These very weak relationships further confirm the validness of the conclusions from their Wilcoxon rank-sum results.

A one-tailed Wilcoxon rank-sum test was used to determine the relative locations of the two screening samples' medians for glass, porcelain, oxidized metal, and bricks/shingles because they rejected the two-tailed null hypothesis. All four categories rejected the directional hypothesis, which stated the dry-screening station sample's median weight is less than the median weight of the wet-screening sample, or the true location of the median shift is less than zero (Table 4.8). This indicates dry screening resulted in a greater overall collection for these four artifact types.

Table 4.8. Results of the one-tailed Wilcoxon rank-sum test. * indicates approximate p-value due to tie present in the data.

Artifact Category	**Mann-Whitney *U*, p-value**
Glass	$U = 59$ $p < 0.01$
Porcelain	$U = 57$ $p < 0.01$*
Metal	$U = 60$ $p < 0.01$
Bricks/Shingles	$U = 61$ $p < 0.01$

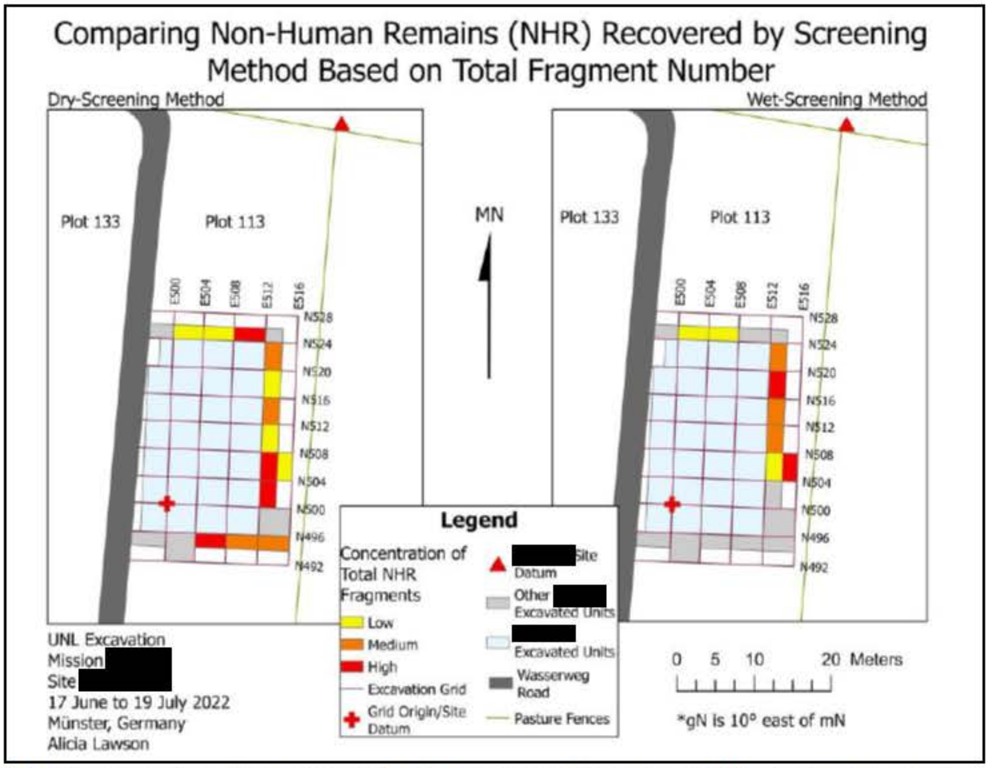

Figure 4.4. Concentration distribution of NHR fragments throughout UNL excavation units.

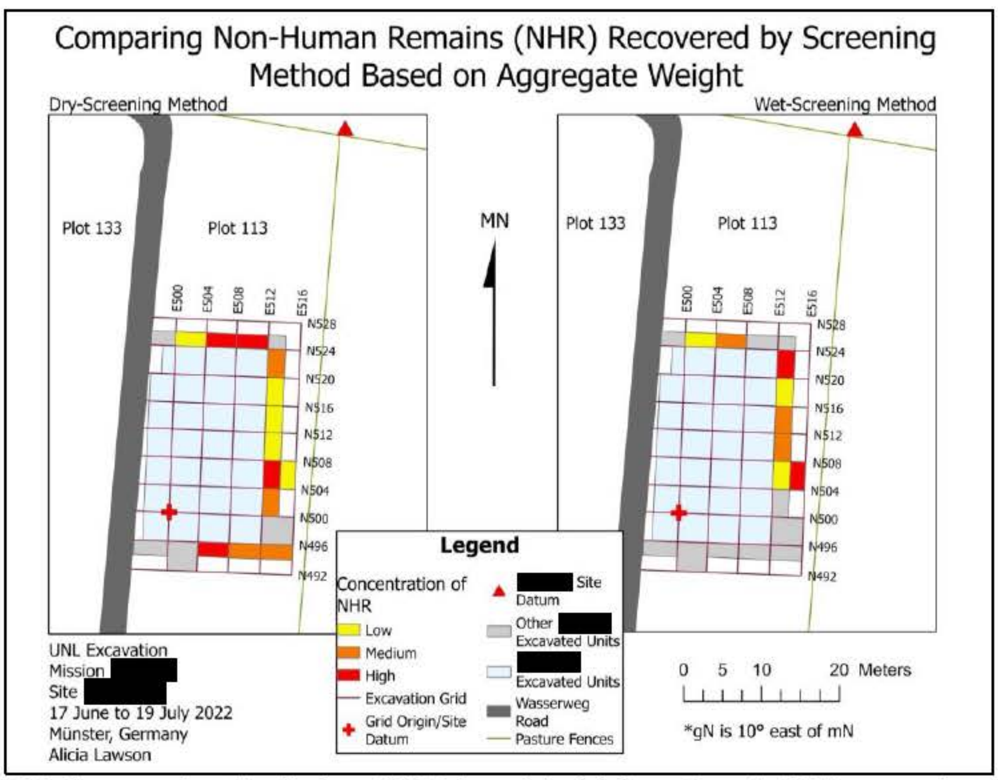

Figure 4.5. Concentration distribution of NHR by weight (g) throughout the UNL excavation units.

NHR Categories

Spatial Analysis. Both total fragment number (Figure 4.4) and aggregate weight (Figure 4.5) of NHR were analyzed according to quantities recovered by each screening method for their concentration distributions. Both generally seem to follow the second pattern explained in the "Artifact Categories: Spatial Analysis" subsection. They have both the characteristic tradeoff in concentration intensities for units screened by both stations and the higher concentrations for the dry-screening map being associated with units only dry screened.

Wilcoxon-Rank Sum Statistical Analysis. Total fragment number ($p = 0.8$) and aggregate weight ($p = 0.28$) retained the two-tailed Wilcoxon rank-sum null hypothesis, indicating the two samples are not significantly different (Table 4.9). However, total fragment number ($\tau = 0.21$, $p = 0.55$) has only a weak positive relationship between the two samples and cannot reject the Kendall's tau null hypothesis of sample independence. This testing contradiction is also reflected in the aggregate weight Kendall's tau results ($\tau = 0$, $p = 1$), which reflects absolutely no relationship between the two samples. Diagenetic processes and thermal alterations modify the weight and structural integrity of osseous remains, the effects of both evident on Plot 113's fragments. These will be important categories to analyze for formation processes present at the site as their influences are the likely explanation for these contradictory statistical results.

Table 4.9. Results of the two-tailed Wilcoxon rank-sum test and the Kendall's correlation coefficient test. Dry-screening sample median (Mnd_{DS}), wet-screening sample median (Mnd_{WS}).

NHR Category	**Medians**	**Mann-Whitney *U*, p-value**	**Kendall's τ, p-value**
Total Fragment Number	$Mnd_{DS} = 52.5$ $Mnd_{WS} = 56$	$U = 35$ $p = 0.8$	$\tau = 0.21$ $p = 0.55$
Weight	$Mnd_{DS} = 49.5$ $Mnd_{WS} = 38$	$U = 43$ $p = 0.28$	$\tau = 0$ $p = 1$

Results for the ACW and NHR Concentration Analysis

ACW Concentration Spatial and Statistical Analysis.

The graduated symbols ACW distribution map (Figure 4.6) reflects the same pattern identified above in the ACW recovery and distribution analysis map (Figure 4.1). The highest concentrations of ACW are between N504-512/E512-516. The two 2-x-4-m

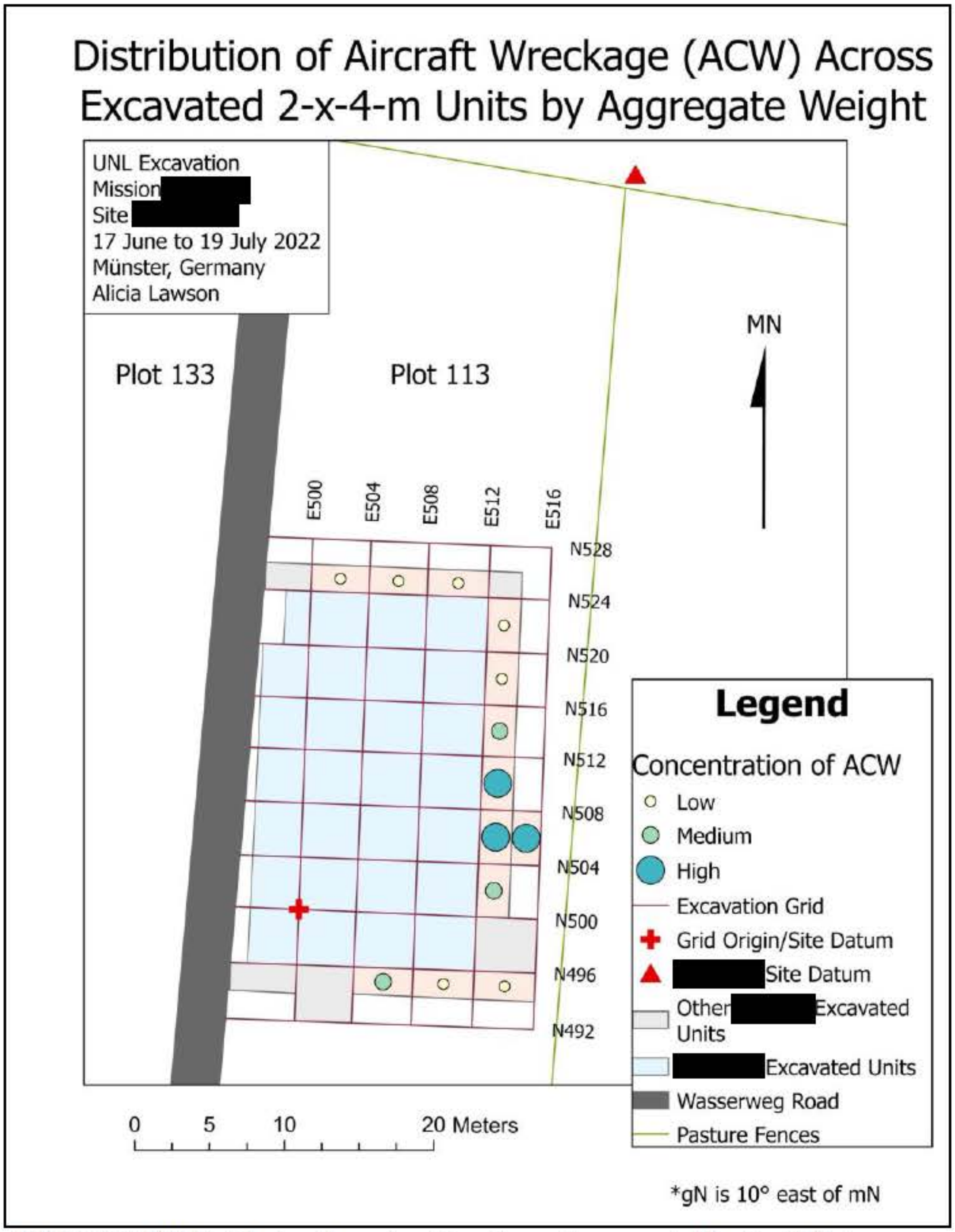

Figure 4.6. Total ACW distribution throughout 2-x-4-m units excavated by the UNL team.

units excavated to the north and south of this area are two of the three total units classified as having a medium ACW concentration. The other medium concentration unit is N494-496/E504-508, which is isolated on the south edge of the perimeter excavation. Its presence though could have implications for the movement of B-24H [redacted] during the crash and its final resting spot in Plot 113. All units north of N516 were again categorized with low ACW concentrations, further supporting the proposition that the northern extent of the crash site in Plot 113 was reached. The Kruskal-Wallis statistical test demonstrates there is a statistically significant difference ($X^2 = 9.89$, df = 2, $p < 0.01$) between the low, medium, and high concentrations of ACW samples identified by ArcGIS Pro (Table 4.10). The eta-squared effect size test further indicates this is a large variance ($\eta^2 = 0.79$, n = 13). However, the pairwise Wilcoxon rank-sum test determined only pairwise comparisons between the low and medium concentration samples (p = 0.03) and the low and high concentration samples (p = 0.03) are significantly different enough to come from separate populations. The medium and high concentration samples do not reject the null hypothesis that they originate from the same population (p = 0.1).

Table 4.10. Results of the Kruskal-Wallis test and the Eta-Squared effect size test. * indicates approximate p-value due to ties present in the data. Low concentration sample median (Mnd_L), medium concentration sample median (Mnd_M), high concentration sample median (Mnd_H), extreme concentration sample median (Mnd_E).

Category	**Median**	**Kruskal-Wallis Test**	**Eta-Squared Test**	**Pairwise Wilcoxon Rank-Sum Test**
ACW	$Mnd_L = 50$ $Mnd_M = 179$ $Mnd_H = 410$	$X^2 = 9.89$ df = 2 $p < 0.01$	$\eta^2 = 0.79$ n = 13 magnitude = large	$p_{L-M} = 0.03$ $p_{L-H} = 0.03$ $p_{M-H} = 0.1$
Total NHR Fragment Number	$Mnd_L = 45$ $Mnd_M = 73.5$ $Mnd_H = 119$ $Mnd_E = 179$	$X^2 = 15.17$ df = 3 $p < 0.01$	$\eta^2 = 0.87$ n = 18 magnitude = large	$p_{L-M} = 0.03$ $p_{L-H} = 0.06$* $p_{L-E} = 0.13$ $p_{M-H} = 0.03$* $p_{M-E} = 0.13$ $p_{H-E} = 0.07$*

This further delineates between areas of medium and high concentrations compared to areas of low concentration, emphasizing the limited spread and decrease of materials north of N516 and other areas identified previously.

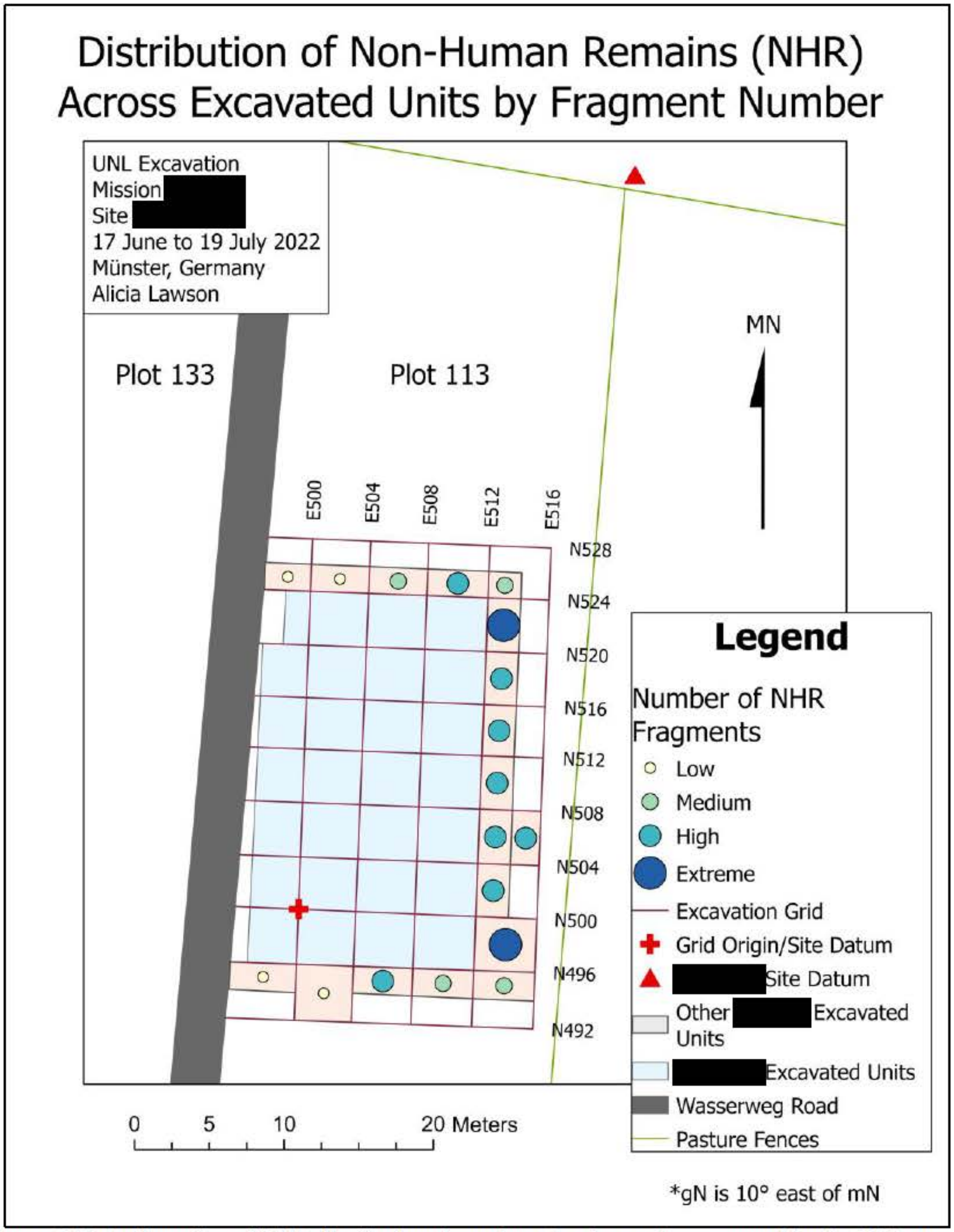

Figure 4.7. Total number of NHR distribution throughout 2-x-4-m units excavated by the UNL team.

NHR Concentration Spatial and Statistical Analysis.

The total number of NHR recovered from each unit, as shown in Figure 4.7, is indicative of a new distribution pattern. The units classified as containing medium, high, and extreme concentrations of NHR are fairly evenly distributed between the units excavated within N494-526/E504-516. While it could be expected a 4-x-4-m unit is one of the two extreme concentration units, it is interesting the other is N520-524/E512-514, a 2-x-4-m unit located a fair distance away from it. One truly notable feature of this map is all four units classified as containing the lowest numbers of NHR are the ones closest to the road, and all of variable unit size (4-x-4 m, 2-x-4 m, 2-x-2.2 m, and 2-x-3.3 m). This will be discussed in the following chapter as evidence of modifications to Wasserweg Road impacting the western edge of Plot 113.

The Kruskal-Wallis test returned a $p < 0.01$ ($X^2 = 15.17$, df = 3), meaning there is a significant difference between the concentration samples' populations (see Table 4.10). The eta-squared effect size test further indicates this is a large difference ($\eta^2 = 0.87$, n = 18). The pairwise Wilcoxon rank-sum test only returned significant p-values for the pairwise comparisons of low and high concentration samples ($p = 0.03$) and medium and high concentration samples ($p = 0.03$). The tie within the data comes from two high concentration units sharing the same number of NHR fragments, so these p-values are approximate. It is important to note that both the low and medium concentration test and the high and extreme concentration test returned borderline significant p-values ($p = 0.06$ and $p = 0.07$ respectively). All pairwise tests between sequential concentration classes are either significantly different or have a borderline significant p-value. However, the fact that more pairwise comparisons retain the null hypothesis, meaning the two samples could originate from the same populations, provides insight into the method of deposition within Plot 113, especially when compared to the ACW concentration statistical results.

Site formation processes can be identified in a variety of ways. These spatial and statistical results are used in conjunction with the volume experiment to examine which processes are present in Plot 113, and the extent of their impact upon the archaeological and incident-related materials. Both the artifacts and NHR's sizes and distributions are the main characteristics considered. Furthermore, these results along with the identified formation processes' effects are the basis for the excavation methodology recommendations for Site [redacted] and other similar aircraft crash sites.

CHAPTER 5: DISCUSSION AND CONCLUSION

Site formation and taphonomic processes have great effects on the archaeological record, modifying artifact size, structure, and relative locations after deposition in a sediment matrix. Rarely can artifacts be considered *in situ* or their forms unaltered at the time of their recovery due to various post-depositional processes. Furthermore, excavation methodology can either assist or prevent the identification of site formation processes and the assessment of their impacts on the archaeological record. The recovery methods used also affect which modified materials are recovered during the excavation, as seen below with the analysis of dry- versus wet-screening methods at Site [redacted] and the differential recovery of archaeological artifacts and small NHR fragments. This thesis concludes with recommendations for future DPAA/academic partner excavation methodology at aircraft crash sites with similar site formation processes to those at Site [redacted].

Site Formation Processes Identification

Archaeologists must consider and identify all possible formation processes that a given deposit has been subjected to based off its structure and context before drawing inferences about the individuals and events under question. As such, one needs to review the context and makeup of a site to first identify potential formation processes that could have affected it over time before concretely identifying the specific processes present based off the deposits' artifact patterning. This section considers the traditional farming methods, the methods of deposition for and presence of historic artifacts recovered during excavation, and the sediment matrix of Site [redacted] to identify the potential cultural and noncultural processes at work. These processes are reviewed then in terms of the recovered artifacts' characteristics and spatial locations to determine which ones have most likely affected the site.

German Agriculture during the Industrial Revolution to Present

Although the [redacted] have only worked their land for three generations, parts of the [redacted]' farmhouse date to the seventeenth century, meaning their land was farmed in some fashion for multiple centuries in the modern historical period. There is little information on how the land was used prior to the [redacted] family, but some inferences can be made based on local and regional agricultural practices. Before the Industrial Revolution, most German farms engaged primarily in subsistence farming for themselves or their community and were a combination of crop production and livestock operations. The Industrial Revolution in the mid-nineteenth century and the two world wars in the first half of the twentieth century radically changed farm composition and created national agriculture goals for Germany. Along with other technological advances, the Industrial Revolution brought the creation of chemical fertilizers, a product of the new field of industrial chemistry. Their introduction drove the intensification of agriculture to feed the growing German population (Chickering 2011:643). The [redacted] indicated they used both chemical fertilizers and manure for their fields although Plot 113 rarely required human intervention or fertilization for regenerating its grass crop. However, Münsterland has a traditional fertilization practice involving the collection and burning of household trash, including food scraps and broken objects, which was mixed with manure and spread over fields, according to archaeologist Dr. Bernhard Stapel of the LWL Museum (personal communication 2022). This practice had the potential to create deposits more than a meter thick; however, for Plot 113, SU 2 generally marked the deepest extent of these materials, approximately 30 to 40 cmbs.

This intensification was further driven by the national push toward self-sufficiency in food supply brought about by the food instability present in Germany, in part a subsequent effect from the two world wars (Bender et al. 2005:156). The second half of the twentieth century saw increased mechanization and specialization of farms into either crop production or livestock operations, a trend reflected in the [redacted]' solely cow and then later pig livestock operations between the 1960s until the 1990s before transitioning to a horse stable in 1993 (Chickering 2011:643). Extensive use of Plot 113 for livestock indicates the ground has been heavily trampled by large animals over at least the past eight decades. This is a surficial disturbance process that needs to be considered a site formation process for Plot 113.

The [redacted] primarily relied on annual precipitation rather than any active irrigation method. It is unknown what types of irrigation systems were used when Plot 113 was planted for crop production; however, water is an important consideration for environmental processes affecting a site because its combination with oxygen is sufficient to initiate chemical reactions on deposited artifacts, especially oxidization of metals. Moreover, it contributes to the leaching of minerals and other components in sediment, artifacts, and osseous materials as well as deteriorating their structural integrity (Schiffer 1996:148, 189).

Methods of Artifact Deposition into Site [redacted]

The incident-related and archaeological materials recovered from Plot 113 represent different forms of refuse. B-24H [redacted]'s crash represented one depositional event of primary refuse into Plots 113, 133, and 7. Similar to other primary refuse deposits, it has very low artifact diversity, with all deposited objects being a form of ACW. A type of ad hoc maintenance was performed on the deposit post-crash through the hauling away of the larger engine and metal pieces by the state as well as the collection of remaining pieces by the landowners (Schiffer 1996:65). Because the crash did not create a crater, the ACW's removal was necessary to return the fields to a usable state. The other part of this maintenance was the collection of the deceased crew members' remains. The remaining ACW and possible human remains at Site [redacted] are considered residual primary refuse, which are generally smaller pieces or fragments not removed or missed during the maintenance process (Schiffer 1996:62). This conclusion is supported by the UNL team's recovery of small aircraft fragments and ammunition. The 2019 recovery team excavated the highest concentration areas of ACW and possibly recovered some larger fragments compared to UNL, but it is unlikely even their fragments would have been large due to the nature of the crash and removal process.

The archaeological materials are secondary refuse, or refuse discarded in places other than their locations of use (Schiffer 1996:58). Throughout their life cycles, the artifacts have gone through periods of discard, reclamation, and reuse. Most of the artifacts and NHR recovered from Plot 113 were deposited there due to the traditional fertilization practice for Münsterland described previously. This includes the glass, porcelain, and earthenware sherds; the vast majority of the NHR, especially the thermally altered ones; the miscellaneous objects; and the bricks/shingles. All except the bricks/shingles were probably part of the burned household trash mixed with the manure. The bricks/shingles most likely were incorporated through the decay and renovation of the farm buildings where the adjacent manure was stored and were already mixed in the manure when it was combined with the trash. The different artifact sherds and miscellaneous objects were probably broken or could not perform their intended functions due to deterioration or wear, common reasons for object discard. All these objects and osseous remains were later reclaimed to be used as fertilizer and deposited as secondary reused refuse (Schiffer 1996:113).

The oxidized metal and some NHR were likely deposited separate from this fertilizer. While some metal objects would probably have been discarded into the trash, many of the recovered oxidized ones were different farm-related implements, possibly lost and incorporated into the fields through various farming activities. Examples of these include an oxidized truck hitch and iron machinery fragments. Furthermore, because Plot 113 has primarily been dedicated to livestock operations, some of the cattle and pig osseous remains recovered from the fields, especially teeth, were likely deposited naturally within the fields from the animals directly.

The great variety of artifacts recovered from Plot 113 further supports the deposit being secondary refuse from fertilization practices because these types of deposits, especially ones encompassing objects from multiple activities over an extended period, often have the highest levels of artifact diversity (Schiffer 1996:282). Plot 113's secondary refuse originates from the whole farmstead's activities over an undetermined, but most likely extended, period of farming. This extended period is presumed due to the vast quantity of materials recovered from the pasture. The archaeological artifacts recovered are also expected based on the objects available to German consumers during the modern historical period, dating especially to the eighteenth and nineteenth centuries. This is supported by the glass, porcelain, clay pipes, and lead seals recovered in Plot 113.

Large quantities of green and amber glass were recovered with both commonly produced by Rhine region glassmakers for everyday vessels and containers during the historical period, the color being based off the potash derived from the remains of burned wood (Phillips 1981:47, 90). Germany[11] and neighboring countries also had bustling porcelain and other stoneware industries by the late eighteenth century, making these products more widely available to the larger population, especially with the factories' industrialization. The blue-and-white designs, popular in Europe from the sixteenth century through the twentieth, were recovered in the highest frequency from Plot 113 (Macintosh 1977:105). Less common but still seen in the deposit were sherds with no designs and rare sherds with other color designs, such as dark pink or green. This high incidence of higher quality ceramics could in part be explained by the traditional dowry practices, as described by Frau [redacted]. New brides were expected to bring their own tableware among other objects as part of their dowry into the marriage. The [redacted] still have some of these dishes that have stayed with the farmhouse over the generations ([redacted], personal communication 2022).

Two types of miscellaneous objects, kaolin clay pipes and lead textile seals, were recovered repeatedly in multiple units excavated by UNL. Clay pipes are a common historical artifact for European historical sites. The UNL team recovered over 10 pipe stem fragments and one pipe bowl from seven units. Although most were plain, there was

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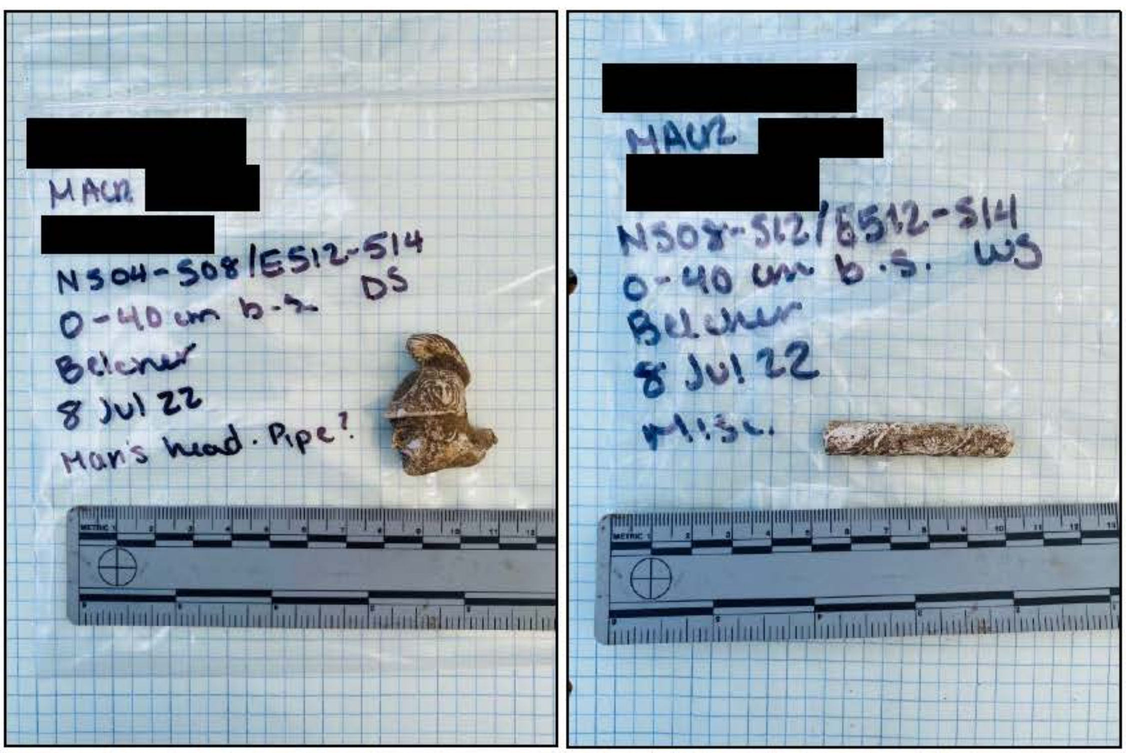
[11] One of the primary industrial centers for potters was the Westerwald region in western Germany, located to the south of Münster (Mehler 2009).

one highly decorative pipe stem with a vine design and one anthropomorphic pipe bowl, which probably depicted a soldier's head, recovered from successive units (Figures 5.1 and 5.2). These were potentially two fragments of the same pipe. The other recovered pipe stems were probably discarded broken fragments. Kaolin clay pipes were an extremely common way to smoke tobacco and were popular from the seventeenth through the nineteenth centuries. Several German clay pipe workshops date to the late eighteenth and nineteenth centuries, and the Westerwald region was home to Germany's largest pipe industry (Mehler 2018:458; Mehler 2009:266). Cessford (2001:86) characterizes clay pipes as a cheap luxury item due to nineteenth century industrialization. As tobacco residue built up in the stem, they would either need to be refired or were discarded, a possible explanation for their occurrence in Plot 113 (Cessford 2001).



Figures 5.1 and 5.2. Pipe bowl (5.1) and pipe stem fragment (5.2) found in N504-508/E512-514 and N508-512/E512-514 respectively.

Lead textile seals have a long history, with the practice of sealing goods or bundles being traced to the Roman Empire.[12] Europe began sealing their cloth and other goods as markers of quality with the advent of long-distance trade in the Middle Ages. However, with the mass production of textiles in the Industrial Revolution, they became obsolete in the nineteenth century and largely fell out of use (Endrei and Egan 1982). The

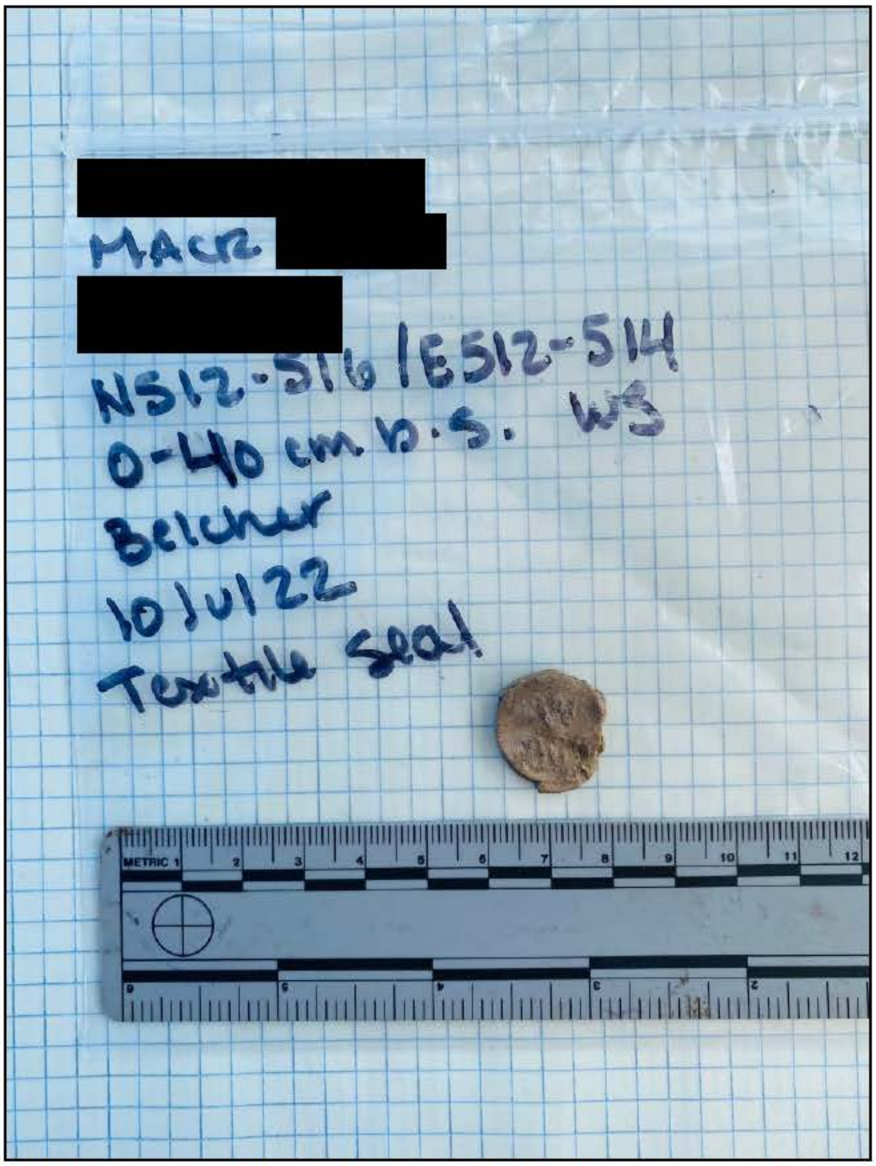


Figure 5.3. Lead textile seal recovered from N512-516/E512-514. This side embossed with "990 M." Also noted the distinct lack of oxidization of the seal's surface.

[12] For the history of cloth seals, see Endrei and Egan (1982) for use throughout Europe and Mordovin (2014, 2017, and 2019) for Hungary and other Central European countries.

Prussian state control offices were responsible for sealing cloth beginning in the eighteenth century and used different letters to indicate quality (Endrei and Egan 1982:53). It is possible a lead seal recovered from N512-516/E512-514, marked with an "M" on one side is one such example of a Prussian state seal (Figure 5.3). This would date the seal to the period between the eighteenth and nineteenth centuries. In their system, the "M" stood for "middling" quality fabric (Endrei and Egan 1982:53); however, the vast number of seal types used over the centuries means it would be hard to concretely identify this seal as part of the Prussian system. Lead seals were also used for other goods, including tobacco, grain, and wheat, but these often had different forms than the medallion ones recovered from Plot 113 (Mordovin 2014:196).

Sediment Matrix of Site [redacted]

Pedogenic, or soil forming, processes and the pedoturbation processes that affect different soil or sediment matrixes both impact the artifacts located within them and must be considered when distinguishing site formation processes. Pedoturbation is defined as noncultural disturbance processes that modify horizons particularly through the movement of sediment particles (Schiffer 1996:206). There are four general categories of pedogenetic processes, classified by their effects of adding to, removing, transferring, or transforming the sediment matrix. The two broad consequences resulting from these four processes are horizonation, or the production of soil or sediment horizons, and haploidization, also called homogenization, or the mixing of these horizons (Holliday 2004:262). All of them result, therefore, in the disturbance of the archaeological record.

As previously mentioned in the methodology chapter, SU 2 is considered an A, or the subclassification Ap, horizon. This type of horizon is characterized by a higher organic content due to the presence of plant and animal matter on or below the surface, meaning there is generally a strong presence of floralturbation and faunalturbation. An Ap horizon is a designation given to A horizons subjected to plowing, creating a plowzone. That SU 2 is a plowzone stratum indicates Plot 113 was tilled for crop production at some point. A horizons are often also subjected to eluviation in which clay-sized particles and water-soluble minerals, such as sodium, salts, and calcium, are transported to a lower horizon, called a B horizon, resulting in a more acidic A horizon (Holliday 2004:266). SU 3, which is a lighter, more yellow strata would constitute a B horizon based on its higher clay content, more compact nature, and less organic content (Schiffer 1996:201). This creation of a B horizon from eluviation is one indicator of aquaturbation, or the disturbance of soils and sediments by water (Blake et al. 2008:520).

One final pedoturbation process impacting Plot 113 is cryoturbation, which is determined based on the seasonal environmental changes in northern Germany. Münster is located in northern Germany and experiences freezing temperatures annually from late November through February. Cryoturbation is defined as the disturbance of the soil or sediment matrix based on the freeze-thaw cycle common in places where the ground freezes seasonally or is continuously frozen (Wood and Johnson 1978).

Site Formation Processes Impacting Site [redacted]

There are seven primary site formation processes, cultural and noncultural, that have impacted Plot 113 since the deposition of the archaeological and incident-related materials. The noncultural environmental ones are aquaturbation, faunalturbation, floralturbation, and cryoturbation while the cultural processes are plowing, trampling, and scavenging. Formation processes are generally identifiable because they result in multiple physical effects (Schiffer 1996:266); however, most are dependent on the extent of the disturbance to determine how greatly each formation process has impacted the site. This is normally a function of time, in case of faunalturbation and cryoturbation, or the number of disturbance events, such as the number of times a field is plowed.

Generally, these patterns of disturbance would be identified through careful excavation of the site by stratigraphic units. Given the inherent nature of DPAA excavations and their goal to excavate a site as efficiently as possible while still performing as complete a recovery of possible human remains and other probative evidence as possible, stratigraphic excavation is seldom recommended. For [redacted], the UNL team mainly used a mechanical excavator to efficiently dig to incident-sterile sediment in excavation units, so horizonal and vertical provenience of all recovered materials is only specific to the excavation unit's grid designation and the deepest vertical extent of that unit. This means relative vertical location of materials, commonly a key identifier of formation processes, cannot be used for this thesis. This has implications for the concrete identification of some disturbance processes and the extent of their disturbance on the archaeological record discussed below.

Aquaturbation

Although aquaturbation as defined by Wood and Johnson (1978:359) exists solely as the impact of water pressure disturbance on the mixing of the sediment matrix, others, such as Blake and others (2008:520), have a more inclusive definition that considers all disturbances by water. This thesis will consider all effects water has on sediment and archaeological deposits, including chemical reactions, weathering, and leaching from artifacts, under the heading of aquatrubation. As previously mentioned, water is a primary manner by which minerals are leached from or moved throughout the sediment matrix. It is also often a necessary component for chemical reactions to occur, especially oxidization. The [redacted] currently rely on precipitation as their main water source for Plot 113, and rainwater, in the form of rain or snowmelt, often contains atmospheric pollutants like gaseous oxides that will intensify these effects (Schiffer 1996:148). The impacts of water's presence and its percolation through Plot 113 can have significant effects on ceramics, metal, osseous remains and other archaeological materials.

Multiple post-depositional modifications of ceramic sherds, particularly the low-fired earthenware, are linked to the presence of moisture within the surrounding sediment matrix and result in the weathering of sherds, including loss of structural integrity and size reduction. Earthenware is porous, which creates a greater surface area for chemical reactions and decay to work upon, including the leaching of minerals and oxidization of oxides in the clay (Schiffer 1996:158). The pores allow for porous artifacts to be physically and chemically weathered simultaneously on the inside and outside, causing their rapid deterioration (Holliday 2004:269).

There are two different types of corroded metals recovered from Plot 113, oxidized metal objects and the corroded ACW metal components, both of which experienced a high level of corrosion. Corrosion occurs when metals react with various ions in the environment in an attempt to return to their more stable ore chemical makeup. This process is exasperated by the presence of moisture in which the ions are frequently dissolved, the wet-dry cycle, and burial underground (Schiffer 1996:192). Most of the oxidized metal recovered were farm implements, bolts, and nails that contain some amount of iron, which is highly corrosive. In comparison, the lead textile seals exhibited little to no corrosion due to lead's resistance to oxidization (Schiffer 1996:195). The B-24 Liberator's main component was aluminum, the largest contributor being the aircraft's metal shell ("aircraft skin"). Aluminum is generally nonporous and resistant to corrosive processes; however, the aluminum recovered in Plot 113 is highly corroded, most likely due to the combined effect of burning in the fire post-crash and burial in the moist, probably slightly acidic environment of the Ap horizon. This results in a bluish-white powdery appearance quite distinctive from other metals recovered (Figure 5.4).

Figure 5.4. Fragment of corroded aluminum from the B-24's metal shell. The burning and subsequent corrosion of the aluminum has created the bluish-white appearance.

The most significant impact of aquaturbation in Plot 113 is its destructive processes upon osseous material, causing bone fragments to decay from the leaching of their mineral compounds, especially hydroxyapatite. As mentioned previously, the eluviation of water-soluble alkaline minerals from A to B horizons normally results in a more acidic A horizon, which is one expected effect of aquaturbation on the sediment matrix in Plot 113. Dissolution of the mineral component of bone is exasperated by the presence of acids in surrounding moist sediments. The organic component, particularly the proteins that makeup collagen, is also altered as hydrolysis leads to free amino acids leaching (Schiffer 1996:183-184). Both processes can dramatically alter the bone and its structural integrity, decreasing its chances of preservation.

However, much of the osseous material recovered from Plot 113 has undergone some form of thermal alteration. Almost half of the NHR fragments are charred or calcined, and there is a high probability any possible human remains still present at Site [redacted] were charred during the post-crash fire. These human remains would not be calcined because B-24 aircraft fuel did not burn at high enough temperatures to cause bone to calcify (William Belcher, personal communication 2022). Although burned bone is structurally more fragile, the growth of hydroxyapatite crystals as bone experiences higher temperature provides it some resistance against diagenetic processes, including mineral leaching (Thompson 2015). This could account for the high preservation rate of thermally altered NHR and suggest a similar preservation bias for potentially present human remains, which were deposited after the majority of the burned NHR had been deposited; thus, these human remains would have been exposed to environmental processes for a shorter duration.

Faunalturbation

Faunalturbation primarily is the disturbance by burrowing animals, both subsurface and surface foragers, on the sediment matrix. For in depth explanations of the total impacts by various burrowing species, see Holliday (2004:271-275) and Wood and

Johnson (1978:318-328). Although there is probably some limited insect and other faunal activity, the main subsurface foragers disturbing Plot 113 are earthworms. Earthworms burrow to ingest sediment which contains their necessary nutrients in organic matter, and this process can have dramatic impacts upon the sediment structure through sediment homogenization and horizonation. Earthworms tend to limit their activities to moist sediment layers, though they can burrow to depths of 3 m or more during dry times or when the ground is frozen (Wood and Johnson 1978:325). There are two types, surface feeders, which ingest materials near the burrow opening and excrete casts on the surface, and subsurface feeders, which ingest materials below the surface and excretes it in sediment crevices (Stein 1983:279).

Jänsch and others (2013) study on earthworms within German sediment types suggest both surface- and subsurface-feeding earthworms are common in crop fields and grasslands. Surface-feeding earthworms especially prefer both grass and dung as food sources, which makes Plot 113 with its grass vegetation and use as a livestock pasture an excellent environment for them to flourish (Stein 1983:280). Estimates range from 1 to 25 tons per acre of earthworm casts being deposited annually on the sediment surface in areas of high worm activity (Wood and Johnson 1978:325-327). This has the dual effects of blurring present sediment horizon boundaries while also developing a new sediment structure in which smaller sediment particles are moved on top of larger particles and any large objects unable to be ingested by the worms. These larger materials and any materials deposited onto the surface will be buried over time as casts are deposited on top of them and as objects sink from the collapse of old earthworm tunnels (Holliday 2004:274; Wood and Johnson 1978:328).

The [redacted] reported keeping Plot 113 fallow for two years after the war ([redacted], personal communication 2022). This would conceivably be enough time for earthworms, through their processes of faunalturbation, to begin to bury the residual primary refuse in the form of smaller ACW fragments and any human remains not collected post-incident. This process would also have continued over the past approximately eight decades, incorporating these materials deeper into SU 2.

Floralturbation

Floralturbation disturbance processes are principally the result of root action as they grow and decay within the soil or sediment's top layers (Wood and Johnson 1978:328). According to the [redacted], they have primarily allowed grass growth for hay production within Plot 113 throughout the second half of the twentieth and twenty-first centuries. As documented in Figure 3.3, SU 1 represents the thin layer of concentrated and "concreted" root mass that is the result of this vegetation type. The roots of this grass rarely extend into SU 2 and has probably had a limited impact on the incident-related materials since their deposition. The presence of this root mass has probably prevented the eolian and alluvial processes from eroding small particles of sediment from Site [redacted] (Schiffer 1996:212).

The archaeological materials were deposited as a form of fertilizer in crop production. It is unknown which crops were grown in Plot 113 by previous landowners, but an inference can be made based on the other crops grown by farmers in the region. Likely, Plot 113 was used at some point for maize or grain agriculture ([redacted], personal communication 2022). The roots of these crops do extend significantly deeper into the earth, often extending several feet down for fully developed maize (Hay 2017:1). This expansive root system would affect the artifacts through breakage, spatial movement to accommodate root growth, and the root casts that allow for other materials to penetrate deeper sediments or cause the collapse and downward movement of particles and objects (Holliday 2004:275).

Cryoturbation

Cryoturbation as a pedoturbation process results in the contortion, deformation, and displacement of sediments due to the pressure induced by the freezing of a sediment matrix's water content (Wood and Johnson 1978:341). For objects within the matrix, this results in their deterioration and upwards vertical movement. The exceptions to this are some microartifacts and ecofacts small enough to be forced down by the pressure buildup, similar to small sediment particles which are pushed ahead of the freezing ground front (Wood and Johnson 1978:343). Porous materials, such as ceramic sherds and bone that normally trap water within them, and materials with existing decay are particularly susceptible to the mechanical stress produced by the expansion of ice particles as water freezes as well as the pressure caused by the downward freezing direction of the moisture within the sediment matrix. These pressures contribute to the weathering of objects (Schiffer 1996:151, 186).

Frost heave is defined as the vertical movement of buried objects upward caused by the freeze-thaw cycle. Multiple factors affect the rate of movement, including sediment composition, moisture content, artifact to sediment matrix thermal conductivity ratio, shape and orientation of the artifact, and extent and rate of freezing (Schiffer 1996:213). There are two types of frost heave: frost pull and frost push. The type of frost heave experienced by an object is determined based on their thermal conductivity compared to the surrounding matrix. Frost pull acts upon objects that have less thermal conductivity than the matrix, such as bones and wood, while frost push acts upon objects with better thermal conductivity than surrounding sediment like metal (Wood and Johnson 1978:338-339). Frost heave is a cumulative disturbance process, affecting the object more the longer it remains buried. Because it is upward movement, it impacts vertically oriented objects to a greater extent, but it also causes objects to become more vertically oriented over time (Holliday 2004:279). One of the main ways to identify frost heave then is by the vertical orientation of artifacts, noticed during the excavation.

Plowing of Plot 113

The indicator for plowing affecting a site is a plowzone, the homogenous stratigraphic unit that spreads from the surface to the deepest vertical extent the plow can reach. It results in a random orientation and roughly even distribution of artifacts throughout the field over time (Holliday 2004:329; Frink 1984). The two considerations plowzone archaeology offers based on its disturbance processes are the movement of artifacts within the field post-deposition and the size of the materials upon recovery. With each consecutive plowing event, these two characteristics will reach an equilibrium point. The spatial movement equilibrium is reached when an object is as likely to move closer or further away from its initial deposition point. The size reduction experienced by an object depends particularly on its composite material and mechanical strength. Both these characteristics are seen in the osseous remains and artifact assemblages recovered from Plot 113. However, both equilibria vary depending on the composite material and its relative strength. Although most experimental archaeology studies on artifact behavior in the plowzone are on stone tools, high-fired ceramics, such as porcelain, will often behave like low-porosity stone while the ceramic sherds included in some referenced experiments cover earthenware and the bricks/shingles (Schiffer 1996:158). Therefore, these studies encompass most artifact categories identified from Plot 113's assemblage.

Spatially, both osseous remains and artifacts moved parallel and perpendicular to the direction of plowing with a pre-disposition to greater parallel movement. The distance each artifact type moves is variable with some indication osseous fragments will move a greater distance than artifacts. Bone could move up to 12 m parallel and 4 m perpendicular to plowing direction while most artifact types only moved within 2-3 m^2, though this difference could also be in part a function of the plow used (Newcomb et al. 2017; Odell and Cowan 1987; Roper 1976). Vertical movement remains harder to quantify, although there is a noted size effect by which artifacts are sorted with respect to length and width rather than weight, and larger objects are more likely to be sorted upward and appear on the surface (Frink 1984; Odell and Cowan 1987).

As mentioned previously, there are two ways mechanical damage by a plow is caused: more rarely through physical contact with the plow blade and, most commonly, through the creation of sediment pressure within the sediment because of the plow's movement. Once objects reach an equilibrium size, their forms are stable enough to resist most additional change with each following plow event (Dunnell and Simek 1995:307, 309). Only Lyman and others (2017) quantified the size reduction within their experiment, with most deer long bone fragments recovered under 4.5 cm. This number likely reflects in part the minimum length at which the researchers were still able to identify the species and skeletal element from which the fragment originated, and the true minimum NHR fragments' equilibrium size is actually under 4.5 cm (Watson 1972). For artifacts, a size reduction is an expected consequence of plowing, though studies have not previously identified this size equilibrium for the artifact categories recovered from Plot 113.

Trampling of Plot 113

The [redacted] have dedicated Plot 113 primarily to their livestock operations since WWII, which has created a low penetrability surface, likely influencing the direction of movement for deposited materials and impacting the materials within the upper stratigraphic layers of the field. The sandy silt substrate of the loam site in Gifford-Gonzalez and others (1985) experiment is comparable to Plot 113's current low penetrability substrate, meaning Plot 113 infrequently incorporates new materials into the substrate solely from trampling. Wilk and Schiffer's (1979) conclusions would predict artifacts concentrations in low trampling zones, such as along the pasture fence line between Plot 113 and Wasserweg Road. However, looking at the spatial distribution of NHR fragments across all excavation units (see Figure 4.7), the pattern seen deviates dramatically from the expectations of artifact movement for low penetrability substrates. Instead of collecting along the western edge of Plot 113, where the pasture fence was removed to allow UNL to excavate close to Wasserweg Road, the NHR fragments have been distributed evenly throughout the pasture, including expected high trampling areas. This spatial pattern is likewise replicated in the distributions of other archaeological materials recovered from the plot. This is probably due to the conditions of the sediment matrix during the materials' initial deposition. Plowing creates high penetrability, causing a greater degree of materials to be trapped within the sediment, and field cultivation decreases the frequency of trampling in a field. Because most these materials were deposited as fertilizer for a crop field rather than a livestock pasture, it is expected the sediment matrix has become more compacted over time after this transition in land use and increase in trampling, explaining the equal density of archaeological materials. It is important to mention that the four units closest to Wasserweg Road contain the lowest number of NHR fragments, a pattern also continued for other archaeological materials, and is likely due to road construction and maintenance over the years disturbing the sediment along the pasture's edge. The UNL excavation was inhibited from excavating into the road due to the presence of a fiber optic cable somewhere in the boundary between Plot 113 and Wasserweg Road.

Trampling generally causes microflaking and rounding of edges along with evidence of abrasions and striations on glass and ceramic sherds. For hard paste ceramics like porcelain, striations are normally seen while a more general exfoliation of the surface is common for earthenware (Schiffer 1983:683). The glass sherds recovered from Plot 113 exhibited microflaking of their edges and general surface abrasion. The earthenware edges were fairly round as well. Osseous remains, specifically structurally compromised ones, are also very susceptible to breakage from trampling. This susceptibility can be further compounded by general weathering and other deterioration of bone fragments over time (Schiffer 1996:189).

Scavenging of B-24H [redacted]'s Crash Site

In addition to the ad hoc maintenance of Site [redacted] after the aircraft crash, there are multiple recorded instances of scavenging by locals following the incident. Scavenging is considered a subtractive process in which reusable materials or objects are recycled and re-enter the systematic context (Wandsnider 1987:157). In his initial interview with the DPAA IT in 2016, Herr [redacted] reported locals and the police salvaged the KIA crew members' shoes and socks while one of [redacted]' farm workers found a watch among the wreckage (Report of Investigation: CIL [redacted] 2016). The watch, if recovered in the modern excavations, would have been considered a piece of potentially probative material evidence as possible identification media. One of the [redacted]' neighbors [redacted], now 97 years old, reported salvaging pieces of ACW to repair his motorcycle in November 1945 ([redacted], personal communication 2022). Not only does this indicate scavenging of Site [redacted] took place over at least a period of months but also there were still recyclable wreckage pieces for an extended time post-incident.

Combined Effect of Site Formation Processes on Site [redacted]

Site formation processes have additive, subtractive, and transformative effects upon the archaeological record. The combined effects of these formation processes create unique assemblages specific to each site. Schiffer (1983:677) emphasizes how site formation processes impact the artifact populations and how each consecutive process further transforms the already altered archaeological record in various ways.

One of the most important indicators of formation processes is the types of artifact materials recovered, particularly whether they are perishable or non-perishable. As is seen with most archaeological assemblages, decay processes will generally diminish the number of perishable objects over time. For Site [redacted], the only organic material recovered in large quantities was NHR. Most other organic materials originally in the household trash deposited as fertilizer in the field were likely either degraded or destroyed by the fire before being incorporated into the fertilizer for Plot 113. The pattern of thermal alteration on bone fragments and the presence of a number of tooth fragments, both of which have some resistance to taphonomic processes due to their mineral components, further suggests the destruction of other perishable materials from the assemblage. On the other hand, the high quantity of glass, ceramic, and metal artifacts indicates fairly good preservation for these materials even if their forms have been modified over time.

Orientation changes and size effects of artifacts are assumed to have been two main consequences of the site formation processes identified for Site [redacted] but were not confirmed due to UNL's excavation methods. Various processes impact the orientation of artifacts differently. Three of the formation processes discussed above have documented effects on orientation. Plowing generally creates a random orientation, and when the archaeological materials were initially deposited as fertilizer and the field was regularly plowed, the artifacts likely exhibited this randomness (Holliday 2004:329). In the intervening years since Plot 113's conversion to a livestock pasture, two other formation processes, namely trampling and cryoturbation, have likely altered this pattern. The trampling of smaller artifacts probably resulted in a similarly random orientation to that of plowing (Schiffer 1983:681). However, frost heave tends to force artifacts into a vertical orientation (Holliday 2004:279; Wood and Johnson 1978:340). Most likely, there was a combination of both vertical and random orientation. Artifact orientation potentially could have been one indication if trampling or cryoturbation formation processes acted upon the field to a greater degree.

The two factors that lead to a size effect in the archaeological record are the site formation processes' abilities to both reduce artifact size and sort the artifacts vertically based on their sizes. Most archaeological materials have been reduced to a more stable forms by the chemical, biological, and physical agents of formation processes that act upon them, such as chemical weathering, plowing, and trampling (Schiffer 1996:143). For Site [redacted], 86.3 percent of all NHR fragments recovered by the UNL excavation were less than 2.5 cm in length. This would suggest the NHR size equilibrium for Plot 113 is under 2.5 cm. This equilibrium point is probably not comparable to the results of other studies on formation processes (e.g., Lyman et al. [1987]) because of the decrease in structural integrity due to the loss of organic content from thermal alteration. Furthermore, the rare instances of NHR fragments greater than 5 cm, approximately 1.6 percent of all NHR fragments recovered, lends support to Dunnell and Simek's (1995) proposition that objects deviating from this equilibrium represent new additions to the zones the formation processes act upon. Glass, porcelain, and earthenware sherds also likely reached their own equilibrium forms based on their notably uniform sizes although no measurements were taken for these categories. The author estimates all were generally less than 5 cm in length.

Some formation processes also select for smaller objects to be incorporated in the archaeological records. For the wreckage of B-24H [redacted], the overwhelming inclusion of smaller wreckage fragments due to the removal of larger ones through the clean-up and scavenging of the crash site are two such selections. The crash incident and ensuing fire largely contributed to the destruction of the aircraft based on eyewitness accounts and historical reports, resulting in the creation of the smaller pieces left in the pasture post-incident. Some ACW, such as the aluminum shell, ammunition, and plexiglass, have generally withstood further decreases in size while materials like

Bakelite and the navigator's protractor have likely experienced further size reductions over the decades.

Although not generally considered as a form of trampling, the force applied to the sediment matrix during the aircraft impact influenced the vertical location of the archaeological material within Plot 113 and the ACW. Specifically, this force likely caused both archaeological materials and ACW fragments to embed themselves into the lower reaches of SU 2 and even into SU 3, something that was reported particularly in the 2019 excavation (Interim Search and Recovery Report: CIL [redacted] 2019). This one-time event might have caused some vertical randomization of object size.

Plowing, trampling, and cryoturbation all sort artifacts based on size within the sediment matrix to different extents. Plowzone archaeology experiments have best documented plowing's size effect, with successive passes increasing the quantity of larger artifacts collected on the surface. Length has been confirmed by multiple studies as being one determining factor for the plowing size effect (Odell and Cowan 1987; Frink 1984). Some trampling experiments reference observing possible size sorting effects; however, not all studies note this as a discernable pattern (Schiffer 1983; Gifford-Gonzalez et al. 1985). With cryoturbation, rather than disproportionally making larger objects move upwards are a greater rate through frost heave, the smallest artifacts can potentially be pushed downward by the sediment pressure created by the downward front of freezing sediment (Wood and Johnson 1978:343). All these processes have impacted Site [redacted] at different periods and their effects have likely created a combined sorting effect with larger artifacts being closer toward the surface than smaller ones although this cannot be verified.

Site Formation Processes Effects Seen Through the ACW and NHR Concentration Analysis. Schiffer (1983:686) argues an artifact's density throughout the deposit is directly impacted by the concentrating and dispersing effects of various formation processes. The different patterns of artifact densities for NHR and ACW reflect the different depositional events and formation processes that have influenced their location within Plot 113 since entering the archaeological context.

As discussed previously in "Trampling of Plot 113," the relatively equal density of NHR throughout Plot 113 is likely a function of the secondary deposition of the traditional fertilizer throughout the entire field and the plot's frequent plowing when it was used for crop production. Plowing is the main post-depositional formation process in Plot 113 that creates random horizontal movement of materials. Newcomb and others' (2017) plowzone archaeology study highlighted the ability for NHR to be horizontally dispersed considerably throughout plowing, especially when the materials were previously incorporated into the plowzone. The Kruskal-Wallis and pairwise Wilcoxon rank-sum test results indicate a large difference between the low and medium and medium and high units' samples as well as a borderline significant high to extreme samples' comparison, which could be influenced by the low sample size for extreme concentration units (see Table 4.10). These statistical results are offset by the spatial distribution of the concentration categories highlighting a more even dispersion of NHR fragments. There is no concentration within the field of medium or extreme values according to Figure 4.7. The location of low concentration units next to Wasserweg Road is probably a result of road modification rather than another formation process, and the high number of units classified with a high concentration of NHR fragments indicates the relatively equal quantities of fragments throughout the field.

In comparison, the ACW assemblage is considered residual primary refuse, which limits its spatial extent to the initial deposition location within Plot 113. This is seen in a sharp divide statistically between low and medium concentrations of ACW with a large statistically significant difference between low versus medium and high concentration unit samples; this distinction is further seen through the clustering of medium and high concentration units along the eastern UNL excavation edge (see Figure 4.6). These results imply negligible horizontal displacement since deposition, which is supported by the types of site formation processes acting upon the field in the past eighty years. Only trampling has the potential to horizontally disperse surface artifacts notable distances, and the two years Plot 113 was fallow post-incident likely allowed the residual ACW refuse to become incorporated into the sediment matrix through sediment-depositing processes, especially faunalturbation. Any horizontal movement of ACW was probably small enough to be confined to the medium concentrated units acting as buffers between the low and high concentrations. There has possibly been a greater vertical movement of ACW because of faunalturbation, cryoturbation, and trampling processes for material incorporated into the sediment matrix than horizontal movement from all site formation processes identified.

Site Formation Processes Effects Seen Through the Dry- Versus Wet-Screening Recovery and Distribution Analysis.

Two general spatial patterns were identified during the spatial analysis comparing the quantities of artifacts recovered by both screening stations per unit. These can be explained through the different types of artifact densities throughout Plot 113 noted in the concentration analysis discussion above. The first pattern solely concerned ACW in which both screening methods recovered low, medium, and high concentrations for the same units (see Figure 4.1). This pattern is upheld through the Kendall's tau results that indicated a strong positive relationship between screening methods by unit. Because ACW retained its initial spatial extent, the UNL excavation team only recovered high concentrations of it from one location in the field. The difference between low, medium, and high concentrations was enough to still be reflected when the total ACW quantity for a unit was divided between wet and dry screening. These results along with the statistical determination that the two screening samples could derive from the same population further demonstrate how both screening methods can be effective for the collection of ACW.

The other spatial pattern was noted for both the NHR categories of comparison by total fragment number and aggregate weight (see Figures 4.4 and 4.5) as well as the other artifact categories in which units screened by both methods will alternate concentration levels. The bricks/shingles category further exemplified this pattern through its Kendall's tau results, indicating a moderate negative relationship, so as the bricks/shingles quantity recovered by one screening station for a unit increased, the other station's quantity decreased. Both these spatial and statistical results highlight the even material densities throughout Plot 113 as the distribution and the inverse relationship suggest no significantly high concentration of these materials in one location, especially when compared to the ACW results.

A discussion of the formation processes affecting the NHR assemblage is necessary to reconcile the NHR statistical results for the wet- and dry-screening samples' comparisons. Both the weight and fragment number have been altered as a result of their thermal alteration prior to deposition and the formation processes modifying their structure, weight, and size. Bone's organic content comprises a significant factor for bone weight and structural integrity. By 500ºC, the temperature at which bone will char, 50-55 percent of the total bone mass is lost due to the decomposition of organic proteins (Gallo et al. 2021). At least half of all small NHR fragments exhibit some stage of thermal alteration, a good portion of which have calcined, the stage following charring. The thermal alteration to the NHR fragments has two possible sources, the first when the food waste was burned prior to its inclusion in the fertilizer and the second when the aircraft burned post-crash thermally altering the sediment matrix around it evidenced through the burned pieces of silica recovered by the team. Diagenetic processes further deteriorate bone's organic content post-deposition through the leaching of free amino acids by water. This NHR fragment weight loss meant aggregate weight was substantially impacted and not a true reflection of the NHR assemblage. The variability introduced by the weight loss probably caused the conflicting results from the Wilcoxon rank-sum and Kendall's tau tests (see Table 4.9).

The loss of organic content also affects osseous tissues' structural integrity, as these proteins are responsible for bone's elasticity and ability to withstand external forces to prevent fractures. Another factor of fragmentation is loss in bone density that can be caused by leaching of mineral content from diagenetic processes. This means all thermally damaged and leached NHR fragments are particularly susceptible to breakage from the formation processes present in Plot 113, including plowing, trampling, and cryoturbation. The excavation methods used have likely compounded this from the forces generated by using a mechanical excavator, metal shovels, and pickaxes while excavating units as well as mechanical pressure during screening. All these processes and methods can increase fragmentation substantially, resulting in a variable NHR assemblage total fragment number and the conflicting Wilcoxon rank-sum and Kendall's tau test findings.

Dry- Versus Wet-Screening Recovery Methods

The one- and two-tailed Wilcoxon ranks-sum tests and the N504-508/E14-516 volume experiment results indicate dry screening generally results in a greater collection of most archaeological materials, except in the case of earthenware. Bricks/shingles' one-tailed Wilcoxon rank-sum test indicates that dry screening resulted in a larger recovery overall; however, the volume experiment returned that more g/gal of bricks/shingles were collected for wet screening, which is likely due to the fact the statistical tests looked at overall collection compared to the recovery from a single 2-x-4-m unit. The greater wet-screening collection for earthenware from N504-508/514-516 seemingly confirms the contradictory nature of this artifact category, and its data was likely too variable to obtain an accurate statistical measure for it. It should be excluded from consideration.

ACW and NHR fragments are used as a proxy in this analysis for the recovery of probative material evidence and possible human remains respectively from Site [redacted] and similar sites. The two-tailed Wilcoxon rank-sum test indicated the two ACW screening samples come from the same distribution, or that there is very little difference in the quantities recovered by both stations overall. The volume experiment results contradict this slightly with dry screening recovering 0.72 g/gal while only 0.42 g/gal were recovered through wet screening. This is a notable gap, especially for a unit designated through spatial analysis as having a high ACW recovery for both screening methods (see Figure 4.1). Nevertheless, there is no significant difference in the recovery of ACW, and thus probative material evidence, between the two screening methods, and if one did exist, dry screening would probably result in a slightly greater recovery. However, probative material evidence, though helpful for later identification, is a secondary consideration compared to the recovery of human remains.

Due to their problematic nature, the statistical results of the two NHR screening samples are not included in this analysis. The volume experiment indicates a greater number of NHR fragments recovered per gallon by wet screening (0.28 number/gal) than by dry screening (0.09 number/gal). The deciding factor is the collection of small NHR fragments, as both medium and large fragments were recovered in roughly equal amounts. The results suggest wet screening allowed for a greater collection of small osseous fragments, an important consideration for excavations with the principal goal of possible human remains recovery. However, this conclusion has two caveats. First, spatial analysis shows unit N504-508/E14-516 had a high recovery for wet screening and low recovery for dry screening (see Figure 4.4), meaning the averaged results of number/gal collected by each might be closer together if more units were included in the experiment. Second, these results do not indicate if wet screening makes the NHR fragments more visible, and that is why they were collected in higher frequencies for each unit or if the water pressure applied during the wet-screening process increased bone fragmentation. It is possible that both may have occurred.

Regarding the idea that wet screening is quicker and more "efficient" than dry screening, the volume experiment demonstrated that the average person took roughly the same duration to wet and dry screen one bucket for SU 2 and SU 3, which contained little vegetation or vegetation remnants. For the concentrated root mass that comprised SU 1, dry screening was much quicker, as indicated by a noticeable increase in buckets processed by the dry-screening station of the final day, a total of 111 buckets compared to 44 for wet screening (see Table 4.1). This was also observed by the 2019 recovery team, who dry screened this root mass as well (Interim Search and Recovery Report: CIL [redacted] 2019).

Recommendations for Screening Methods

The type of screening method recommended is rooted in the excavation's goals. For an excavation team aimed at understanding land use of Münsterland's farmland for example, dry screening would be the preferred method for excavating Site [redacted] and similar sites. Wet screening comes with additional considerations, such as water access, site accessibility, excavation budget, and time lost removing screened sediment from the pools. Dry screening is as good, if not better, at recovering most archaeological materials for this site type, including porcelain, glass, and oxidized metal. If the excavators require a sample of the smaller osseous fragments, the author suggests screening a portion of the sediment with a mesh finer than ¼ inch to collect a representative sample for the site.

For future DPAA/academic partner excavations, deciding on which screening method to use requires a few more considerations. First, an assessment of expected fragmentation of possible human remains is required. Site [redacted], based off incident reports and its site formation processes, has a relatively high fragmentation rate expected.

Main factors were post-crash burning and removal of the large wreckage fragments and identifiable human remains as well as the repeated trampling, aquaturbation, and cryoturbation processes over the past eight decades. For sites with lower expected fragmentation, dry screening is likely the better option. The volume experiment demonstrates almost equal recovery rates per gallon for osseous fragments 2.5 cm or greater. Based on this fact and the above considerations, dry screening would be a better use of money, time, and labor resources.

For sites with an expected high fragmentation rate similar to Site [redacted], wet screening is recommended to ensure the recovery of small (less than 2.5 cm) human remains fragments. This thesis' results indicate there is a relationship between low-pressure wet screening and a higher recovery of smaller osseous fragments. However, it is only recommended when the other wet-screening factors' possible process costs do not outweigh the benefits of increased smaller fragments' recovery.

The second consideration for screening method is how small of fragments are desired and viable for further study. Watson (1972) suggests there is a critical recovery length for osseous fragments, which is noted by a rise in collection frequency as size decreases before a sharp fall off as length decreases further. That there is a high frequency in recovery of small fragments by UNL indicates for Site [redacted] and other comparable ones, this critical recovery length is less than 2.5 cm. This author is not recommending a change in screen size or dry- or wet-screening methods, because 2.5 cm exists as a relative cut off for which indistinguishable human and non-human bone fragments are considered usable for scientific analysis. At 2.5 cm, DPAA forensic anthropologists have only two potentially applicable analyses: histology and DNA testing. Main problems at this size are histology is not a conclusive human/non-human test and current DNA testing would likely consume the entire bone fragment. Moreover, academic partner archaeologists are not able to make field determinations of human/nonhuman for recovered osseous material. All smaller fragments found would need to be repatriated back to the U.S. for analysis by forensic anthropologists, no matter if they are analytically viable or not. The next step in this regard is to determine the minimum desired fragment size for DPAA recovery to factor into this dry- versus wet-screening evaluation.

Conclusion

DPAA's mission is to provide the fullest possible accounting of MIA U.S. service members. Field missions are only one step within the identification process, which includes historical research, archaeological excavation, and laboratory analyses. The primary goal of field excavations is the recovery of possible human remains, but there is considerable variation in how this can be achieved most efficiently and completely. A site assessment of expected assemblage conditions based on all known information should be carried out prior to the excavation and should include considerations of the impacts of past and current site formations processes to determine the optimal excavation strategy and methods.

Archaeological excavation methods are their own formation processes, which variably affect the types and frequencies of materials collected as well as influence site descriptions. These excavation methods introduce bias into the assemblage, and the ways in which they do so need to be well-understood by the investigator before they are applied to a site. These biases might also be different depending on the type of site being excavated. This thesis is an important first step into understanding the efficiency of dry versus wet screening and their associated recovery rates for probative material evidence and possible human remains on DPAA/academic partner field missions. In a highly fragmented site with low dispersal of incident-related materials, low-pressure wet screening is the recommended method. However, the benefits of recovering small osseous fragments must be considered with respect to other excavation constraints to determine the true practicality of wet screening at a given site.

Further excavation at Site [redacted] should continue to use a low-pressure wet-screening setup. A hybrid approach would be most efficient with a small dry-screening station to process SU 1's concentrated root mass while all SU 2 and SU 3 sediments are wet-screened using a scaled-up version of the UNL excavation's wet-screening station to accommodate more screens. Based on the identified locations of high ACW concentrations and the recovery locations of potentially probative material, future excavations should focus on the area directly east of N500-512/E512-516. Based on the evidence of Wasserweg Road construction affecting the quantity of material recovered from Plot 113's excavation units adjacent to it, the initial excavation by the 2019 recovery team into Plot 133 might not have been sufficient to determine if the field is clear of any probative material. The author proposes test pit excavations for Plot 133 in areas further away from the road to confirm [redacted]'s initial conclusions.

Future studies are necessary to validate this thesis' findings. Two possible options would be to consider the replicability of these findings for other academic partner excavation teams and for other sites similar to Site [redacted]. The [redacted] UNL excavation was a field school for upper-level undergraduate and graduate anthropology students; however, this is not often the case with academic partner teams. Further research is needed to determine if the results are consistent for teams of variable composition and archaeological skill level. Additionally, other sites need to be tested to see if this thesis' results are translatable for other WWII aircraft crash sites impacted by similar cultural and noncultural formation processes. These data would indicate the importance of particular assemblage characteristics and patterns when deciding excavation-specific methods, especially concerning wet- versus dry-screening systems for sediment processing.

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