Simulating Fluvial Transport Patterns of Human Remains in the Tennessee River

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ABSTRACT

Law enforcement and search and recovery personnel often encounter difficulties when trying to determine where to find a decedent within an aquatic environment. Drowning, boating accidents, and other water related deaths are not uncommon. However, expensive equipment such as sonar and remote operated vehicles, or specially trained rescue divers are often required when searching for remains. Due to both public health and ethical concerns, there is a lack of controlled studies on aquatic decomposition and fluvial transport of human remains, which has contributed to the difficulty of predicting where remains in the water may be located. The purpose of this thesis is to gain a better understanding of the variables that influence fluvial transport patterns of human remains by using rescue manikins embedded with a sensor system that records small changes in acceleration, as well as GPS technology that allows for tracking the path of the manikin in the Tennessee River for 7-8 hours. A total of twenty-five trials were conducted, twenty of which simulated a floating body that was either clothed or unclothed, and five trials that simulated an unclothed, sunken body. Additionally, half of the floating trials were conducted with the manikin placed along the riverbank, and the other half conducted with the manikin placed in the center of the river, to determine how this influenced distance traveled and whether the manikin would stay on the same side it was placed on. Environmental variables for each trial such as rainfall, reservoir water level, and wind speed were also recorded for analysis. Results showed no significant difference between clothed and unclothed trials, but did find a statistically significant difference in distance traveled and average speed of travel between manikins placed in the center of the river versus along the riverbank, as well as between trials taking place in different segments of the river. This study demonstrates the need for more research on fluvial transport of human remains in different rivers throughout the United States, as well as a need for better technology that can be utilized in the water and allow for better simulation of human decomposition.

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CHAPTER ONE: INTRODUCTION

The Problem

Drowning is the third leading cause of unintentional death, with an estimated 236,000 deaths annually worldwide (World Health Organization, 2021). In the United States alone, there are approximately 3,960 drowning deaths per year (Centers for Disease Control and Prevention, 2022). Unfortunately, it is often extremely difficult for law enforcement and rescue personnel to pinpoint the location of human remains in the event of accidental drownings in rivers, or when human remains enter rivers due to suicide or homicide. Because not all of the variables impacting fluvial transport are fully understood, drownings and/or intentional body disposal in large bodies of water can result in extensive search and recovery efforts that can cost thousands of dollars. For example, a remote operated vehicle (ROV) may be necessary for searches in deep water, but usually costs over $10,000. When dive teams are sent underwater for retrieval, they must be properly equipped with basic scuba equipment, such as buoyancy control devices, air tanks, and dive weights. They must also be given special training on recovery diving (Winskog, 2011). Additionally, it is usually recommended that a dive team include at least three individuals: two working together in the water and one on land or in the boat ready to assist (Schultz et al., 2013). Even with proper equipment and training, search and rescue missions can put recovery personnel in peril, both due to the environment under the water, and due to hazards, such as boats, when searching in heavily trafficked areas. In addition to risk of injury, divers are also at risk of developing health issues such as nitrogen narcosis, decompression sickness, and hypothermia (Schultz et al., 2013). In summary, underwater search and recovery operations are resource heavy, requiring both significant time and monetary investment in order to be performed safely. In many cases, recovery teams may be looking in the wrong place by unsuccessfully guessing where a body might move under the water or where and when the body will resurface, which further expends resources and puts dive personnel at risk for longer periods of time.

A primary reason for the difficulty of predicting the movement of human remains in water is the lack of controlled experiments on fluvial transport of human remains and decomposition in aquatic environments. The ethical restrictions prohibiting the use of actual human remains in waterways is an obvious limitation. In addition to being a potential public health hazard to put human remains in publicly accessible waterways, it may be difficult to find donors who will consent to being studied in an aquatic environment and having their remains subjected to the trauma associated with fluvial transport of a human body. Because of these issues, studies of aquatic decomposition have thus had to use non-human proxies, such as pigs, instead of actual human remains (Haefner et al., 2004; Barrios & Wolff, 2011; Anderson & Bell, 2014; Dalal et al., 2020; Wallace et al., 2021). Though these studies have garnered valuable information about the process of underwater decomposition, they have not taught us much about fluvial transport. One reason for this is that such experiments usually were performed with the remains placed in a cage in oceans or ponds (Anderson & Bell, 2014; Dalal et al., 2020; Wallace et al., 2021). Even were these experiments carried out without cages, it is unclear how representative they would be of human remains, especially given that the limbs of a pig are much shorter than that of a human. The different body shapes between pigs and humans could result in different travel distances and speed, as longer human limbs may be more likely to get snagged on obstacles in the river. The abundant studies on fluvial transport patterns of sediment (Holnbeck, 2005; Sivakumar & Wallender, 2005; Vercruysse et al., 2017), microorganisms (Fischer et al., 2003; Zhang et al., 2019), or live fish (Clark et al., 2008; Rosenfeld et al., 2011; Grantham, 2013) are also not useful in this case, not only because of the larger size of human remains, but also because live animals or abiotic materials will not undergo the decomposition process, including re-floating and gradual limb disarticulation, that makes fluvial transport of human remains so complex. While it may theoretically be possible to construct an artificial flume in which to conduct human fluvial transport studies, this would be extremely expensive as well as time, labor and land intensive. Due to the aforementioned challenges, the information that is available in the literature about human aquatic decomposition and fluvial transport of human remains comes from anecdotal reports of body recoveries and forensic case reviews (Anderson & Bell, 2014; Bassett & Manhein, 2002; Heaton et al., 2010; Mateus et al., 2013; Ličer et al., 2020).

This study will explore the fluvial transport patterns of a human body-shaped object in the Knoxville, Tellico Lake, and Fort Loudoun Dam areas of the Tennessee River by placing rescue manikins in the river and tracking their travel path for a period of seven to eight hours. The goal of this thesis will be to demonstrate which, if any, variables in the environment directly impact travel path, speed, and distance of a human body in a riverine environment. It also aims to compare the movement of a body that has sunken to the bottom of a shallow portion of a river to a body that has re-floated due to putrefaction. This expands on previous studies, such as the research of Dilen (1984), that have made general observations about manikin travel paths in other inland rivers. Specifically, this thesis builds on previous studies by tracking the manikins for a longer period of time and attempting to utilize a sensor system to track miniscule changes in manikin behavior (such as velocity increase or decrease) throughout the period of fluvial transport.

Research Questions

In order to assist recovery efforts to be more efficient, this study seeks to simulate how human remains travel in water and how they may be more efficiently recovered by addressing the following questions:

- Are there consistent and identifiable patterns in the travel of a human body (or objects resembling one) in riverine environments?
- What environmental variables (e.g. water depth, water velocity, obstructions, clothing) most impact these patterns?
- How might whether the body is floating or sunken during the decomposition process impact these patterns?

Hypotheses

The objective of this study is to determine whether there are consistent patterns in fluvial transport of human remains and how variables in the decomposition process, particularly re-floating, and in the environment impact fluvial transport patterns. Hypothesis 1 states that an adult human body of average stature and weight deposited in water will follow a consistent travel path and distance if the same environmental and taphonomic conditions are upheld for each trial. This hypothesis will be upheld if the manikin follows a consistent track through the water when it is placed in similar conditions (time of day, location in river, water depth etc) for multiple trials. Previous research has also indicated that a body that sinks to the bottom of the riverbed may stay in approximately the same place that it sank (Dilen 1984, Bassett & Manhein, 2002). To test this, Hypothesis 2 states that a sunken body will remain stationary or remain within a mile from its point of entry into the river. The literature has also shown that human remains tend to remain on the same side of the riverbank that they were deposited into (Bassett & Manhein, 2002). Thus, Hypothesis 3 states that a body placed on one side of the river will stay on that side of the river. In other words, if the manikin is placed along the right bank of the river at the beginning of each trial, it should remain on the right side of the river until it is retrieved. Finally, as clothing would theoretically create more of a drag force for the body to overcome in order to move, and also may be more likely to snag on debris in the river, Hypothesis 4 is that a body wearing clothing will travel a shorter distance than an unclothed body within the same period of time.

Significance

The aim of this project is to gain a better understanding of what environmental variables impact the trajectory of human remains in fluvial transport, as well as how sinking and re-floating during the decomposition process, impacts fluvial transport patterns. Increased knowledge of the variables that influence fluvial transport of human remains may allow for more accurate hydraulic modeling for predicting the location of human remains. Also, the sensor-outfitted manikin could be a potential tool, or at least a prototype, that could be used by investigators in the future to reduce the search area where human remains are likely to have moved in a particular body of water. The ability to narrow down the search area would increase investigators' chances of success in locating the remains and reduce the manpower, risk, and resources required.

Additionally, no river is identical to another, and even different segments of the same river may exhibit very different fluvial transport patterns. This thesis includes the first controlled experiment on fluvial transport of a human-shaped object in the Knoxville, Tellico Lake and Fort Loudoun Dam area of the Tennessee River. Thus, it provides valuable data to law enforcement and rescue personnel in these areas, which previous case studies or controlled studies in the ocean or other rivers would not.

Chapter Organization

Following this introduction, Chapter Two provides necessary background information on the process of decomposition and reviews the literature on decomposition in aquatic environments specifically. This chapter also provides background information on how search and recovery operations are typically performed in the water, and what strategies are employed in attempting to locate and retrieve human remains in the water. The use of hydraulic modeling to predict the location of human remains is also discussed. Finally, Chapter Two is supplemented with information provided by Loudoun County Marine Rescue about members' own first-hand experience with searches for and retrievals of human remains.

In Chapter Three, the materials and methods for the experiments conducted for this thesis are described. Additionally, the locations in which trials were conducted and the frequency of water related deaths at these locations will be discussed.

In Chapter Four, I will provide the results of the study. This includes both qualitative observations made from comparing travel path maps between different trials, as well the statistical relationship between variables tested, such as presence of clothing, and the number of miles traveled by the manikins.

In Chapter Five I will discuss the significance of the results, as well as the limitations of the experiments conducted. I will also make recommendations for how future experiments may be improved to better simulate the decomposition process of human remains and garner more accurate results. Additionally, this chapter will include a discussion of the challenges of operating technological tools, such as GPS and sensor systems, within an aquatic environment, and how this impacted the results of the experiment. Finally, Chapter Six will provide the overall results and conclusions of this thesis in terms of the stated research questions and hypotheses.

CHAPTER TWO: BACKGROUND

The Literature Review section of this chapter provides a necessary review of the known processes of decomposition within an aquatic environment, as well as how different environmental variables might impact decomposition rate and fluvial transport of human remains. Additionally, this section also reviews the search and recovery strategies that Search and Rescue teams employ to locate human remains in the water. Finally, the use of hydraulic modeling to predict where human remains will be found based on their original entry point into the water is discussed. Though hydraulic modeling is often used to track sediment particles, travel of oil spills etc., its accuracy in locating human remains can be compromised by decompositional changes of the body and the environmental interactions that slow or increase decomposition rate. The second section of this chapter, Experiential Observations From Loudoun County Rescue, addresses the first hand experiences of Loudoun County Marine Rescue, the primary search and rescue/recovery group operating in the area in which trials were conducted. Members of this group have years to decades of experience locating and recovering human remains within the lakes and rivers of Loudoun County, and thus can provide practical, firsthand knowledge of aquatic decomposition, fluvial transport, and search and recovery methods.

I. Literature Review

Stages of Human Decomposition

The process of decomposition in a terrestrial environment is relatively well understood and can inform our knowledge of the decomposition process in an aquatic environment (Mann et al., 1990; Bass, 1997). The decomposition process is typically broken into several stages based on the external changes to the body: the fresh stage, early decomposition, advanced decomposition, skeletonization, and skeletal decomposition (Bass 1997, Galloway 1997; Marks et al., 2009). The external changes associated with each stage are briefly summarized in Table 1. Many of the changes throughout the decomposition process are driven by autolysis, which is the self-digestion and destruction of cells in the body through the activity of enzymes within the

Table 1. Stages of Decomposition and Associated External Changes. Data summarized from Bass (1997), Galloway (1997) and Marks et al (2009).

Stage of Decomposition	**Description of External Changes**
Fresh	Algor mortis Livor mortis Rigor mortis No discoloration Egg masses laid by flies may be present on the body
Early Decomposition	Skin slippage Some initial hair loss Maggots have hatched and are active in the face Discoloration ("Green gut" and "marbling") Abdominal distention/bloating Odor of decomposition is present Initial skeletonization of face around nose and eyes Fluids flowing from nose, mouth, and rectum
Advanced Decomposition	Extensive maggot activity Appearance of beetles Bloating has ceased Hair loss Scavenging by mammalian animals Hair loss Abdominal caving due to loss of internal organs More than half the skeleton covered by decomposing or mummified tissues Potential adipocere development Outer tissue may be mummified
Skeletonization	Less than half of skeleton covered by decomposing/mummified tissues Bones mostly dry but may retain some grease Rodent gnawing and scavenging activity continues
Skeletal Decomposition	All soft tissue has been consumed Complete disarticulation of skeleton Cancellous bone exposed in long bones and vertebrae Surface of bone exfoliated/flaking off Bleaching of bone and longitudinal cracks in long bones due to sunlight exposure Extensive rodent gnawing

cells (Clark et al.,1997; Zhou & Byard, 2011). This process will begin within minutes of death. The cessation of blood flow throughout the body after death leads to an accumulation of waste products within the cells of the body, including lactic acid, which damages the cells. Additionally, the pH of the cytoplasm in each cell is reduced, weakening the cell membrane and the membrane surrounding the lysosomes within the cell. Lysosomes are organelles within cells that contain digestive enzymes. Thus, when the lysosomal membrane ruptures, this leads to the release of digestive enzymes such as proteases, lipases, and amylases into the rest of the cell. (Clark et al., 1997; Zhou & Byard, 2011). These enzymes will then begin to digest surrounding organic substances in the cytoplasm of the cell. Eventually, the cell membrane itself is destroyed, releasing nutrient-rich fluids that contain fatty acids, amino acids, and sugars. These nutrients will be digested by the micro-organisms in the body, aiding putrefaction, a process which will be discussed later in this section (Zhou & Byard, 2011).

The first stage of decomposition based on visible external changes to the body, commonly called the “fresh” stage, begins within the first few hours of death. The skin may be unusually pale due to oxygenated blood no longer being pumped through the body by the heart. This is referred to as “pallor” (Clark et al, 1997). Other physiological changes during this stage include algor mortis, livor mortis, and rigor mortis (Marks et al., 2009). These processes usually can be observed within the first two to four hours after death (Clark et al., 1997). Algor mortis is the cooling of the body. When alive, normal metabolic processes keep the body at a temperature of around 98.6 °F. However, once these processes are no longer active, the body will cool to the temperature of the surrounding environment (Clark et al., 1997; Marks et al., 2009). Livor mortis refers to the gravitational pooling of blood in the body. Because the circulatory system is no longer functioning to pump blood throughout the body, the blood will pool in the parts of the body closer to the substrate, causing these areas to exhibit a red or purple color (Clark et al., 1997; Marks et al., 2009). Rigor mortis refers to the stiffening of the muscles due to biochemical changes in the muscle fibers after death. Finally, though there is not maggot activity within the fresh stage of decomposition, flies may be attracted to a body in an accessible location and lay egg masses in orifices of the body, such as the eyes, ears, nose, mouth, and genitals (Bass, 1997; Galloway, 1997).

The next stage of decomposition is often referred to as the "bloat" stage or as "early decomposition" (Bass, 1997; Galloway, 1997). This stage typically occurs within a week after death, though the process may be delayed in cold temperatures and will be accelerated in warm temperatures (Bass, 1997; Galloway; 1997). It is also the stage in which putrefaction takes place. Putrefaction is the destruction of an organism caused by bacteria within the body. Without any immune response to keep it in check, the body's microbiota is free to grow and feed on the nutrients released from the breakdown of cells in the body after death. As they digest, bacteria produce large amounts of gas, leading to bloating and the odor associated with decomposition (Clark et al., 1997; Marks et al., 2009). Because the largest bacterial population in the body during life and soon after death is in the cecum, putrefaction is often first recognized by distention of the abdomen due to these gasses (Clark et al., 1997; Marks et al., 2009). Additionally, a large component of the bacteria-produced gas is hydrogen sulfide, which reacts with the hemoglobin in the blood to form a green pigment (Clark et al., 1997; Marks et al., 2009). This causes discoloration of the skin, usually first observable in the abdominal region ("green gut"). This reaction also blackens the blood vessels throughout the circulatory system, causing the outlining of superficial blood vessels on the body's surface. This event is typically called "marbling" (Clark et al., 1997; Marks et al., 2009). Finally, the decomposition of the lining of the gastrointestinal tract forms "purge fluid," which flows from the nose, mouth, and rectum as a result of the gas pressure in the gastrointestinal tract (Clark et al., 1997). In addition to these changes due to putrefaction, skin slippage occurs during early decomposition as a result of autolysis. When the cells at the junction of the dermis and epidermis of the skin release their enzymes, it loosens the epidermis from the dermis. This results in the epidermis detaching from the dermis, especially when a body is touched or moved. Additionally, hair and nails begin to loosen and will eventually separate from the body due to this process (Clark et al., 1997). Finally, another event which marks the early decomposition stage is that maggots have hatched and are particularly active in the face. Maggot activity also leads to the initial skeletonization of the face as the skin around the eyes and nose is consumed, exposing the bone beneath (Bass, 1997).

Advanced decomposition, the actual reduction of tissue on the body, begins when bloating has ceased and with the sagging of tissue in the thorax and abdomen as the organs break down (Galloway, 1997). In dry and/or sunny environments, the external layer of tissue on the body may begin to mummify and become dry and leathery, while the internal tissues that are shielded from the sun remain moist and exhibit maggot and insect activity (Bass, 1997; Galloway, 1997). Though maggot activity is often extensive at the beginning of advanced decomposition, it will gradually wane, and most of the insect activity at the end of the stage will be consumption of tissues by dermestid beetles (Bass, 1997; Galloway, 1997). In moist environments, a waxy substance called adipocere may form around the body due to the break down of body fat into fatty acids. This process is facilitated by bacteria, and also requires water either from the environment or the body itself. Thus, adipocere formation is more common in areas on the body covered by clothing and in graves and aquatic environments (Clark et al., 1997). Lastly, mammalian scavenging of remaining flesh and skeletal elements may occur if the body is accessible (Bass, 1997).

The skeletonization stage of decomposition is marked by the loss of tissue, including mummified material, exposing the skeletal elements beneath (Galloway, 1997). Initially, ligaments and tendons may remain at articular surfaces after the rest of the flesh is gone. However, these eventually will be lost as well (Clark et al.,1997; Galloway, 1997). The skeletonization stage ends when the remains have been reduced to clean bone (Galloway 1997).

The final commonly recognized stage of decomposition is the “skeletal decomposition” stage. This stage occurs in skeletal remains that are unprotected from environmental forces such as weather, acidic soil, and animals. During this stage, which typically lasts for years, the surface of the bones begins to exfoliate and flake away, particularly in moist environments. If the remains have been exposed to direct sunlight for an extended period of time, the bones will become bleached, and longitudinal cracks may appear in long bones such as the femur and tibia (Bass, 1997). Finally, rodent gnawing may continue to be extensive throughout this stage and result in loss of large portions of bone (Bass, 1997).

Human Decomposition in An Aquatic Environment

Remains in an aquatic environment progress through the aforementioned stages of decomposition. However, the rate at which this occurs is generally considered to be significantly slower compared to in a terrestrial environment due to cooler temperatures and reduced access to insects in the water, particularly when submerged (Rodriguez, 1997). Aquatic environments also introduce additional phenomena such as re-floating and fluvial transport.

When a body first enters the water, it will begin to sink when air in the lungs is replaced by water. This alters the body's specific gravity, or the density of the body in comparison to the density of the water, causing the remains to begin to sink. As the body begins to descend, the hydrostatic pressure of the water compresses the gas-containing cavities in the body, causing it to descend further (Mateus et al., 2013.) Whether the body moves once it has sunk to the bottom of the river, or whether it settles in one place, is dependent on water currents and the type of substrate at the river bottom (Ellingham et al. 2017). In cases in which an individual has drowned, the submerged body will typically assume a position in which the anterior aspect of the individual faces towards the waterbed with the limbs and head hanging downward (Caruso 2016). If the body is subjected to fluvial transport in this position, the hands, knees, feet, and forehead may drag against the substrate at the bottom of the water, creating abrasions or even eburnation of the tarsal and carpal bones (Caruso, 2016; Byard, 2017). Additional damage to the body may occur due to animal scavenging. Though insects and other terrestrial scavengers may not be able to access the submerged remains, aquatic organisms such as fish, amphibians, and crustaceans will feed on the flesh of the remains (Petrik et al., 2004; Becker, 2013).

During putrefaction, as in terrestrial environments, bacteria within the body reproduce and digest the internal tissues and organs of the body producing gasses within the body (Lucas et al. 2002). However, in aquatic environments, as these gasses increase in volume, the body bloats and increases in buoyancy, allowing it to float back up to the surface of the water (Nawrocki et al., 1997). This is referred to as "re-floating." The time it takes for re-floating to occur is heavily influenced by temperature, as the bacteria in the body will be less active in colder water temperatures and thus putrefaction and re-floating will occur more slowly (Mateus et al. 2013).

In water that is very cold and/or deep, such as the ocean or deep lakes, the ability of the remains to bloat may be inhibited by the pressure the water exerts on the body and may not float back to the surface at all (Petrik et al., 2004; Anderson & Bell, 2016). Many of the gasses produced through putrefaction are water-soluble and easily compressed. Additionally, water is colder at increased depths, which slows putrefaction and the production of gas, preventing re-floating (Becker, 2013). The specific depth at which a body can no longer resurface is variable. Becker (2013) estimates that re-floating will usually not occur when a body has sunk to a depth exceeding 100ft and the water temperature is below 38°F. Mateus et al. (2013) estimate that a body will not re-float in a depth past 100 meters, or 328 feet. Animal scavenging both in exposed remains and submerged remains can also impact whether the remains will bloat and re-float. Submerged remains that are rapidly skeletonized by scavengers may not float at all (Hobischak & Anderson, 2002). If a body does re-float, insects and other animals such as birds may scavenge from parts of the body that are not submerged (Boyle et al., 1997). Re-floating remains will inevitably sink again as decomposition progresses and the gases built up in the body are released through body cavities. Re-floating remains that are scavenged on the surface of the water, however, have been observed to re-submerge more quickly (Hobischak & Anderson, 2002).

Eventually the decomposing body will begin to disarticulate and skeletonize. According to Haglund (1993), in aquatic environments, soft tissue tends to first be lost from the head, hands, and anterior tibia. The first elements to disarticulate from the rest of the body tend to be the hands, wrists, cranium and mandible. This is followed by the disarticulation of the lower legs, forearms, and upper arms. The upper legs, portions of the trunk, and the pelvic girdle are the last portions of the body to disarticulate (Haglund 1993). This pattern is illustrated in Figure 1. When evaluating the recovered remains of 184 victims of a fishing boat that had sunk in the Mediterranean Sea, Franceschetti et al. (2021) found it necessary to score the stage of decomposition of the face, trunk, and limbs separately, rather than assigning one score to the entire body, because of these differences in decomposition and disarticulation rate between different segments of the body. Additionally, different rates of decomposition were observed in

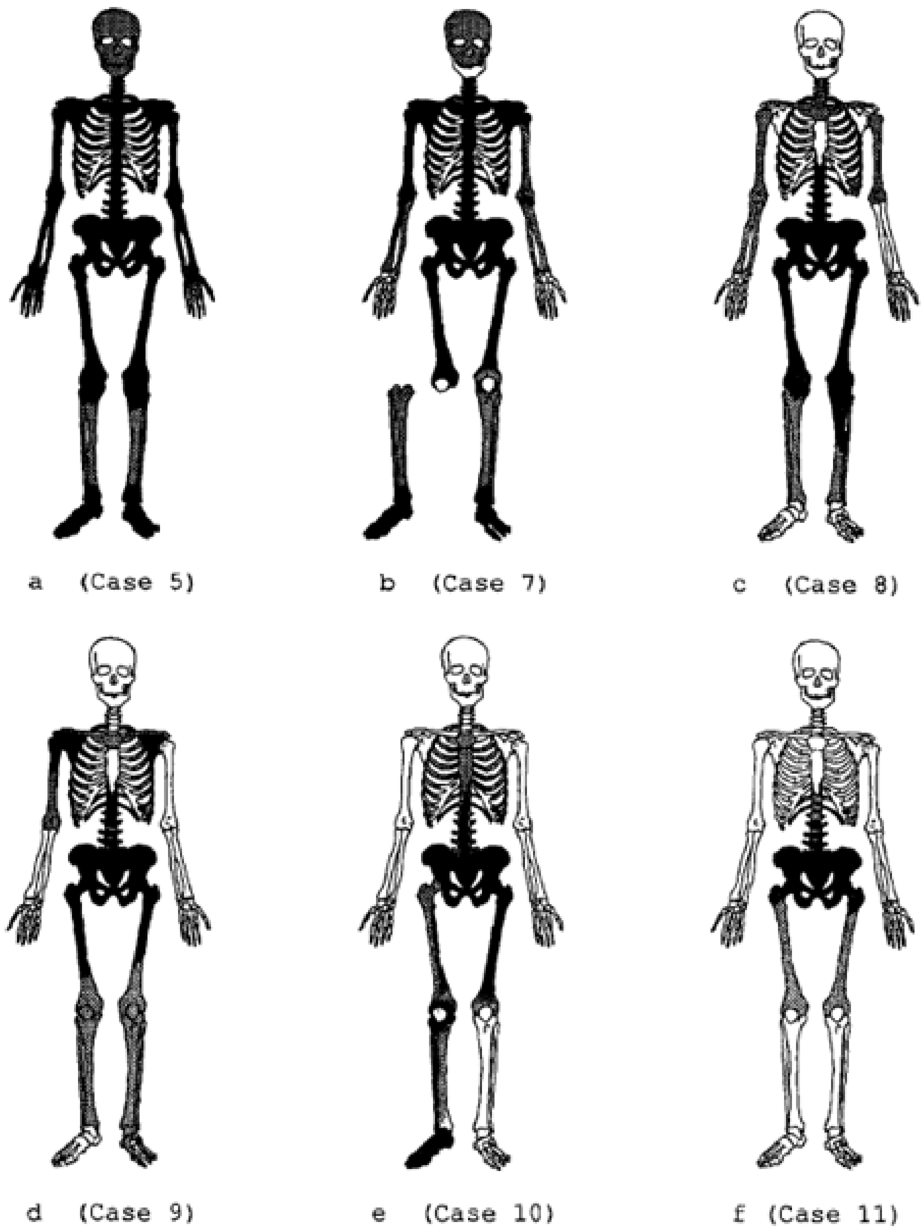

Figure 1: Patterns of bone exposure and disarticulation in remains recovered from water. Dark shading indicates presence of soft tissue over bone, light shading indicates bone exposed from tissue loss, and no shading represents absence of element. From Haglund 1993: 810.

the same limb. For example, the hand may have been entirely disarticulated from the body while the arm remained. Additionally, the impact of clothing on differential rates of decomposition and disarticulation could be observed from the remains. For example, in some instances a part of the body was disarticulated but still present in the clothing that remained on the body (Franceschetti et al., 2021). The decomposition rate of soft tissues was also observed to be slower in parts of the body that were covered by heavier clothing, such as the foot and the pelvic girdle, than parts of the body exposed to the marine environment, such as the head and neck or the arm and wrist (Franceschetti et al., 2021). The observations of Franceschetti et al. (2021) support the order of disarticulation established by Haglund (1993) with loss of soft tissue first occurring at the face, neck, and hands, and occurring at the trunk and pelvic girdle last.

Additionally, because of their different surface areas, densities, and capacity for accumulating bacterial gas, body parts may transport differently as they separate from the body (Nawrocki et al. 1996). For example, the limbs will not accumulate bacterial gas to the same extent as the torso, which houses the digestive organs. Because of this, limbs may sink to the bottom while the rest of the body remains floating. As a result, individual skeletal elements or limbs from the same individual may be recovered in different locations and at different times. For example, in one case, a right lower limb was recovered on the shore of Puget Sound in Washington state, but the rest of the body was not found until two and a half weeks later, when it washed up in Elliot Bay (Haglund & Reay 1993).

Fluvial Transport of Skeletal Elements After Disarticulation

The few controlled experiments on fluvial transport of remains have primarily utilized already fully skeletonized human and animal remains in artificially created flumes (Coard & Dennell 1995; Boaz & Behrensmeyer 1976). Boaz and Behrensmeyer (1976) recognized several different types of movement patterns that different disarticulated elements exhibited when traveling through the water. Some elements would slide along the bed of the floom in the same orientation they had originally been placed in, some had little or no movement at all, some would roll over only once or twice during travel along the flume bed, and other elements would continuously roll along the bottom of the flume. Multiple flume experiments have also shown that different individual skeletal elements tend to travel at different rates and often in different positions in the current. For example, disarticulated long bones tended to travel in a position oriented parallel to the current, with the heavier end downstream. Certain skeletal elements, such as the cervical and lumbar vertebrae, the sacrum, and metatarsals tended to travel more swiftly with the current, while heavier elements, such as disarticulated mandibles, scapulae, the radius, ulna, and tibia tended to move very little (Coard & Dennell, 1995). Boaz and Behrensmeyer (1976) found that complete human crania were the fastest moving elements, though cranial fragments did not move at all. Interestingly, Coard & Dennell (1995) conducted experiments with both fully disarticulated non-human skeletal remains, and with articulated regions of the body (for example, four articulated cervical vertebrae, or an articulated canine forelimb), and found that the transportation of the skeletal elements was enhanced with articulation. For example, every skeletal element from a sheep was transported when articulated with other elements whereas certain elements such as the sheep tibia would not move at all when disarticulated (Coard & Dennell 1995). It is also worth noting, however, that the skeletal elements had been artificially articulated using thread, water-proof tape and rubber bands, which could have impacted the weight and transport potential of the articulated elements. Coard & Dennell (1995) also observed that articulated canine rear limb bones would travel over short distances before eventually the longer elements would get lodged in the flume transverse to the current. This indicates that articulated limbs can get caught and wedged in places when traveling through narrow channels of water.

Variables Affecting Aquatic Decomposition Rate and Fluvial Transport Patterns

Water Temperature, Depth, and Current

Temperature has a large impact on fluvial transport of human remains because warmer temperatures result in faster putrefaction, leading to an earlier re-floating time and a potentially higher probability that the remains will be transported to a different location from where they entered the water. Colder water temperatures during the winter and/or at greater depths of water will lower the activity of the bacteria living within the body, hampering gas production and the ability of the remains to re-float. An analysis of cases of bodies recovered between 1991 and 2007 in the River Clyde and the River Mersey in the United Kingdom observed the influence of temperature on the length of time it took for bodies to resurface, making them easier to locate and recover (Heaton et al. 2010). Bodies that had entered the water during the warmer months in the spring and summer tended to resurface more quickly than bodies in the winter and autumn. The authors also indicate that depth of the water is a variable that influences how quickly a body decomposes and resurfaces, as bodies that have settled to a depth that sunlight cannot penetrate will be in a colder environment than bodies in shallow water (Heaton et al., 2010).

Lucas et al. (2002) reviewed the case records for all decedents who were recovered from New York City waterways and were autopsied by New York City's Office of Chief Medical Examiner between the years 1997 and 2000. This included 123 decedents, 42 of whom who had not yet undergone putrefaction at the time they were recovered. This analysis found that most decedents (89%) who were recovered after three days in the water had begun to show putrefactive changes. All decedents recovered after 14 days exhibited some degree of putrefaction. In addition, the case analysis showed that the number of decedents recovered from waterways changed depending on the season, with most recovered between June and October. There was also a difference between seasons in the amount of time before bodies were found and recovered from the river. All the decedents recovered between June and October had been in the water for fewer than eight days, while all decedents who remained in the water for over two weeks were recovered in the winter and spring months. This was likely a result of slower putrefaction, and thus a longer period before resurfacing in the winter months due to colder water temperatures (Lucas et al. 2002).

In addition to water depth having an influence on the speed of decomposition, Dilen (1984) observed that if a human-like manikin sank to the bottom of the river at a depth of at least 5.5 ft, it could be expected that it would stay in approximately the same place until changes to the river, such as a rise in water level, occurred. The influence of water depth on the displacement of human remains was also noted by Ellingham et al. (2017), who noted that the velocity of the water current is reduced at greater depths. This, combined with increased frictional forces due to the substrate at the bottom of the river, reduces horizontal displacement of remains until resurfacing occurs, if it occurs at all (Ellingham et al., 2017).

In general, a strong water current can be expected to transport human remains further than a weak current. However, part of this distance may be attributed to fast currents creating a dangerous environment for search and recovery personnel, making it challenging to see and identify remains in the water. For example, strong currents, particularly as a result of flooding, may have a larger amount of debris and environmental obstacles present underwater, such as fallen trees and logs (Caruso, 2016). If remains become caught in these obstacles, they may not resurface even during putrefaction, making them much more difficult to locate (Caruso, 2016). Additionally, rivers that are flooded may be filled with silt, reducing visibility under the water for divers, and potentially increasing the time it takes to locate a body (Byard, 2017). Low visibility is commonly cited by rescue teams as a difficulty in locating remains in the Tennessee River. Divers typically have to perform their search operations by feeling around with their hands because visibility is so low, which is especially challenging given the large amount of pollutants in the river, including shopping carts (Knoxville County Rescue, personal communication, July 2021; Loudoun County Rescue, personal communication, November, 2021).

Finally, a rarely studied phenomenon that should be mentioned is that of fluvial transport in an unexpected direction due to tidal systems. It was observed by Heaton et al. (2010) in the rivers Clyde and Mersey, which are part of tidal systems, that the motion from the tides made it possible for remains to be transported upstream. This phenomenon could potentially make it more difficult to locate human remains because the need to search upstream from the point of entry may not be obvious. Instinctively, search and rescue operations may assume that human remains will always travel downstream, when this may not be the case in certain locations.

Location of Deposit into the Water

An experiment with floating and sinking manikins in the Chattahoochee River of Atlanta, GA in 1984 indicated that the location at which a body-shaped object enters a river tends to have an impact on the object’s patterns of travel (Dilen, 1984). A manikin deposited near the right bank of a river tended to continue to travel along the right bank, and a manikin deposited near the left bank continued to travel along the left bank of the river (Dilen 1984). The finding that human remains will stay on the same side of the river on which they were deposited appears to be corroborated by the case studies of real human remains discussed by Bassett & Manhein (2002). Their analysis of 233 cases of human remains located in the Mississippi river between the years of 1957 to 2001 observed that human remains did tend to be located and recovered on the same side of the river as where the decedent first entered. In other words, human remains were unlikely to cross to the opposite side of the river from the side of entry. The analysis of cases in the Mississippi river also determined that remains tended to stay in nearly the same location or move less than a mile in the first few days after entering the river (Bassett & Manhein, 2002). This suggests that remains that have only been in the water for a few days will typically be located near the original point of entry. Though it is possible that the observations of Dilen (1984) and Bassett & Manhein (2002) are universal patterns that bodies in fluvial environments will follow, a sample size of two rivers is not sufficient to prove this. Additionally, given that the Chattahoochee and Mississippi rivers vary significantly in length, depth, width, and flow rate compared to the Tennessee River, it was necessary in this project to test the impact of river depth and side of the river a body enters on where a body ends up in the Tennessee River as well.

Animal Predation

Animal predation also impacts decomposition and fluvial transport in aquatic environments. This includes insect activity, which will change depending on whether the body is fully submerged or whether it is floating. If the body is floating in the water, exposed surfaces are accessible to the same insects associated with decomposition on land, such as blowflies and carrion beetles (Caruso, 2016; Hobischak & Anderson, 2002). Generally, the presence of these insects can be expected to increase the rate of decomposition, and the absence of them tends to result in slower decomposition (Simmons et al., 2010; Hobischak & Anderson, 2002). This implies that an already fully submerged body may have a different decomposition rate than one that is floating. However, even a fully submerged body may still be subject to scavenging by other organisms. For example, small fish and invertebrates, as well as shrimp and crabs may de-flesh submerged parts of the body (Caruso, 2016). While the damage from small fish is relatively light, large numbers of scavenging crustaceans, such as crayfish, shrimps, and crabs, are much more destructive (Petrik et al., 2004; Becker, 2013). Additionally, Hobischak & Anderson (2002) observed that heavily scavenged pig carcasses submerged much more quickly than un-scavenged carcasses, suggesting that scavenging activity will alter the timeline of floating/re-floating and sinking. Organisms feeding off of a submerged body influence not only the decomposition rate of the body, but also the displacement of the body in the water. For example, Anderson & Bell (2014) found that even when pig remains were placed in a water depth too great for re-floating to occur, the remains could still be transported away from their original location due to animal scavenging activity. This means that even when a human body is determined to have sunk to the bottom of a deep body of water, it cannot necessarily be assumed that it will always remain in the same place it originally entered the water.

Prescence of Clothing on the Body

The presence of clothing on the body also influences both the decomposition process in the water and fluvial transport. As stated earlier, Franceschetti et al. (2021) recognized that skeletonization and disarticulation tended to first occur in areas of the body that were bare of clothing: the face, neck, hands, and forearms. While soft tissues tended to be mostly complete on areas typically covered by clothing, such as the pelvis and feet, many of the remains exhibited exposure of portions of the skull and degloving of the hands (Franceschetti et al., 2021). The presence of clothing on remains in water also has an impact on the ability of scavengers, including freshwater invertebrates such as crayfish, to access and remove soft tissues (Hobischak & Anderson, 2002). Thus, a partially or fully submerged body that is covered by clothing might decompose at a slower rate because it is more protected from animal and insect predation.

In theory, the presence of clothing should have an impact on fluvial transport of human remains as well, though formal experiments on this are virtually non-existent. The impact of clothing on hydrodynamics and swimming speed of living individuals has been tested, and may have implications for the fluvial transport potential of clothed human remains as well. For example, clothing can decrease swimming efficiency and lead to quicker fatigue in a swimmer wearing clothing vs. an individual swimming unclothed due to the increase in drag resistance it creates (Bowes et al., 2016). In theory, this could mean that clothed human remains are also less likely than unclothed human remains to be transported long distances in the water due to increased drag resistance. Characteristics of the clothing itself are also considered to have an impact on speed of movement in the water when studying the performance of live individuals in swimwear. This includes surface roughness, seam position, fiber orientation, air permeability, and number of layers of clothing (Nazemi et al., 2018). It is likely that these same factors would also apply to drag resistance and travel speed of clothed remains being carried by the water current. Finally, clothing, particularly when loose fitting, also could be an impactful variable on fluvial transport distance because it may be more likely to snag on obstacles in the river. For example, a body with a shirt on may be more susceptible to getting snagged on rocks and branches in the water, causing it not to travel as far as a body without clothes.

Search and Recovery Methods

Mateus et al. (2020) break down the search and rescue process into four stages, summarized in Figure 2. These stages roughly correspond to the sinking and re-floating behaviors of a decomposing body in an aquatic environment, with different degrees of searching activity depending on whether the body is expected to be sunken to the bottom or floating on the surface. The first stage, “first response”, takes place immediately after a search and rescue team has been notified of a missing person who is likely to have entered the water, such as if an individual was spotted jumping from a bridge or exhibiting signs of drowning in the water. Searching for the victim may involve scouting the water from the shore, as well as surface exploration of the area in which they were last seen by boat or by aerial searches (Mateus et al., 2020). The methods and patterns used to search for an individual in the water will vary depending on the resources available to search and recovery teams as well as the characteristics of the body of water being searched. For example, a narrow riverway where both banks are visible from the center of the river may require only a single boat traveling parallel

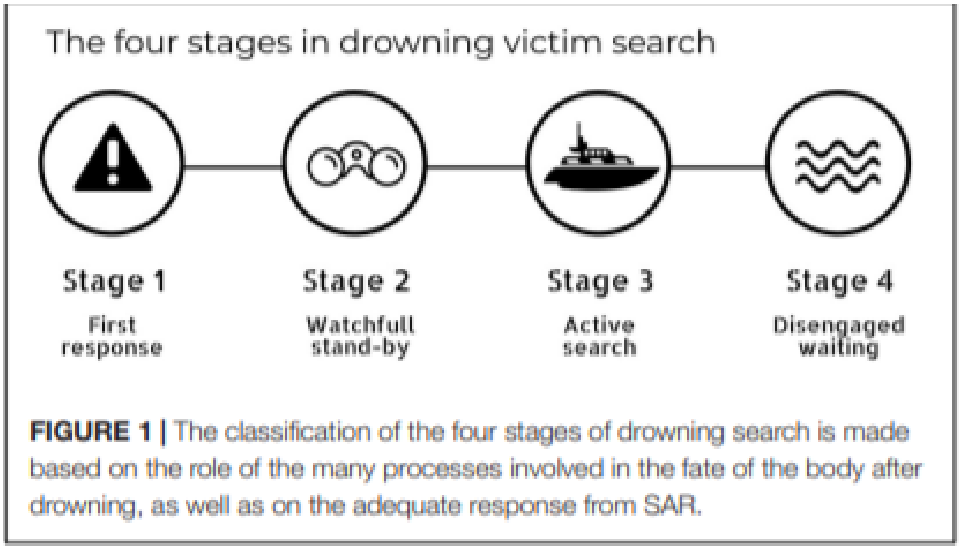

FIGURE 1 | The classification of the four stages of drowning search is made based on the role of the many processes involved in the fate of the body after drowning, as well as on the adequate response from SAR.

Figure 2. Stages of search and rescue response when a drowning is reported. From Mateus et al., 2020

to the bank (Vidan et al., 2010). A search conducted on a wide waterway where the water banks are not visible from the center of the waterway may be performed by multiple boats traveling parallel to the bank lines (Vidan et al., 2020). If the river is wide but only one boat is available, Vidan et al. (2010) recommend the search be conducted in a zigzag pattern. Vidan et al., (2010) also recommend that searches start at a particular reference point based on the following equation, wherein D is the distance in kilometers downstream from the last known place of distress, $Br_{(max)}$ is the maximum speed of the river current, and t is the period of time reported since the distress call:

$$D = Br_{(\mathrm{max})} * t$$

According to Mateus et al., (2020) this first stage of search and rescue may continue for one or two days. However, the authors also note that if the body is not found within the first few hours of searching, it is unlikely to be found until the remains resurface. Once it has been determined that the body has sunk to the bottom of the water reservoir, Mateus et al. (2020) suggest moving on to Stage 2: “watchful standby”. This stage assumes that a fatality has occurred - there is no longer any possibility that the individual who entered the water survived. At this stage, Mateus et al. (2020) recommend essentially waiting for the remains to resurface during putrefaction. The duration of this stage is dependent upon several factors, such as water temperature and depth, the size and age of the victim, and the hydrodynamics of the site.

If the search and rescue team has the resources at their disposal, they may, instead of waiting for the remains to resurface, choose to send divers to search the bottom of the water for submerged remains. Specially trained recovery dive teams are commonly employed for this. However, when searches are conducted in water that is too deep for divers, search and recovery teams may use remove operated vehicles (ROVs) to traverse the bottom of the waterbed instead (Schultz et al., 2013). Access to an ROV will be dependent on the funding of individual search and recovery teams, as well as whether the ROV can be employed without getting stuck in underwater obstructions. ROVs are robots equipped with lights and a video camera that are tethered to a boat and manned from on board. Often, they are also equipped with other tools such as side scan sonar and “arms” than can be manipulated and used to retrieve submerged remains at the bottom of the waterbed (Shultz et al., 2013). Another method that is frequently employed when searching for submerged remains is the use of side-scan sonar. Side-scan sonar was initially developed to map the seafloor, and works by sending and receiving acoustic pulses to detect raised objects on the floor of the reservoir (Schultz et al., 2013). These acoustic signals are then converted into electrical signals and displayed on a monitor. Search teams using side scan sonar start at a body’s last known location in the water and drive the boat with the sonar unit attached in straight and parallel transect lines to map the search area (Schultz et al., 2013.) If an anomaly is detected, divers or an ROV may be employed to further investigate and/or recover the object from the floor of the reservoir.

Stage 3 of a search and recovery operation, “active search” occurs after the body is believed to have regained buoyancy and resurfaced. Mateus et al. (2020) recommend calculation of accumulated degree days to predict when the body will resurface based on water temperature, and thus when active search should begin. However, as stated earlier, bodies trapped under rocks, branches, or other debris may not resurface at all. Hydraulic modeling, which will be discussed in more detail below, may be utilized during the active search stage to attempt to determine where resurfaced remains may be (Mateus et al., 2020). However, this is dependent on what resources search and recovery teams have access to. Ultimately, because of the long-distance bodies can travel from their original point of entry into the water, Mateus et al., (2020) recommend that the active search radius is larger than the search radius in Stage 1.

If Stage 3 of the search and rescue operation yields no results, Mateus et al. (2020) warn that the chances of finding the body are slim. Thus, Stage 4, “disengaged waiting”, of the search and recovery process is simply waiting to see if the remains will eventually re-appear, though this may take several weeks and the remains may be found far away from the original location of entry into the water (Mateus et al., 2020). Additionally, if decomposition has progressed to an advanced stage and disarticulation has occurred, different parts of the body may wash up in different locations and at different times (Haglund & Reay 1993).

There could be several reasons for the remains not to re-appear within the time interval predicted. The body could be trapped underwater by environmental obstacles such as fallen trees or even due to the presence of heavy clothing on the body inhibiting re-floating (Mateus et al., 2020). It is also possible that the remains are at a depth at which the bloating of the body cannot overcome the hydrostatic pressure of the water, allowing for refloating (Mateus et al., 2020). Finally, if the remains have already re-floated unnoticed, they may have already been transported away from the area of the search by the water current (Mateus et al., 2020).

Hydraulic Modeling

Hydraulic modeling softwares, such as the U.S. Hydrologic Engineering Center's River Analysis System (HEC-RAS) , the MOHID Water Modeling software, OpenDrift, NEMO (Nucleus for European Modelling of the Ocean), and the International River Interface Cooperative (iRIC) have been utilized to narrow down the potential search areas of objects given a certain starting point, including drowning victims (Ebbesmeyer & Haglund, 1994; Mateus et al., 2015; Hosseiny et al., 2020; Ličer et al., 2020). Typically, these models attempt to estimate the location of a body or other object (oil spills, bacteria etc.) based on water current, wave, and wind data for the area during the time the decedent entered the water (Ličer et al., 2020). Predictive modeling simulations of a body in water can be run for a period in the past (i.e. if the body entered the water several hours or days ago, what path can be assumed given the water current conditions during that time). However, to predict the future movements of a body, one must rely on forecasts, similar to weather prediction models, of what the water conditions will be. Unfortunately, it has been noted that there is not widespread and civilian accessible infrastructure for forecasting water conditions in the United States, making it difficult to accurately run hydraulic simulations for the purpose of finding human remains (Carniel et al., 2002). This is likely due, at least in part, to the high costs associated with modeling, particularly large-scale river modeling. The topography of river channels is considered to be the most important data for effective hydraulic modeling, but unfortunately also tends to be one of the largest sources of uncertainty (Casas et al., 2006; Yan et al., 2015). Many of the data tools that provide the most accurate and high-resolution data, such as LiDAR and aerial photography, are expensive to use over large areas. However, lower cost earth observation satellite data tends to have a lower resolution and low accuracy, leading to less accurate hydraulic modeling (Yan et al., 2015). Additionally, Lord et al. (2009) point out that a river channel is always part of an integrated fluvial system; a particular segment is impacted by events occurring upstream, so it is usually not sufficient to model only a small section of the river. Another consideration is that fluvial systems are impacted by changes in the surrounding terrestrial environment. Thus, if there is an event such as a building project or a forest fire on the land surrounding a river channel, or just the erosion of the riverbank due to water-flow, the hydrological characteristics of the river are also impacted. For this reason, topographical and hydrological measurements need to be repeated at least every decade for hydraulic modeling of the area to continue to be accurate over time. Finally, the most sophisticated data loggers that collect information about the water itself, such as water flow and depth, can cost up to $10,000, and for a large area, multiple sensors may be required (Lord et al., 2009). According to Hosseiny et al. (2020), only 40% of the inland rivers in the United States have been mapped by the Federal Emergency Management Agency because of these high costs associated with river modeling. This means that data for many areas where individuals drown or otherwise enter the water may simply not be publicly available for hydraulic modeling. The United States does have a large-scale hydraulic model called the National Water Model (NWM), which simulates real time flow for 1.7 million sections of river throughout the United States (Hosseiny et al., 2020). However, there are still many areas that are not covered. The NWM estimates how forecasted weather may impact river discharges and elevation (Hosseiny et al., 2020). However, these predictions may at times be inaccurate due to simplifications built into the model in the hydraulics of the water flow and geometry of streams and rivers being modeled (Hosseiny et al., 2020). River and stream data are also mapped and available through the United States Geological Survey's National Water Information System (NWIS) and National Water Dashboard. However, these still operate based on data collection at specific stations throughout the country, and not every river or river segment has a data station. For example, there is no station for the Tennessee River at Knoxville or at Fort Loudoun. Thus, data for these specific segments of the river could not be located through NWM, the NWIS, or the National Water Dashboard. In summary, many search and recovery teams throughout the United States probably do not have access to the data needed to create a truly accurate model. At best, this means that hydraulic modeling is simply not used. At worst, a simplified and inaccurate hydraulic model based off of incomplete data could in theory lead investigators to look for remains in the wrong place.

Additionally, in order for hydraulic modeling to be accurate, the time that the body is thought to have entered the water must be as accurate as possible. One case that utilized hydraulic modeling to locate human remains found that times of entry into the water differing by 30 minutes led to notably different predictions of where the body would be found (Ebbesmeyer & Haglund 1994). Similarly, hydraulic modeling of a case in 1988, wherein a man died after jumping from the Tacoma Narrows bridge near Seattle and was found 32 km north of the bridge, suggested that if the jump had occurred half an hour earlier, the body would have instead floated 10 km to the south because of a change in the water currents around that time (Carniel et al., 2002). The modeling was performed using a physical, scaled-down replica of the area. However, given that a scaled physical model works based on prediction and simulation of water currents, just as hydraulic modeling softwares do, we can assume that the problem of timing persists regardless of whether the model is physical or digital. The importance of accurate timing could also create another roadblock to accurate hydraulic modeling if data on the river is recorded in large intervals, such as once a day or every several hours. If even a half hour can make a difference in predicting the location of human remains, data on water currents an hour before the body entered the water may not be suitable for an accurate prediction.

Another concern with hydraulic modeling is that it often requires the user to have an understanding of physics and hydrology in order to input variables correctly and know what type of modeling to use. It is unlikely that every search and recovery team or police force has someone with such a background who can use hydraulic software accurately and quickly. Finally, the accuracy of hydraulic models may also be limited as they typically cannot take into account animal scavenging, re-floating, the possibility of limbs getting caught in narrow channels of water, or other variables associated with decomposition and how much these factors might slow the rate of travel of the body.

II. Experiential Observations From Loudoun County Rescue

Loudoun County Marine Rescue (LCMR) is a volunteer-staffed organization that performs water search, rescue, and recovery operations in Loudoun County, Tennessee. Members of LCMR are intimately familiar with the area in which the trials were conducted for this study and have experienced an array of different rescue and recovery situations in Tellico Lake and in the Tennessee River near Fort Loudoun Dam. The primary manner of death which occurs in this area is accidental drownings, though there have been some cases of suicide (Anonymous, personal communication, February 2, 2022). In particular, several members of Loudoun County Marine Rescue have stated that Mizell Bluff, a cliff in the Tellico Lake area of the Little Tennessee River pictured in Figure 3, is a common site of accidental death. Many individuals have jumped from the bluff into the water as a recreational activity, not realizing that the water below the bluff reaches a depth of around sixty feet and drown if they are not strong swimmers or are impaired by alcohol and cannot re-surface or swim to shore (Anonymous, personal communication, February 2, 2022). There are also a series of rocky cliffs beneath the surface of the water at the base of the bluff which can cause serious injury to jumpers (Anonymous, personal communication, November 12, 2021). Another common site of water death is near Fort Loudoun dam, pictured in Figure 4. On days when the floodgates of the dam are open, the water volume and speed of flow in the area has been high enough to capsize fishing boats and to tear clothes off of decedents in the water (Anonymous, personal communication, February 2, 2022). Such incidents have occurred often enough that large warning signs, illustrated in Figure 5, can be spotted on either side of the river just downstream from the dam. Therefore, these two sites were used in trials with the intention of collecting data that could simulate real-life recovery situations that the LCMR team commonly faces.

Decomposition and Animal Scavenging in the River

The stage of decomposition and the time it takes LCMR to locate and recover a decedent is heavily dependent on water temperature, water current, the weather, and the accuracy of the information the team has received about the situation (Anonymous, personal communication,

Figure 3. Mizell Bluff. A common drowning site in Tellico Lake, Loudoun County, TN.

Figure 4. Output Side of Fort Loudoun Dam. Another common drowning site in Loudoun County, TN.

Figure 5. Warning sign along river by Fort Loudoun Dam.

February 2, 2022). Consequently, the amount of time it takes to locate and recover a human body from the water has taken from as little as minutes to as long as several weeks (Anonymous, personal communication, February 2, 2022). If a body is not found before it sinks beneath the water, one member of LCMR confirmed that it typically takes several days for enough gases to build up within the body for it to re-float. Because the Tellico Lake and Fort Loudoun area has very high fishing traffic, LCMR will often receive calls from fishermen who find the body after re-floating (Anonymous, personal communication, February 2, 2022). Additionally, when individuals enter the Tennessee River near Fort Loudoun Dam, they may be transported large distances due to the strong current. For example, one individual who entered the water near the dam was found after resurfacing a week later, approximately 22 miles from their entry point into the river (Anonymous, personal communication, February 2, 2022).

Members of LCMR have also reported observing advanced stages of decomposition in recovered human remains, as well as evidence of marine animal scavenging. For example, one diver reported de-gloving on remains he was attempting to recover (Anonymous, personal communication, February 2, 2022). Additionally, remains that have been in the water for several days tend to have evidence of scavenging by minnow-sized fishes, shrimp, and crawfish, particularly around the face (Anonymous, personal communication, February 2, 2022).

Search and Recovery Methods Used by Loudoun County Marine Rescue

Loudoun County Marine Rescue employs several methods in order to locate and recover human remains. The first responder to arrive at the scene interviews anyone in the area who may have witnessed the individual in the water and attempts to discern where the individual was last seen (Anonymous, personal communication, February 2, 2022). If an individual is reported to have entered the water close enough to the shore, LCMR operates on a "tender" system, in which a diver enters the water connected by rope to an individual on the shore. LCMR will pick two points on either side of the place at which the individual they are searching for was last seen and the diver will swim in a crescent pattern between the two points (Anonymous, personal communication, February 2, 2022). The diver and the shore tech they are sharing the rope with communicate with a "four tug pull system" in which different numbers of pulls on the rope mean different things. For example, a diver who thinks they have found what they are searching for will pull on the rope three times to relay this information to the tender (Anonymous, personal communication, February 2, 2022). When a potential recovery object, such as human remains or a lost vehicle, is found, the tender will give several feet more of the rope to the diver to tie so that it can be tied to the object (Anonymous, personal communication, February 2, 2022).

Other methods may be employed when remains are believed to be far enough from the shore that a boat is necessary to reach them. An occasionally used method by Tennessee rescue squads to locate human remains or other objects is “dragging,” in which rescue boats will have a long rope attached with treble hooks at the end and will drag the treble hooks along the bottom of the water as the boat moves (Anonymous, personal communication, February 2, 2022). This method is rarely used in the Loudoun County area by LCMR because of the terrain beneath the water. For example, the bottom of Tellico Lake contains a lot of trees, rocks, and other structures that can snag the hooks and rope, which makes dragging very difficult (Anonymous, personal communication, February 2, 2022). Thus, Loudoun County Marine Rescue is more likely to employ other methods when searching for human remains in areas that are deep and far from the shore. One of these methods is the use of a remote operated vehicle that is able to operate underwater and is equipped with lights, a camera, and sonar, as well as pinchers that can be used to grab onto objects at the bottom of the lake (Anonymous, personal communication, February 2, 2022). LCMR’s rescue boat is also equipped with side-scan sonar, allowing the rescue team to see objects at the bottom of a lake or river, including the shape of a human body.

Summary

Due to ethical and logistical restrictions, there is a gap in knowledge about human aquatic decomposition and fluvial transport of human remains. Though the stages of decomposition in a terrestrial environment can be applied to aquatic decomposition, the time intervals at which changes occur vary according to water temperature, water depth, current speed, and accessibility to aquatic animals and insects. Because of the lack of controlled studies conducted on human aquatic decomposition, it is difficult to determine how long a body will be submerged before it re-floats due to putrefaction, whether it will re-float at all, and how long it will stay on the surface before sinking again. Additionally, even making predictions of body location based off of river modeling is a challenge, because publicly accessible river data and mapping is not complete across the United States. This leaves marine search and recovery teams to operate only from personal experiences and the sparse data available from forensic case studies when attempting to find a body. Though technological advances such as side-scan sonar and ROVs can be extremely helpful, they are very expensive, and may not be available to every search and recovery team in the United States. Additionally, even training search and recovery divers requires a significant time investment and expenses for proper equipment. In addition to academic literature, this thesis was informed by the experiences of the Loudoun County Marine Rescue team. According to LCMR, two hotspots for in-water deaths are Mizell Bluff and Fort Loudoun Dam. LCMR also has observed many of the variables discussed in the literature, such as scavenging of the remains by fish, changes in decomposition speed based off of water temperature, and the sinking and re-floating of human remains in water. This knowledge informed the locations used for the trials conducted in this thesis, as well as which variables that potentially impact the fluvial transport of human remains were simulated.

CHAPTER THREE: MATERIALS AND METHODS

Materials

In order to avoid the ethical and environmental concerns that are associated with placing decomposing human remains within a publicly accessible body of water, trials were performed using a rescue manikin that could mimic the movement of a real human body relatively realistically. The Randy 9000 manikin model by Simulaids™, pictured in Figure 6, was chosen for several reasons. First, this manikin has detachable joints at the shoulders, elbows, hip, and knees, allowing it to simulate the flexibility of the limbs of a real human body. Additionally, almost every piece of the manikin (limbs, torso, pelvis etc.) has a hollow center, allowing the ability to add weight to the manikin. Two of these manikin models were procured, allowing for two trials to be run simultaneously. Test runs in the UT Aquatic Center pool and in the Tennessee River indicated that the Randy 9000 manikin was buoyant and floated without the aid of air bladders. However, the manikin's buoyancy actually needed to be reduced in order to emulate the position of a real human body in water. Without any added weight, the manikin simply floats on the surface of the water like a buoy, rather than assuming the position typical of a drowned body, in which the anterior of the body, as well as the limbs and face, are typically positioned downward and submerged. Thus, for actual trials in which the manikin was floating, approximately 25 pounds of sand were added to the manikin's upper arms, hips, and lower limb compartments. This brought the weight of the manikin, which has a base weight of 68 pounds, to approximately 92 pounds. For sinking trials, in addition to the sand, "seabags" by Seasoft™ were added to weigh down the manikin. These neoprene bags are filled with lead, and are usually used as dive weights. One five-pound seabag was placed in each of the manikin's upper arms upper legs, and two ten-pound bags were added to the hollow chest cavity. This added a total of 40 additional pounds to the manikin used for sinking trials, bringing the total weight of the manikin during sinking trials to 132 pounds.

For data collection, an Oyster2 GPS system, as well as a phone running the Life360 app, were placed inside the manikin to ensure its recovery at the end of each trial. The Oyster2 GPS transmits location points to an app every five minutes when it senses movement, as well as every

Figure 6. Randy 9000 manikin with open chest cavity.

12 hours regardless of whether the manikin is moving or stationary. Life360 is an app that tracks the location of the phone within the manikin's body cavity in real time and can share this location with other phones that have the app installed.

A STEVAL-STLCS01V1 SensorTile was placed within the hollow torso cavity of the manikin. This sensor tile system is capable of logging x, y , and z coordinates, allowing for positional and depth changes of the manikin to be tracked. It also includes an accelerometer, and a gyroscope that detects changes in velocity as the manikin travels. Data for each trial was stored on an SD card within the sensor and retrieved from the SD card after each trial. To maximize trial length, the phone and the sensor were also attached to a battery pack. However, due to charging limitations of the sensor system, trial length was kept to no longer than eight hours in an attempt to avoid losing the data collected by the sensor. To avoid water and other environmental damage to the sensor, phone and battery pack, these materials were placed in ML-47F Outdoor NEMA Enclosure, which is an impact and water-resistant container made of polycarbonate. This enclosure has a NEMA 6P and IP 68 rating which is good for prolonged submersion at a limited depth of approximately 1-1.5 meters. As shown in Figure 7, the phone, battery pack, and sensor were placed into the same waterproof container and Velcro-ed in place within the container to keep them from getting crushed or bumped by the movement of the manikin. For trials in which the manikin was floating, the NEMA Enclosure was then screwed to the wall of the manikin's torso cavity to prevent it from moving around inside the manikin, as pictured in Figure 8. The Oyster2 GPS system arrived with its own IP 67 rated waterproof box, which was also screwed to the wall of the manikin's torso cavity. Additionally, when the manikin is assembled, the torso is bolted shut, and stays relatively watertight for further protection.

Because water interferes with GPS signals, trials in which the manikin was submerged had an alternative configuration. Prior to running trials, the manikin and sensors were tested in the University of Tennessee Student Aquatic Center pool to ensure that the sensors were recording data properly in the water. When attached to the floating manikin, the sensor system and GPS on the phone included with the sensors were able to successfully collect location,

Figure 7. Secured sensor and phone within NEMA Enclosure.

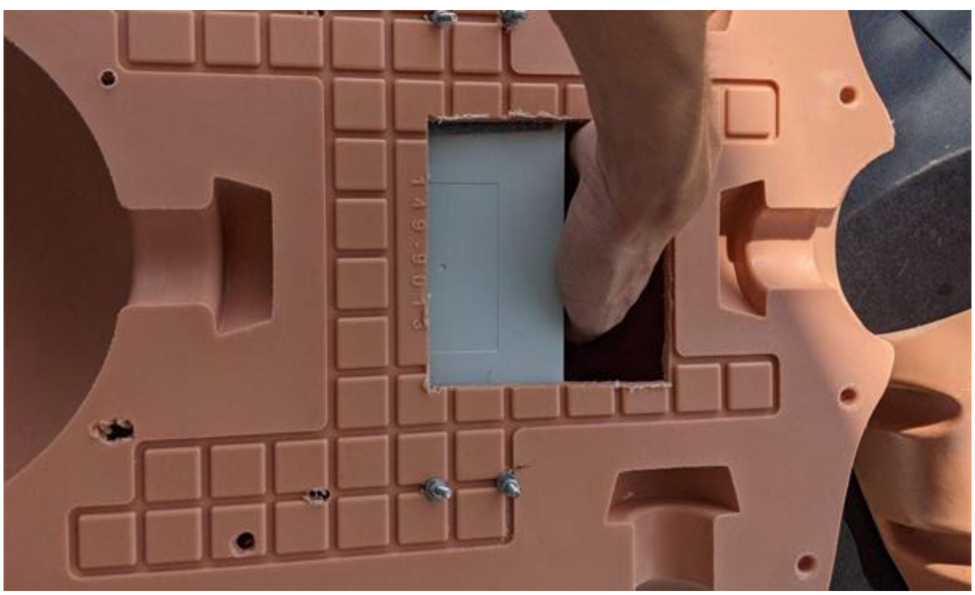

Figure 8. Waterproof box secured within manikin’s chest cavity.

acceleration and velocity. However, when tested beneath the water, it was determined that the GPS tracking on the phone would lose signal if deeper than three feet underwater. For this reason, trials in which the manikin was completely submerged at the bottom of the riverbed were only conducted in shallow water near the riverbank, and rather than being kept inside the manikin's chest cavity with the sensor system, the phone was kept within a second waterproof box secured to a floating buoy-like structure that was attached to the manikin with a rope. This configuration is pictured in Figure 9. This ensured that the manikin could still be located if it were to roll or otherwise move toward a deeper area of the river.

Locations

Permission was obtained to place the manikin in the Tennessee River and Little Tennessee River in the Tellico Village area of Loudoun County, Tennessee for floating trials. Additionally, Loudoun County Rescue and Loudoun County's dispatch services were notified when trials were in progress to avoid false alarms if a concerned onlooker mistook the manikin for a real human body. Placement of the manikin in the river was informed by the Loudoun County Rescue team's knowledge of where decedents tend to enter the water when drowning deaths take place. One of these areas is Mizell Bluff, which people commonly jump off of into the water recreationally. As illustrated in Figure 10, Mizell Bluff is located on the east side of Tellico Lake, which is part of the Little Tennessee River, an offshoot of the Tennessee River. The other location where deaths are quite common is just past Fort Loudoun Dam, where the water can be particularly fast, especially if there has been recent flooding or water release. The manikin was placed in approximately the same spot for each trial. Trials in the center of the river placed the manikin in a starting point parallel to the starting point along the bank, as illustrated in Figures 11 and 12. Though these locations are only about a mile and a half apart, they exhibit very different water conditions. Tellico Lake is typically slow moving, while the river on the output side of Fort Loudoun Dam is fast-flowing and narrow compared to Tellico Lake.

For sinking trials, permission was obtained to place the manikin in the Knoxville area of the Tennessee River. Knox County Rescue and Knox County's dispatch services were also

Figure 9. Floating buoy with phone inside tracking submerged manikin.

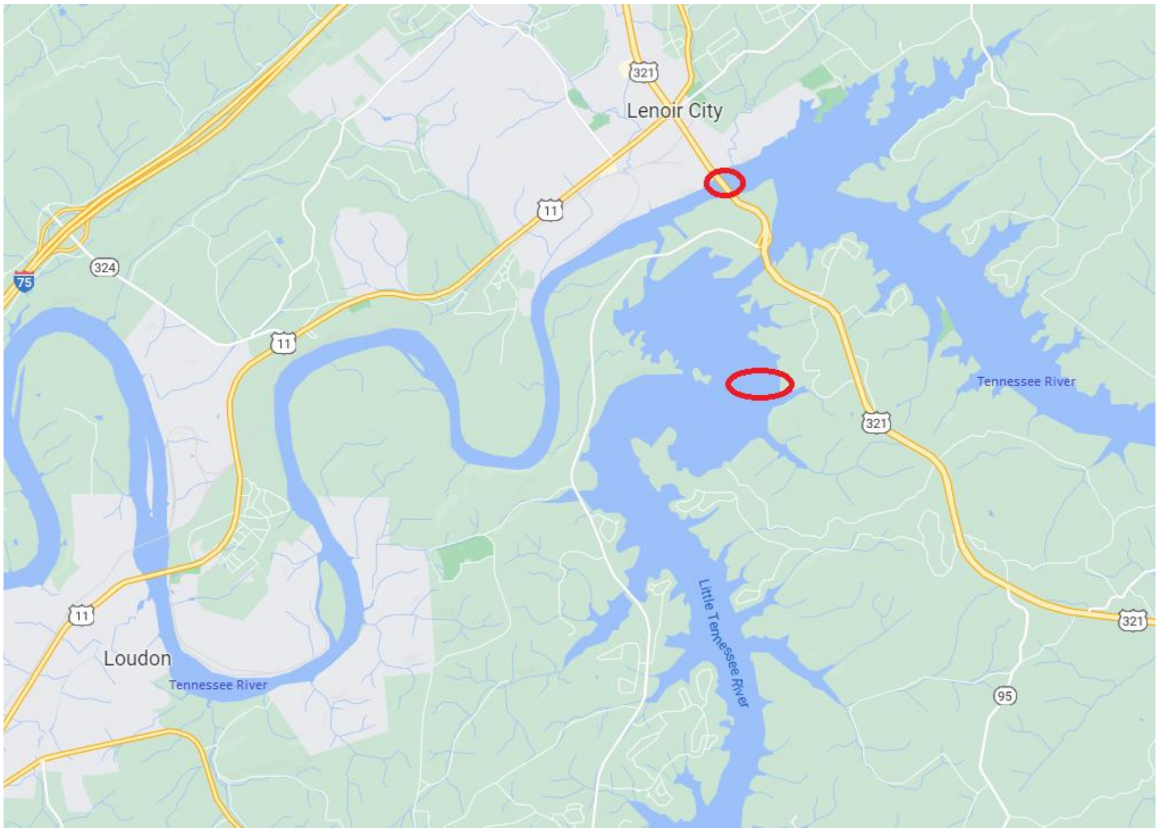

Figure 10: Manikin drop locations for floating trials in relation to the Little Tennessee River and Tennessee River

Figure 11. Approximate manikin entry points into the center of the river and close to the riverbank near Mizell Bluff

Figure 12. Approximate manikin entry points into the center of the river and close to the riverbank west of Fort Loudoun Dam

notified ahead of time about when trials were being conducted to avoid false alarms. Due to the high volume of boat activity and riverside restaurants in the area, the section of the TN river in downtown Knoxville was avoided in favor of placing the manikin in a lower trafficked area downriver. Additionally, placement of the manikin in the river was informed by the Knox County Rescue team's knowledge of where decedents tend to enter the water when drowning deaths take place. One of these areas is a railroad bridge downriver from downtown and spanning from the southern border of the University of Tennessee Knoxville campus, across the river to alongside the Scottish Pike River Park. This bridge is a frequent site of suicides in Knoxville. Manikin placement in relation to the bridge is illustrated in in Figure 13. The river at this location is similar in shape and width to the segment at Fort Loudoun Dam. However, the flow speed is slower as it is not located directly on the output side of a dam.

Procedure

Multiple experiments were conducted to test the hypotheses and impact of different variables in the environment and decomposition process on fluvial transport of a body-like object. Broadly, these trials covered several scenarios:

1. A body submerged in shallow water near the riverbank without clothing.
2. A body floating in the center of the river without clothing.
3. A body floating in shallow water near the riverbank without clothing.
4. A body floating in the center of the river while wearing clothing.
5. A body floating in shallow water along the riverbank while wearing clothing.

Sinking trials were intended to test the movement of the body before decomposition has progressed to putrefaction, while floating trials simulated the behavior of a body that has begun putrefaction and bloated enough to float back up to the surface. These scenarios in relation to the hypotheses they are testing can be found in Table 2. Five trials of each scenario were conducted with each trial lasting approximately 7-8 hours in duration. Unclothed and clothed floating trials were conducted simultaneously in the interest of time. Two manikins were placed in the same

Figure 13. Sinking manikin placement site along riverbank near railroad bridge over TN river.

Table 2. Trials in Relation to Hypotheses

Trial Scenarios	**Hypotheses Being Tested**	**Requirement for Upheld Hypothesis**
All Scenarios	Hypothesis 1: A body deposited in water will follow a consistent travel path and distance if the same environmental and taphonomic conditions are upheld for each trial	For each scenario, the five trials must result in a recovery point within 1 mile from each other, or if the travel path is different, there must be a recognizable environmental variable (i.e. more floodgates open) that was different between the trials.
Scenario 1: A body submerged in shallow water near the riverbank without clothing.	Hypothesis 2: A body that has sunk to the bottom of the river will remain stationary or remain within a mile from its point of entry into the river.	Submerged manikin must be recovered less than a mile away from its original drop point.
Scenario 2: A body floating in the center of the river without clothing. Scenario 4: A body floating in the center of the river while wearing clothing	Hypothesis 4: A body wearing clothing will travel a shorter distance than an unclothed body in the same location within the same period of time.	When an unclothed and clothed manikin are placed within a half hour of each other in the center of the river, the body without clothing must be recovered further away from the place of entry into the river than the manikin wearing clothing in the majority of trials.

Table 2 Continued

Trial Scenarios	Hypotheses Being Tested	Requirement for Upheld Hypothesis
Scenario 3: A body floating in shallow water near the riverbank without clothing. Scenario 5: A body floating in shallow water along the riverbank while wearing clothing.	Hypothesis 3: A body placed on one side of the river will stay on that side of the river Hypothesis 4: A body wearing clothing will travel a shorter distance than an unclothed body in the same location within the same period of time.	H3: The manikin must be recovered from the same side of the river it was placed on for all riverbank trials H4: When an unclothed and clothed manikin are placed together at the same time along the riverbank, the body without clothing must be recovered further away from the place of entry into the river than the manikin wearing clothing in the majority of trials.

location (the center of the river or along one of the riverbanks) within approximately one-half hour of each other, one wearing clothing and one without. Clothing consisted of a size medium men's quilt lined long sleeved flannel shirt and jeans. The same clothes were used for each clothed trial. Each manikin was outfitted with its own phone running GPS, sensor system, and Oyster2 GPS unit. On the morning of each trial, the manikins were brought to the river partially constructed, with the torso pieces still open. On the boat or on the shore, depending on manikin placement location for the trial, the GPS and sensor system were started and placed into the waterproof container, and the start time of data collection for these devices recorded. The waterproof box for each manikin was then secured to the manikin within the chest cavity, as well as attached to the buoy for sinking trials, and the manikin's chest piece bolted closed. The manikin would then be placed into the river by hand or lowered off of a boat. The time that the manikin entered the water, and the weather conditions were recorded. Because the river environment is influenced by dam water release schedules, the Fort Loudoun reservoir elevation and daily rainfall amount according to the Tennessee Valley authority were also recorded. For trials conducted past the Fort Loudoun Dam lock, the number of floodgates open was also recorded as this impacts the speed of the current west of the dam. The manikins were then left in the water without any interference by the researcher for the next 7-8 hours while being GPS tracked, after which it was retrieved by boat or by hand depending on water depth and accessibility of its last location. Time of manikin retrieval, as well as weather conditions and Fort Loudoun reservoir elevation at the time of retrieval were recorded. Anytime the manikin became stuck or hindered by environmental objects during a trial, the type of environmental hazard, as well as the position of the manikin (and its clothing when applicable) was recorded. If the manikin became stuck within the first half hour of the trial, it was dislodged and re-released. However, after the first half hour if the manikin became stuck, it was then left in place to determine whether it would be dislodged by changes in water speed or depth, or if it would stay in place until retrieved. Both the placement and retrieval of the manikins for all floating trials were assisted by volunteers from Loudoun County Rescue using one of their boats.

After each trial was completed, the points recorded by Life360 were re-mapped for visual clarity using ArcGIS Online. This was necessary because if the signal of the phone within one of the manikins is lost at any time, however briefly, Life360 will occasionally mark an inaccurate point on the map. For example, the app might mark the location point of a cell tower near the river rather than the location of the actual phone in the manikin. Any extraneous and inaccurate points on the Life360 map were omitted from the ArcGIS map to make the manikin's path of travel easily visible. Creating individual maps for each trial was also helpful for qualitative analysis comparing the manikin's path both between trials of the same scenario and between different scenarios. Multiple travel paths cannot be viewed at the same time on Life360, so the ArcGIS maps were necessary for these comparisons. Finally, the travel route history for each individual tracked with Life360 is only available for seven days with the free version of the app and a for a month with the Gold Membership Plan. Trials spanned from early November 2021 to April 2022, so re-mapping the pathways was also necessary to prevent data loss. Additionally, the distance traveled between each point on the map was calculated using the measurement tool in ArcGis Online. The average speed of travel for each trial was calculated by dividing the amount miles traveled by the manikin by the amount of time it was in the water.

Several statistical tests were conducted to analyze whether there were relationships between different environmental and manikin-related variables such as clothing. A Kruskal-Wallis test was conducted to determine if there was any difference between the rank means for total miles traveled and average travel speed between the three different locations. Independent T-tests were conducted to compare the mean distance traveled and average speed between clothed and unclothed trials, between placement at the center or the bank of the river, and between floating and sinking trials. Finally, sensor data retrieved for each trial was mapped as a line graph to illustrate changes in acceleration and manikin orientation over time.

CHAPTER FOUR: RESULTS

Qualitative Observations Based on GPS Data

The travel path of each manikin was individually mapped for each trial. These maps can be found in appendix A (Figures 41 - 65). A summary of each trial, including the distance traveled for each, can be found appendix A as well (Table 18). Based on the maps, travel paths were relatively consistent between trials. In six out of the ten trials at Fort Loudoun Dam, the manikins stopped moving and were recovered in Sugarlimb, just after passing Huntsville Hollow. Travel distance from the entry point into the river for these trials ranged from 5.4 miles to 6.7 miles. One of the manikins continued to travel a little further, reaching approximately 7.6 miles from where it entered the river, before stopping in a narrow channel off the river around Carmichael Island. In one trial, the manikin, which was wearing clothing and placed in the center of the river, traveled considerably further than the rest, reaching Harrison Island in Loudoun, about 10.8 miles from where it had entered the water. The manikin may have continued to travel past this point if allowed. However, the trial was cut short after approximately five hours when the manikin was retrieved by firefighters who did not expect the manikin so close to town. The two shortest distances traveled by the manikins at Fort Loudoun Dam were 1.66 miles and 2.18 miles. For these trials, the manikin stopped moving around Riverview Bend. The average distance for all ten trials at Fort Loudoun Dam was 5.91 miles. As shown in Figure 14, it does appear that the trials in which the manikin traveled further were trials in which it was placed in the center of the river rather than along the riverbank. However, it is more difficult to discern whether clothing had any impact (Figure 15). Several of the unclothed trials had a slightly further travel distance, however, the longest travel distance was completed by a clothed manikin. Additionally, the shortest distance traveled at this location was by an unclothed manikin.

At Mizell Bluff, there is an obvious difference visually between the travel path of manikins placed along the bank versus in the center of the reservoir. The majority of trials placed along the riverbank moved so little that the GPS did not detect any changes in location over 7-8 hours (Figure 16). Additionally, any discernable movement that did occur was to the north, which is technically upstream. The trials placed in the center of the reservoir did move, but very

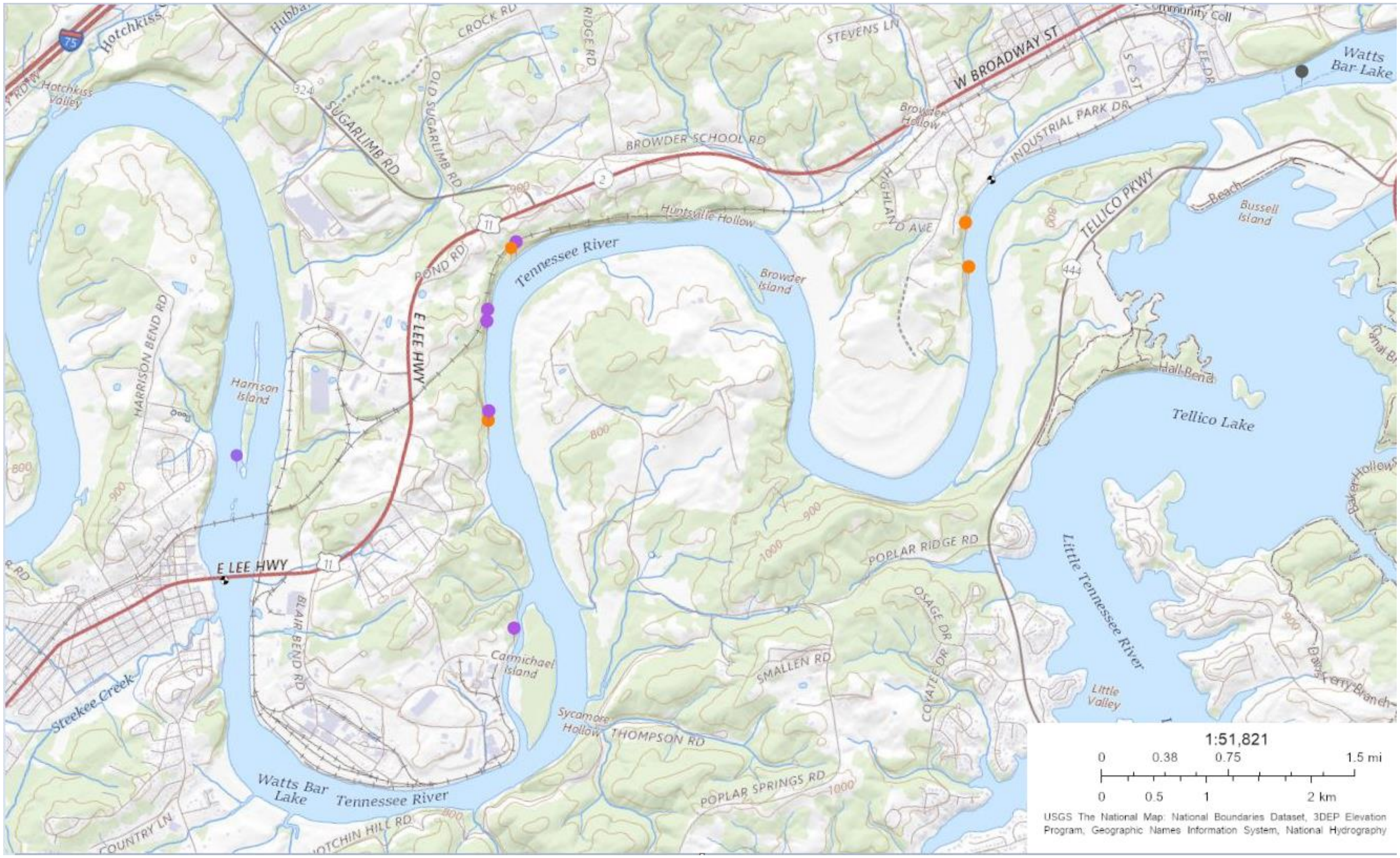

Figure 14. Recovery Locations of All Trials at Fort Loudoun Dam: Bank vs. Center of River. Black marker indicates approximate entry point into the water. Orange marker indicates that the manikin was placed along the riverbank. Purple marker indicates manikin was placed in the center of the river.

Figure 15. Recovery Locations of All Trials at Fort Loudoun Dam: Clothed vs. Unclothed. Black marker indicates approximate entry point into the water. Blue marker indicates manikin was unclothed. Red marker indicates the manikin was clothed.

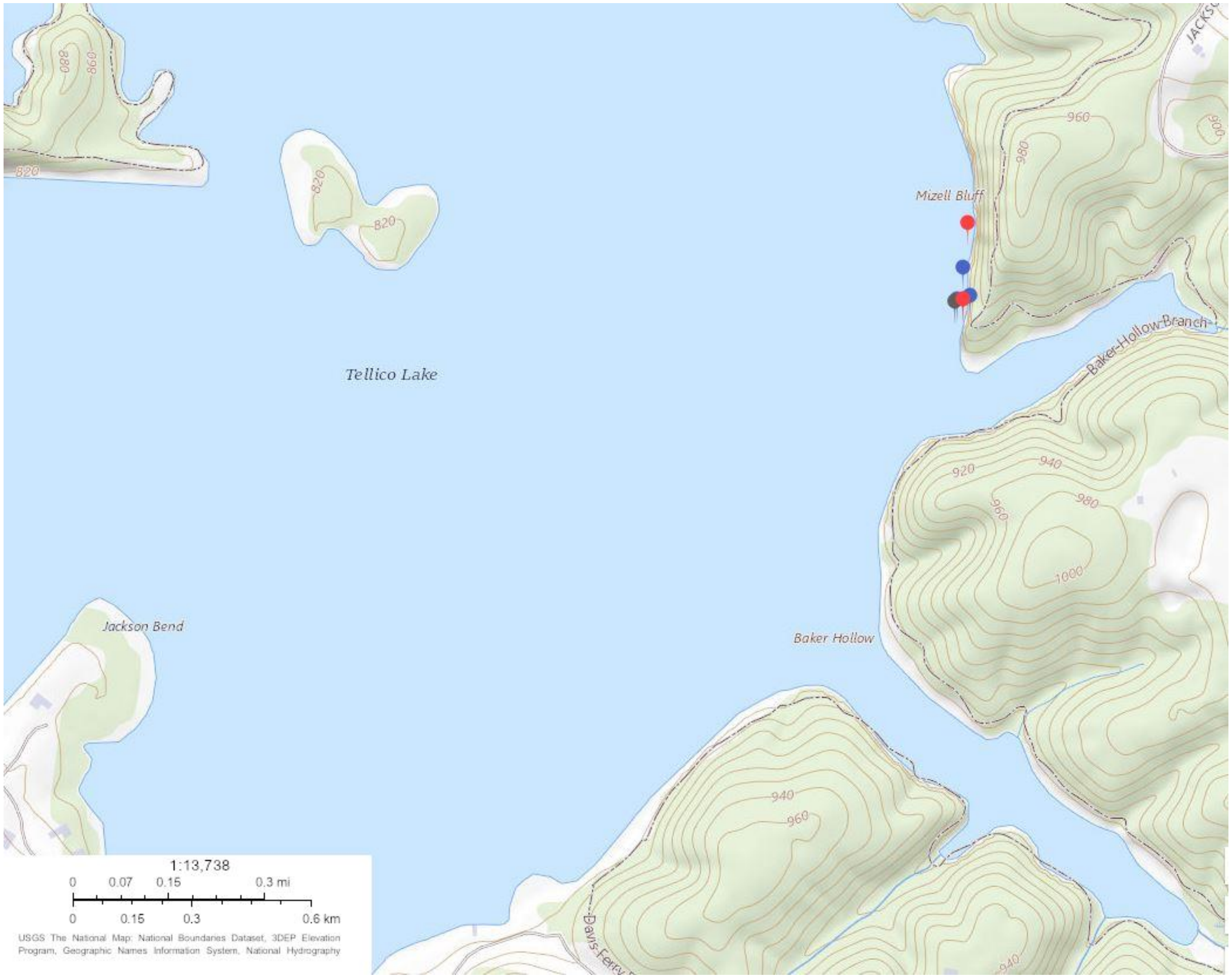

Figure 16. Recovery Locations for all Trials Along the Riverbank at Mizell Bluff. Black marker indicates approximate point of entry into the water. Red marker indicates that the manikin was clothed. Blue marker indicates that the manikin was unclothed.

small distances compared to the trials at Fort Loudoun Dam. All trials in the center of the river parallel to Mizell Bluff had a travel distance of under half a mile, with the longest distance being 0.43 miles. These trials did appear to have movement in the same direction, with the manikin repeatedly ending up within or near the opening to the cove at Baker Hollow (Figure 17). The average distance traveled for all trials at Mizell Bluff was 0.17 miles.

For the five trials at Scottish Pike, which were all sinking trials in contrast to the floating trials of Fort Loudoun Dam and Mizell Bluff, there was no movement detectable by the GPS for any of the trials. Movement was detectable visually in one of the four trials, in which the manikin appeared to be about five feet closer to the shore in the afternoon compared to the morning.

Condition of Manikins Upon Retrieval

Regardless of whether they had initially been placed in the center of the river or along the riverbank, the most frequent reason a floating manikin stopped moving was due to snagging on fallen trees and debris or getting lodged against rocks along the bank (Figures 19 – 23). Snagging in trees, driftwood, and garbage was more common at the Fort Loudoun Dam location, while limbs getting caught in rocky crevices was more common in the Mizell Bluff location. In four out of the twenty floating trials, disarticulation occurred. All four trials were at Mizell Bluff. Three of these occurrences were with an unclothed manikin, and one with a clothed manikin. When disarticulation occurred, it was most common for the forearms of the manikin to detach at the elbow, and for the legs of the manikin to detach at the knee (Figure 18). There was one occasion in particularly rough water wherein a clothed manikin’s hips disarticulated from the torso after being repeatedly beaten against a large rock. The manikin also suffered large gouges and scratches throughout the surface of its body (Figure 24). Additionally, one trial at Fort Loudoun Dam demonstrated how clothes can be ripped off a body by the strong current and other obstacles. Though the shirt ultimately stayed on the manikin’s arms, several buttons were ripped off by the end of the day.

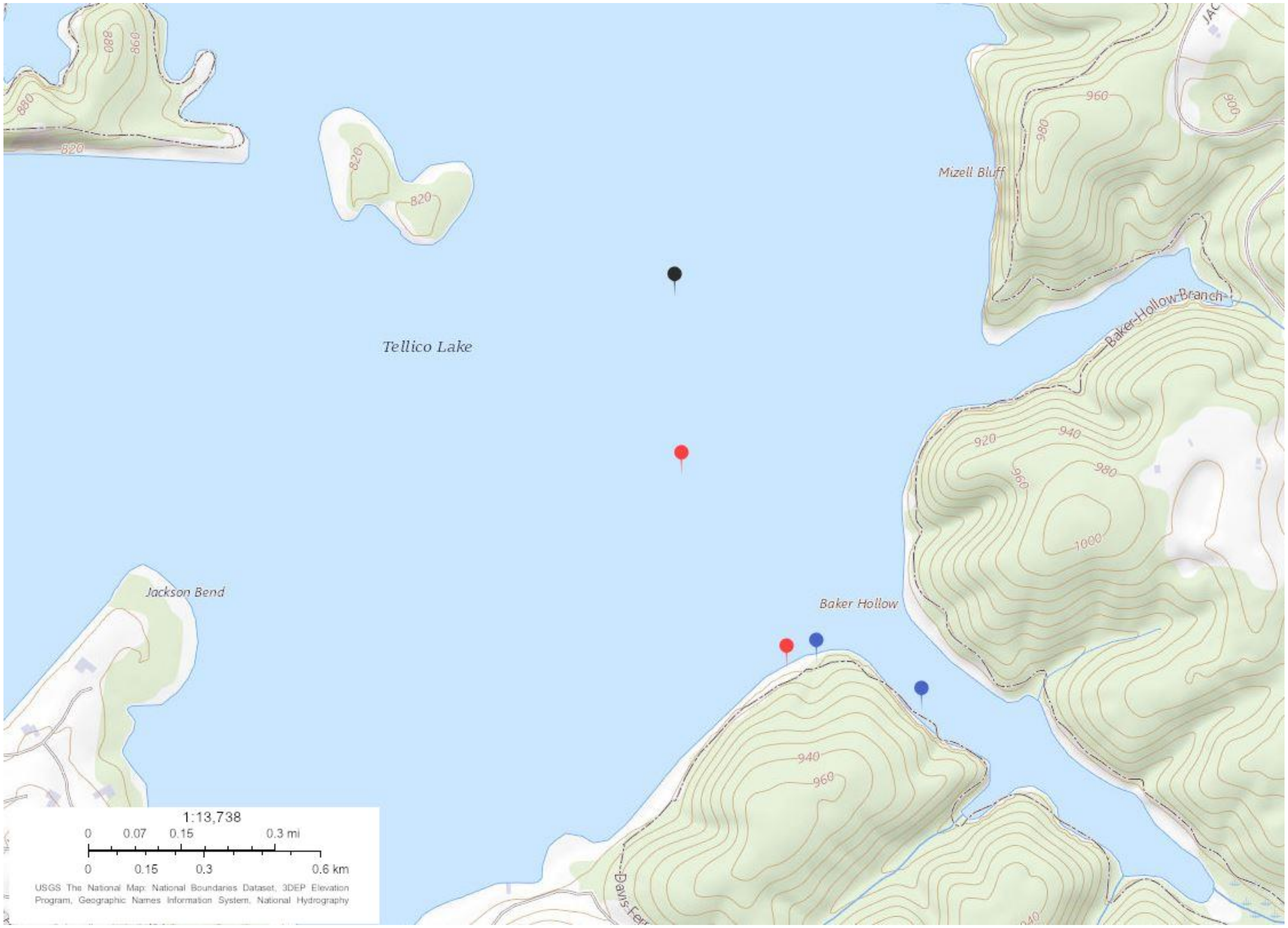

Figure 17. All Recovery Locations for Center of the River Trials at Mizell Bluff. Black marker indicates original point of entry into the water. Red marker indicates that the manikin was clothed. Blue marker indicates that the manikin was unclothed.

Figure 18. Unclothed Floating Manikin Washed Up on Riverbank with Disarticulated Leg. Photo taken November 19, 2021


Figure 19. Clothed Floating Manikin with Body Caught Upon Fallen Tree. Photo taken November 19, 2021.

Figure 20. Unclothed Manikin Surrounded by River Debris and Pollution. Photo taken February 24, 2022.

Figure 21. Unclothed Floating Manikin with Arm Caught in Driftwood. Photo taken March, 25, 2022.

Figure 22. Clothed Floating Manikin Caught in Tree Branches and River Debris. Photo taken February 25, 2022.

Figure 23. Unclothed Floating Manikin with Legs Caught Under Fallen Tree. Photo taken March, 3, 2022.

Figure 24. Scratches on Manikin's Back After Being Battered Against Rocks at Mizell Bluff.

Statistical Analysis

Placement Location

Because the data in this sample are not normally distributed and do not have equal variance according to Levene's Test for Equality of Variances, a non-parametric test, the Kruskal-Wallis test, was conducted to test whether placement location affected distance traveled and average travel speed. As summarized in Table 3, $p < 0.001$ both when the test was run with total miles traveled as the dependent variable ($H = 19.459$), and when the test was run with average speed as the dependent variable ($H = 19.467$). This suggests a difference in mean rank between at least one pair of the placement locations for both total miles traveled and average speed. To determine which pairs had a statistically significant difference between them, Dunn's pairwise post hoc tests were carried out and a box plot was created. Based on the box plots (Figures 25 & 26) and pairwise tests (Tables 4 & 5), there was a significant difference in mean ranks between both miles traveled and average speed between the Fort Loudoun location and the Mizell Bluff location ($p = 0.002$), as well as between the Fort Loudoun location and the Scottish Pike location ($p < 0.001$). There was not a significant difference in mean rank for either dependent variable between the Mizell Bluff and Scottish Pike locations ($p = .759$).

Bank vs Center of the River

Independent T-Tests were conducted to determine whether the means for Total Miles Traveled and Average Travel Speed were significantly different between trials in which the manikin had been placed in the center of the river, or along the riverbank. Due to the significant differences in miles traveled and average speed between different locations, one t-test was conducted for all of the trials at Fort Loudoun, and another was separately conducted for all of the trials at Mizell Bluff. A t-test was not conducted for Bank v. Center of the River at the Scottish Pike location because all Scottish Pike Trials were along the bank to prevent loss of the manikin.

Table 3. Placement Location Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distribution of total miles traveled is the same across categories of placement location.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of average speed is the same across categories of placement location.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

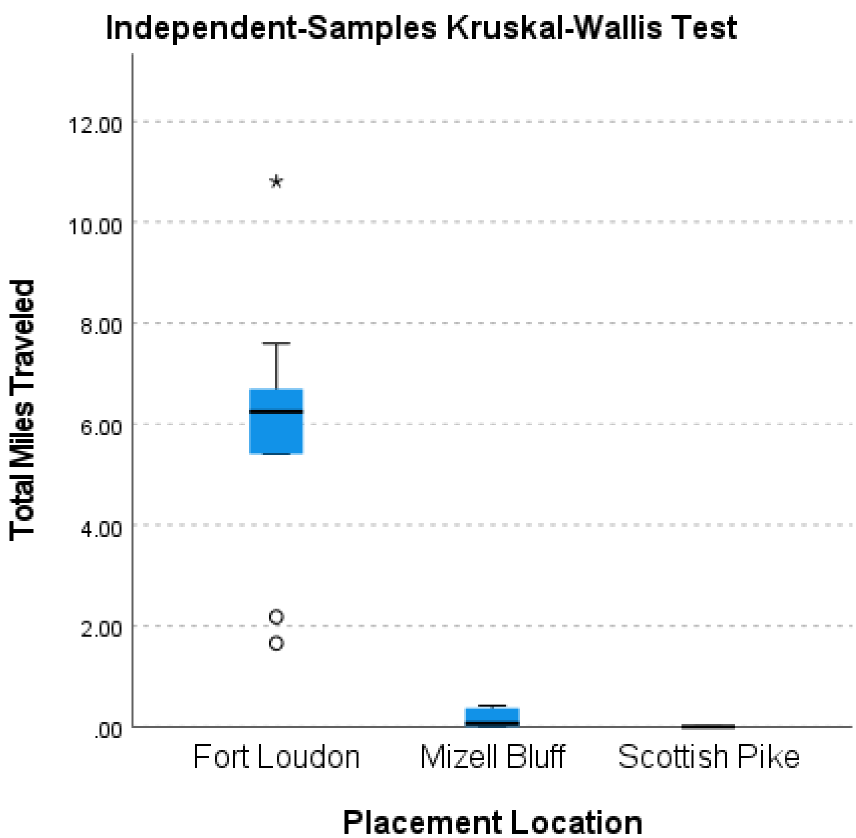

Figure 25. Box Plot of Miles Traveled by Manikin at Different Placement Locations

Table 4. Pairwise Comparisons of Total Miles Traveled at Placement Locations

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Scottish Pike-Mizell Bluff	4.500	3.936	1.143	.253	.759
Scottish Pike-Fort Loudoun	15.500	3.936	3.938	.000	.000
Mizell Bluff-Fort Loudoun	11.000	3.214	3.423	.001	.002

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .050.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

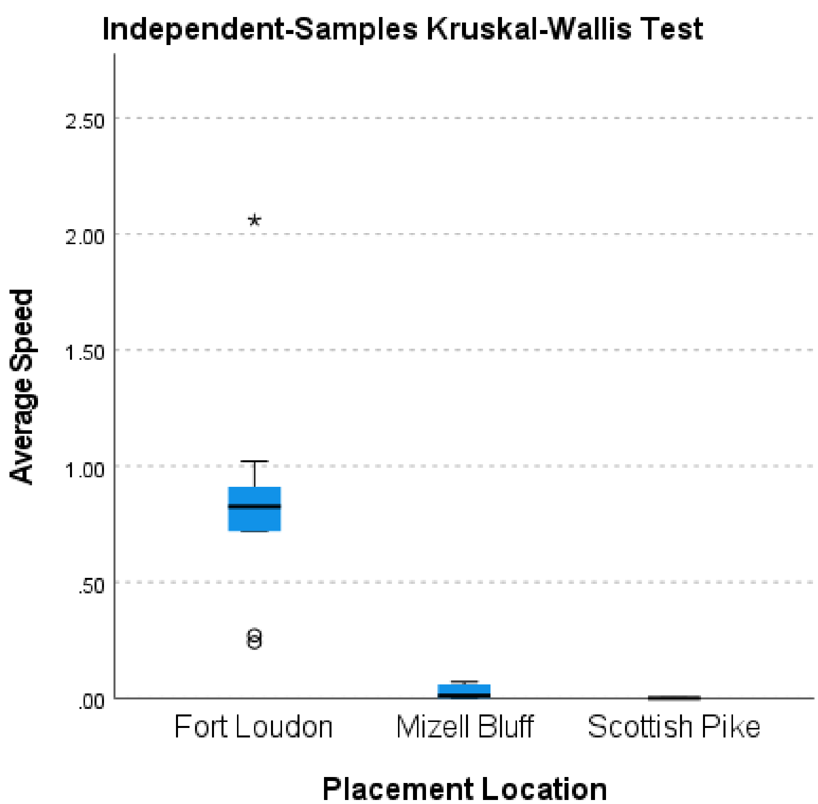

Figure 26. Box Plot of Average Manikin Speed at Different Placement Locations

Table 5. Pairwise Comparisons of Average Manikin Speed at Placement Locations

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Scottish Pike-Mizell Bluff	4.500	3.935	1.143	.253	.759
Scottish Pike-Fort Loudoun	15.500	3.935	3.939	.000	.000
Mizell Bluff-Fort Loudoun	11.000	3.213	3.423	.001	.002

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .050.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

At the Fort Loudoun location (Table 6), the six trials in which the manikin was placed in the center of the river (M = 7.23, SD = 1.85) demonstrated statistically significantly (t = -2.47, p = .038) higher distances traveled than the four trials for which the manikin was placed along the riverbank (M = 3.94; SD = 2.38). However, as summarized in Table 7, the six trials in which the manikin was placed in the center of the river (M = 1.09, SD = 0.48) did not demonstrate a statistically significant (t = -2.22, p = .057) difference in average travel speeds from the four trials for which the manikin was placed along the riverbank (M = 0.49; SD = 0.27).

At the Mizell Bluff location (Table 8), the four trials in which the manikin was placed in the center of the reservoir (M = 0.38, SD = 0.07) also demonstrated significantly (t = -10.61, p < .001) higher travel distances than the six trials for which the manikin was placed along the riverbank (M = 0.02, SD = 0.04). Additionally, as summarized in Table 9, the trials that began with the manikin in the center of the reservoir (M = 0.06, SD = 0.01) also demonstrated significantly (t = -9.17, p < .001) higher average speeds than the six trials for which the manikin was placed along the riverbank (M = 0.003 SD = 0.005).

Clothed vs. Unclothed

Independent T-Tests were also conducted to determine whether the means for Total Miles Traveled and Average Travel Speed were significantly different between trials in which the manikin was wearing clothes and the trials in which the manikin was unclothed. Due to the significant differences in miles traveled and average speed between different locations, one t-test was conducted for all of the trials at Fort Loudoun, and another was separately conducted for all of the trials at Mizell Bluff. A t-test was not conducted for Clothed vs. Unclothed at the Scottish Pike location because all Scottish Pike Trials were performed unclothed.

At the Fort Loudoun location (Table 10), the five trials in which the manikin was wearing clothing (M = 6.1, SD = 3.09) did not demonstrate statistically significantly (t = .210, p = .839) different distances traveled than the five trials for which the manikin was unclothed (M = 5.73, SD = 2.34). Additionally, as summarized in Table 11, the five trials in which the manikin was wearing clothes (M = 0.94, SD = 0.67) did not demonstrate a statistically significant (t = .553, p = .595) difference in average travel speed from the five unclothed trials (M = 0.76; SD = 0.31).

Table 6. Independent T-Test Comparing Total Miles Traveled for Bank vs Center of River Trials at Fort Loudoun.

Independent Samples Test: Bank vs. Center[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total Miles Traveled (Equal variances assumed)	1.258	.294	-2.474	8	**.038**	-3.29833	1.33296	-6.37215	-.22451
a. Placement Location = Fort Loudoun									

Table 7. Independent T-Test Comparing Average Manikin Speed at the Bank and Center of the River at Fort Loudoun

Independent Samples Test: Bank vs. Center[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Average Speed (Equal variances assumed)	.264	.622	-2.221	8	**.057**	-.59750	.26901	-1.21785	.02285
a. Placement Location = Fort Loudoun									

Table 8. Independent T-Test Comparing Total Miles Traveled for Bank vs. Center of River Trials at Mizell Bluff.

Independent Samples Test: Bank vs. Center[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total Miles Traveled (Equal variances assumed)	1.244	.297	-10.614	8	**.000**	-.35833	.03376	-.43618	-.28048
a. Placement Location = Mizell Bluff									

Table 9. Independent T-Test Comparing Average Manikin Speed at the Bank and Center of the River at Mizell Bluff.

Independent Samples Test: Bank vs. Center[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Average Speed (Equal variances assumed)	2.759	.135	-9.169	8	**.000**	-.05667	.00618	-.07092	-.04242
a. Placement Location = Mizell Bluff									

Table 10. Independent T-Test Comparing Total Miles Traveled for Clothed and Unclothed Trials at Fort Loudoun.

Independent Samples Test: Unclothed vs. Clothed[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total Miles Traveled (Equal variances assumed)	.082	.782	.210	8	**.839**	.36400	1.73050	-3.62655	4.35455
a. Placement Location = Fort Loudoun									

Table 11. Independent T-Test Comparing Average Manikin Speed for Clothed vs. Unclothed Trials at Fort Loudoun

Independent Samples Test: Clothed vs. Unclothed[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Average Speed (Equal variances assumed)	1.149	.315	.553	8	**.595**	.18200	.32890	-.57644	.94044
a. Placement Location = Fort Loudoun									

At the Mizell Bluff location (Table 12), the five trials in which the manikin was wearing clothing (*M* = 0.18, *SD* = 0.21) did not demonstrate statistically significantly ($t = .234$, $p = .821$) different distances traveled than the five trials for which the manikin was unclothed (*M* = 0.15, *SD* = 0.2). As summarized in Table 13, the five trials in which the manikin was wearing clothes (*M* = 0.03, *SD* = 0.03) also did not demonstrate a statistically significant ($t = .195$, $p = .850$) difference in average travel speed from the five unclothed trials (*M* = 0.02; *SD* = 0.03).

Floating v. Sinking

Additional Independent T-Tests were conducted to determine whether the means for Total Miles Traveled and Average Travel Speed were significantly different between trials in which the manikin was floating and the trials in which the manikin was submerged. All trials across all locations were used for this analysis. Levene's Test for Equality of Variances produced a significant value when all trials were included, so the significance score for the t-tests was adjusted for equal variances not being assumed.

When testing for Total Miles Traveled (Table 14), the ten trials in which the manikin was floating (*M* = 3.04, *SD* = 3.45) demonstrated statistically significantly ($t = 3.943$, $p < .001$) different distances traveled from the five trials for which the manikin was sunken (*M* = 0, *SD* = 0). Additionally, when testing for Average Travel Speed (Table 15), the ten trials in which the manikin was floating (*M* = 0.43, *SD* = 0.55) demonstrated a statistically significant ($t = 3.594$, $p = .002$) difference in average travel speed from the five submerged trials (*M* = 0; *SD* = 0).

Correlation With Environmental Variables

Spearman's rank correlation was used to measure the correlation between environmental variables (wind speed, average Tellico Lake reservoir levels, and daily rainfall) and the total miles traveled and average travel speed of the manikin at the Mizell Bluff and Fort Loudoun Dam locations. Additionally, for the Fort Loudoun Dam location, the number of dam gates that were open the day of the trial was included as an independent variable. Scottish Pike was not included as there was no detectable movement for any of the trials at that location. There was no significant indication of correlation between average Tellico Lake reservoir levels, maximum windspeed or rainfall amount with total miles traveled at the Fort Loudoun Dam location (Table

Table 12. Independent T-Test Comparing Total Miles Traveled For Clothed and Unclothed Trials at Mizell Bluff.

Independent Samples Test: Unclothed vs. Clothed[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Total Miles Traveled (Equal variances assumed)	.163	.697	.234	8	**.821**	.03000	.12802	-.26522	.32522
a. Placement Location = Mizell Bluff									

Table 13. Independent T-Tests Comparing Average Manikin Speed for Clothed vs. Unclothed Trials at Mizell Bluff

Independent Samples Test: Clothed vs. Unclothed[a]									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Average Speed (Equal variances assumed)	.488	.505	.195	8	**.850**	.00400	.02049	-.04326	.05126
a. Placement Location = Mizell Bluff									

Table 14. Independent T-Test Comparing Total Miles Traveled for Floating and Sinking Trials at All Locations

Independent Samples Test: Floating vs. Sinking									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total Miles Traveled (Equal variances not assumed)	26.125	.000	3.943	19.000	**<.001**	3.03950	.77087	1.42606	4.65294

Table 15. Independent T-Test Comparing Average Manikin Speed for Sinking vs. Floating Trials at All Locations

Independent Samples Test: Floating vs. Sinking									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Average Speed (Equal variances not assumed)	11.443	.003	3.594	19.000	**.002**	.43850	.12202	.18311	.69389

16). However, there was indication of a negative correlation between average travel speed and maximum wind speed at the Fort Loudoun location (r_S = -.745, p =.013). There was no significant indication of correlation between any of the environmental variables tested and average travel speed or max travel distance for trials at the Mizell Bluff location (Table 17).

Sensor Data

Sensor data was successfully recorded for only four out of the twenty-five trials conducted, the reasons for which will be discussed in the following chapter. Sensor analysis was limited by the small sample size of the data collected. However, it can provide some insight into the movement of the manikin in the water throughout different trials. Of the four trials that sensor data was successfully collected for, two were sinking trials, and two were floating trials. The two floating trials both took place on March 26, 2022 at Mizell Bluff, with one manikin clothed and the other unclothed. The sinking trials were conducted on different days, one on October 8, 2021, and the other on April 29, 2022. Both sinking trials were unclothed and were conducted at the Scottish Pike location. The sensor data that was successfully collected shows acceleration of the manikin in different directions (*x, y* or *z*) over time. Based on how the sensor was oriented within the manikin, acceleration in the *y* dimension was vertical movement. For example, a manikin bobbing up and down in the water due to waves. Acceleration in the *x* dimension was side to side movement. Finally, acceleration in the *z* dimension was backward and forward movement in the direction of the head and feet. A visual depiction of these directions is provided in Figure 27. When the data is graphed and compared trial to trial, there is an observable difference in the amount of acceleration the manikin was experiencing in floating trials vs. sinking trials. For example, based on Figures 28 through 33, it is observable that changes in acceleration were minute in sinking trials compared to the two floating trials (Figures 34 - 39). Additionally, the graphs for the clothed trial on March 26, 2022 exhibit noticeably more acceleration in every direction than the graphs for the unclothed trial. Comparing the sensor data to observations on the conditions of the manikins when they were recovered for these trials helps to explain the sensor readings. The water at Mizell Bluff was extremely choppy on the day these trials were conducted, with many waves. As a result, both the unclothed and clothed manikins were repeatedly bashed up against the rocks near the base of the bluff. The unclothed manikin was found mostly articulated with one leg stuck deep in a rock crevice. However, the clothed

Table 16. Correlations With Environmental Variables at Fort Loudoun Dam.

			Rainfall Gauge (in)	Max Wind Speed (km/h)	Avg. Tellico Lake Reservoir Level (ft above sea level)	# Flood Gates Open
Spearman's rho	Total Miles Traveled	Correlation Coefficient	-.220	-.404	-.341	.417
		Sig. (2-tailed)	.541	.247	.335	.231
		N	10	10	10	10
	Avg. Speed	Correlation Coefficient	-.138	-.745*	-.379	.581
		Sig. (2-tailed)	.705	.013	.280	.078
		N	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
a. Placement Location = Fort Loudoun

Table 17. Correlations With Environmental Variables at Mizell Bluff

			Rainfall Gauge (in)	Max Wind Speed (km/h)	Avg. Tellico Lake Reservoir Level (ft above sea level)
Spearman's rho	Total Miles Traveled	Correlation Coefficient	.000	-.013	-.331
		Sig. (2-tailed)	1.000	.972	.350
		N	10	10	10
	Avg. Speed	Correlation Coefficient	.000	-.013	-.332
		Sig. (2-tailed)	1.000	.972	.348
		N	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
a. Placement Location = Mizell Bluff

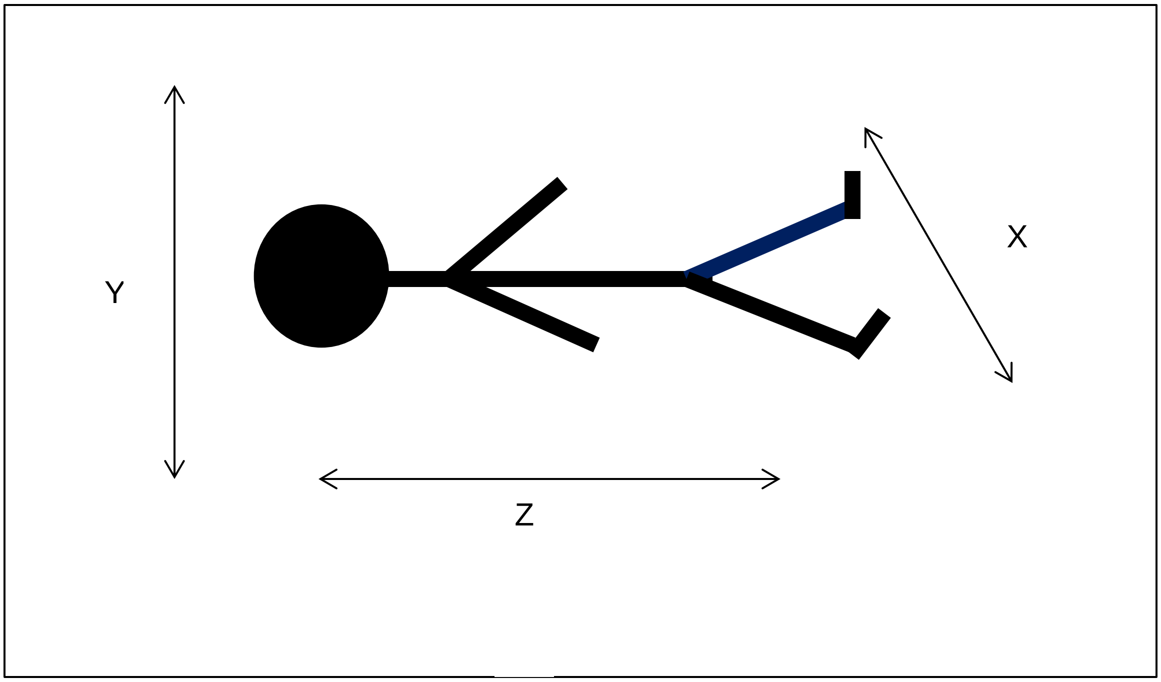

Figure 27. Direction of Manikin Movement Based on Sensor Orientation.

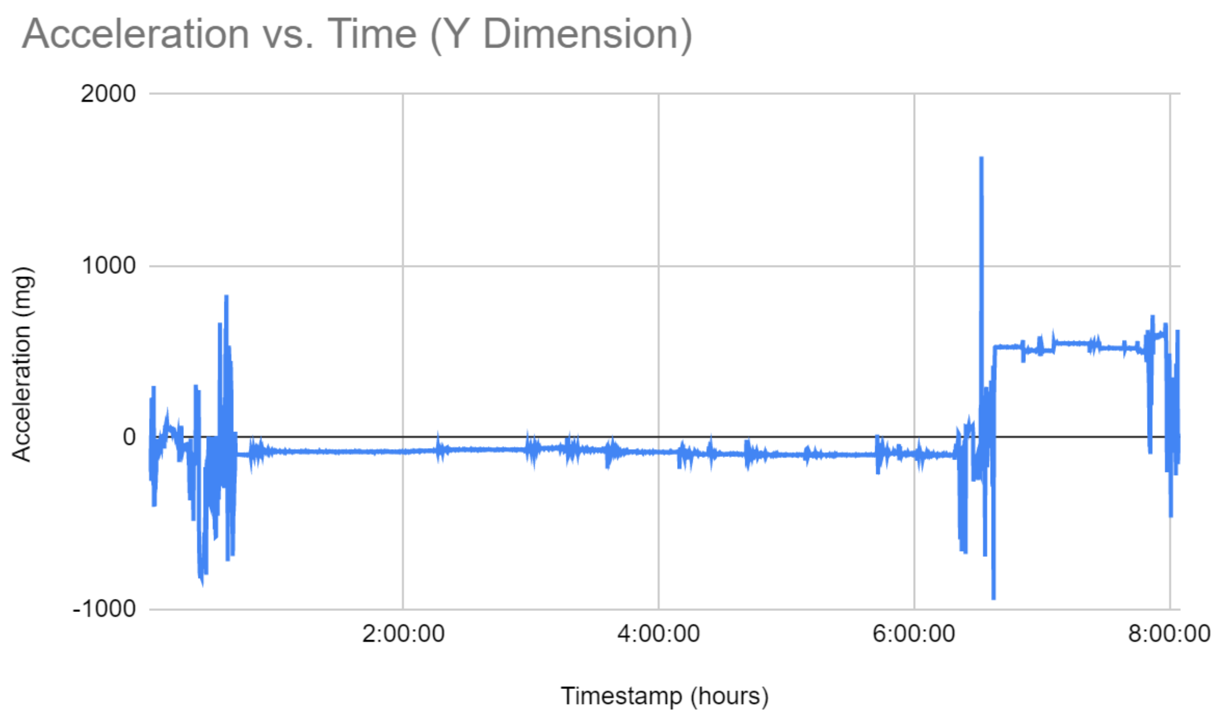

Figure 28. Vertical Acceleration of Manikin Over Time During 10/08/2021 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

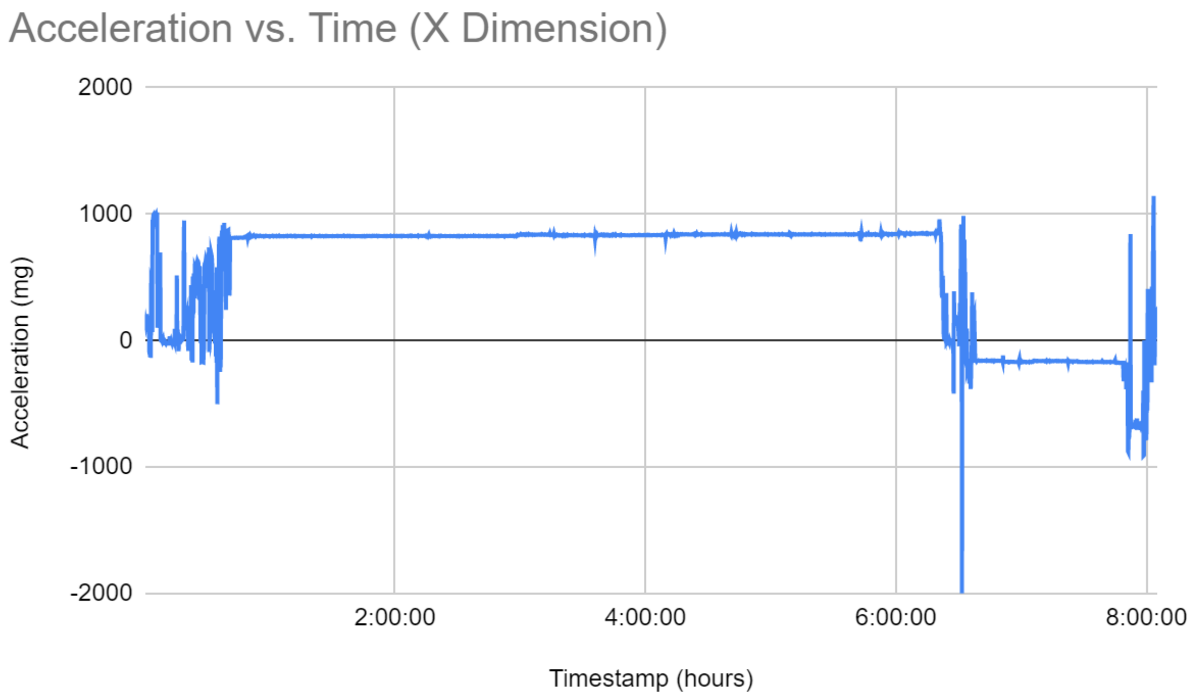

Figure 29. Side to Side Acceleration of Manikin Over Time During 10/08/2021 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

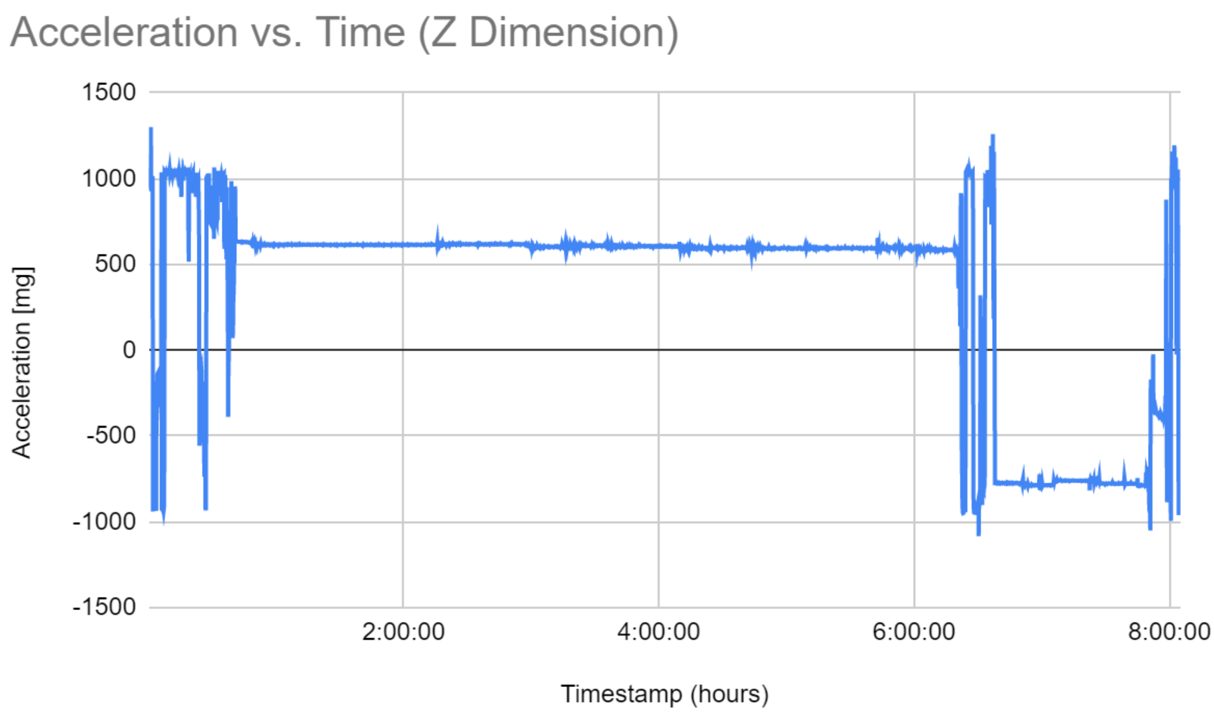

Figure 30. Cranial-Caudal Acceleration of Manikin Over Time During 10/08/2021 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

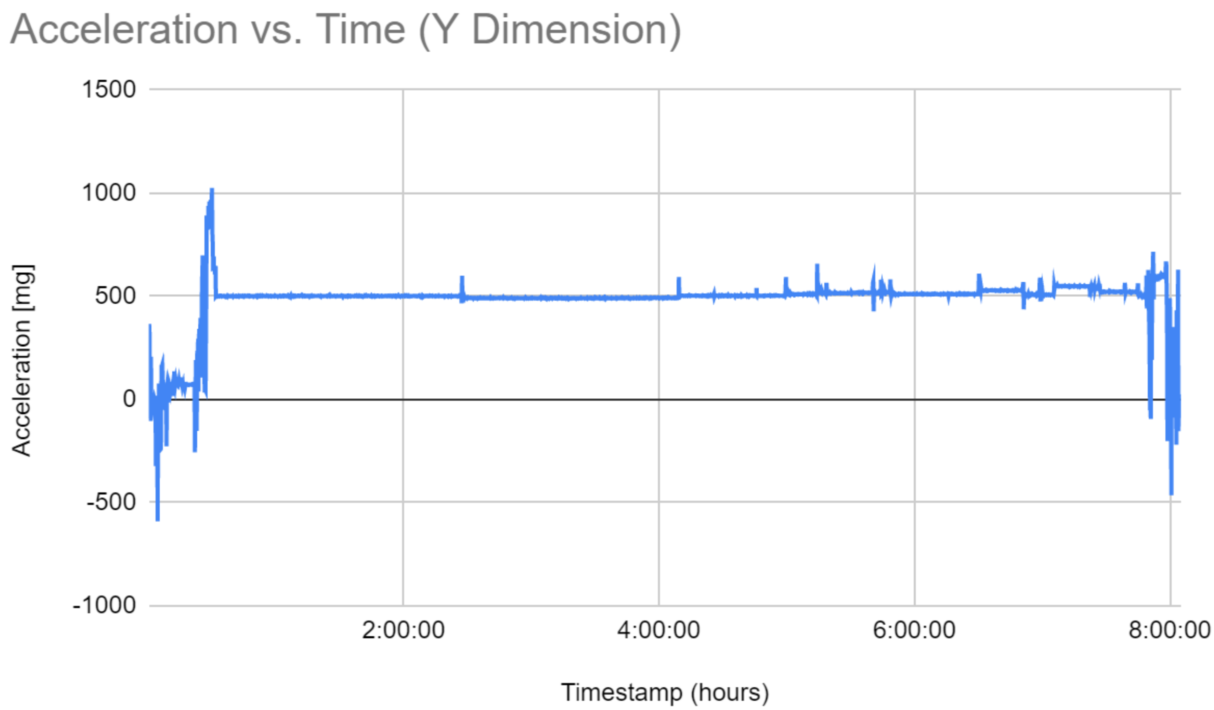

Figure 31. Vertical Acceleration of Manikin Over Time During 04/29/2022 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

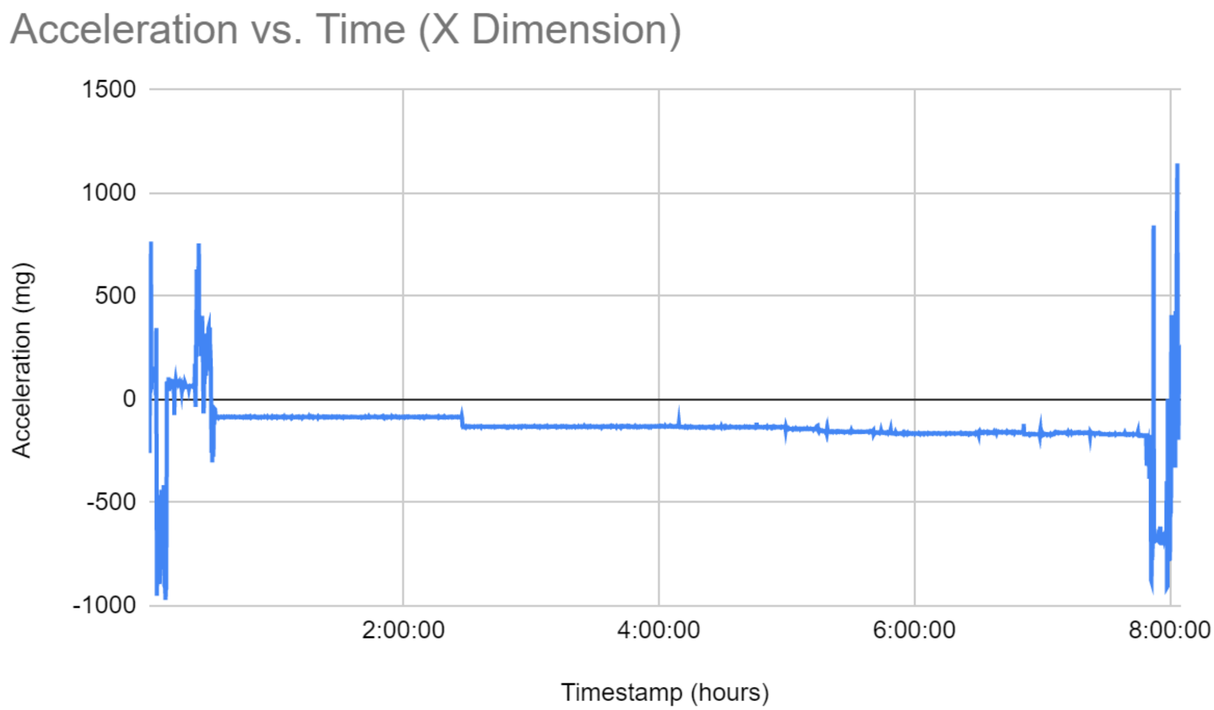

Figure 32. Side to Side Acceleration of Manikin Over Time During 04/29/2022 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

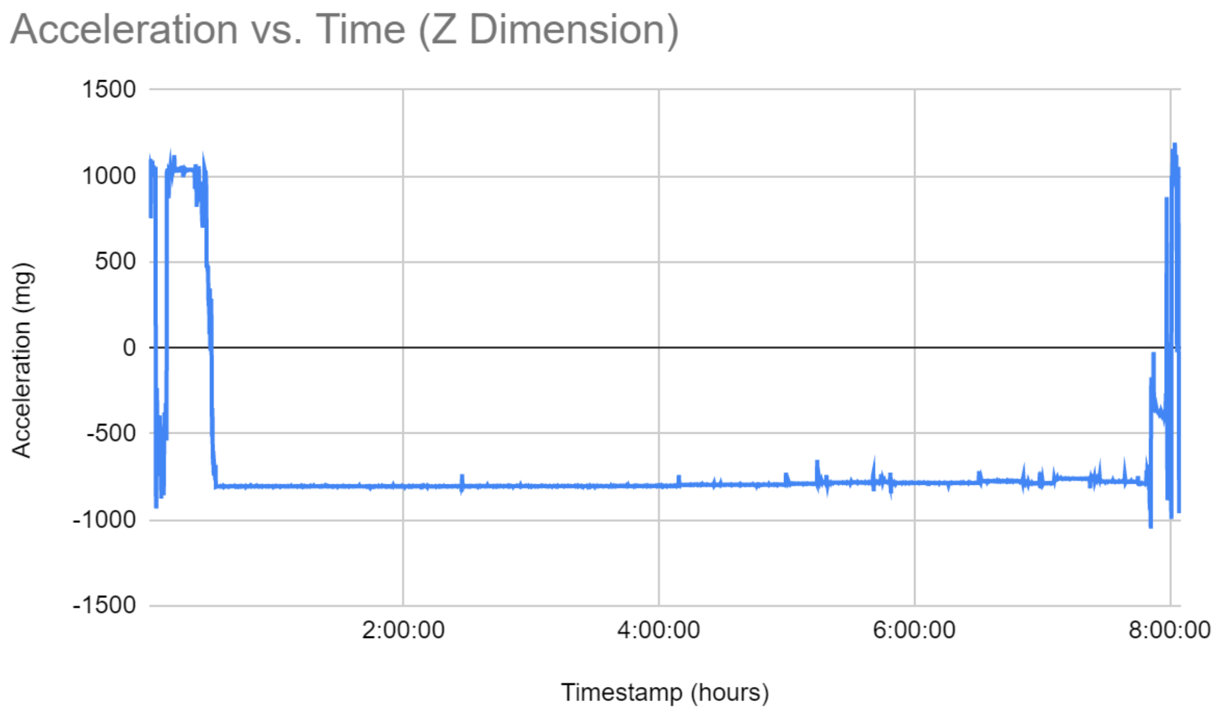

Figure 33. Cranial-Caudal Acceleration of Manikin Over Time During 04/29/2022 Sinking Trial at Scottish Pike. Note that increases in acceleration on either end of the graph are due to placing the manikin into and removing it from the water.

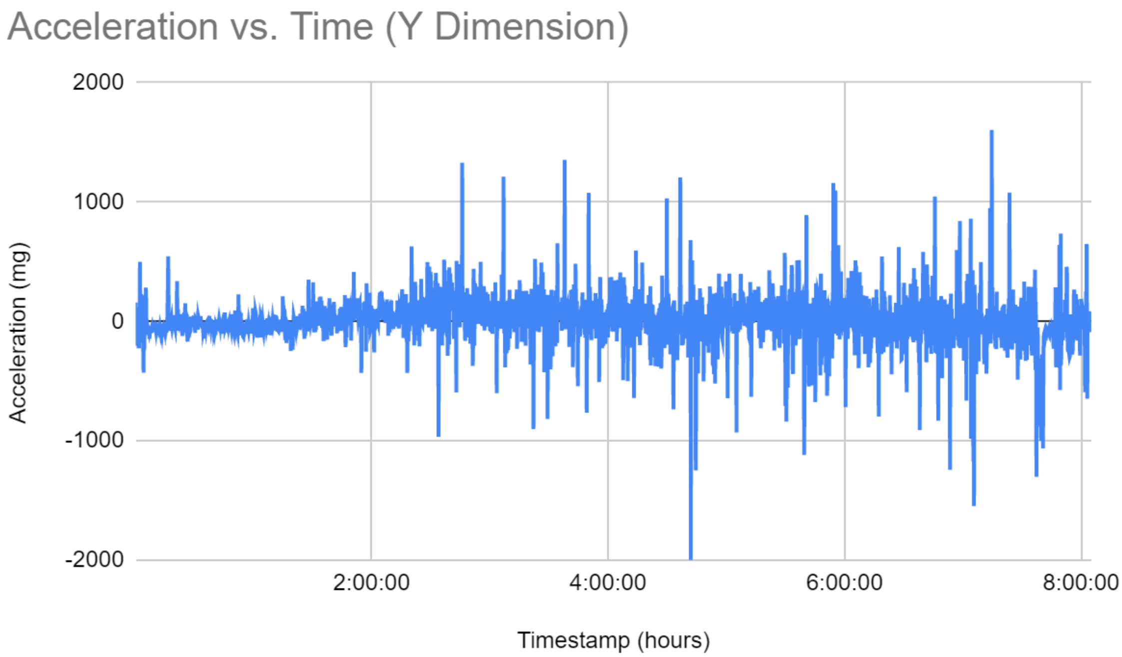

Figure 34. Vertical Acceleration of Clothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

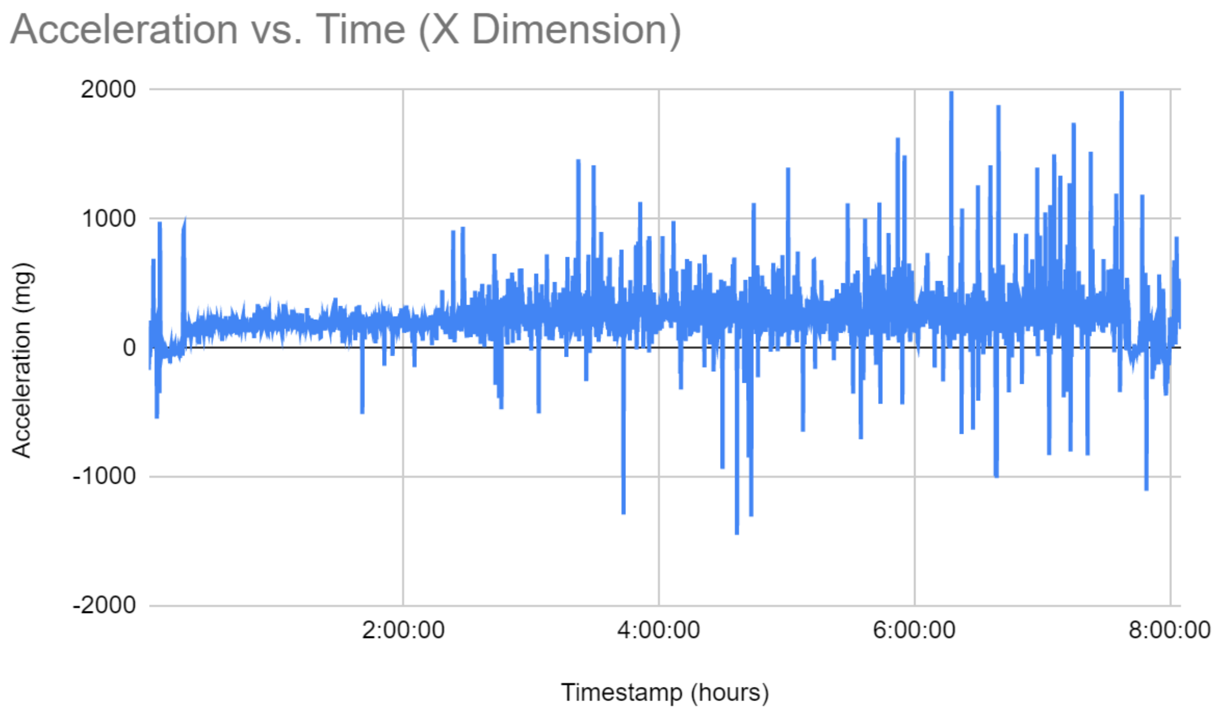

Figure 35. Side to Side Acceleration of Clothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

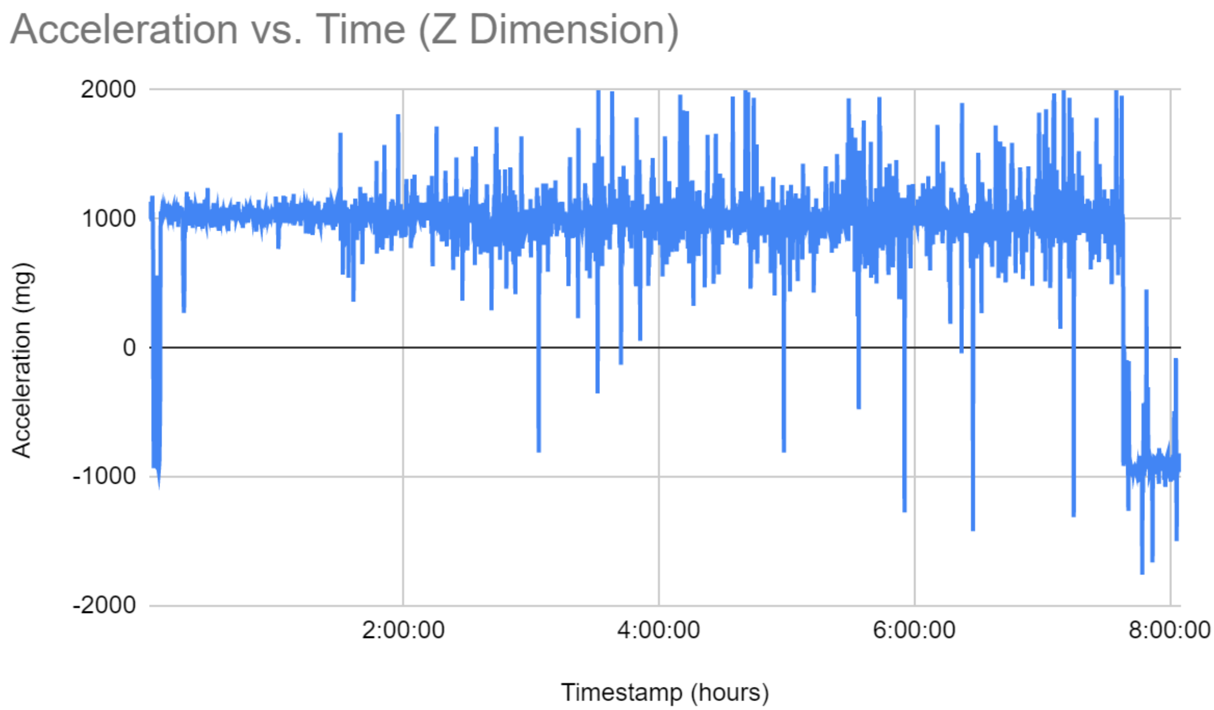

Figure 36. Cranial-Caudal Acceleration of Clothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

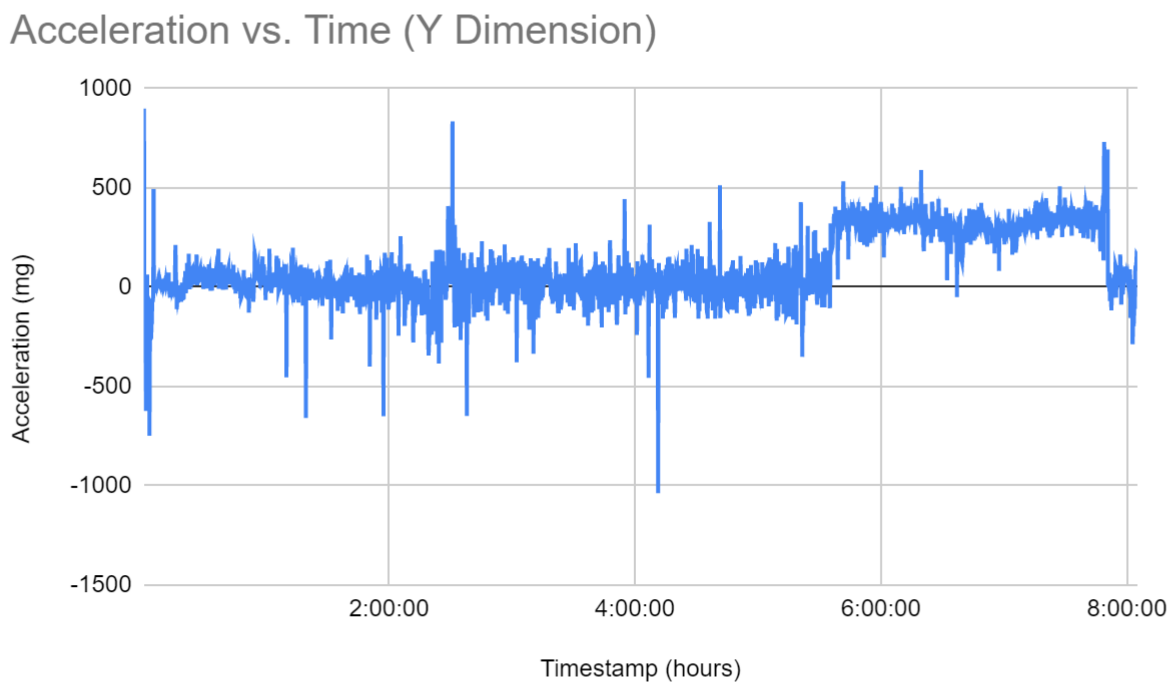

Figure 37. Vertical Acceleration of Unclothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

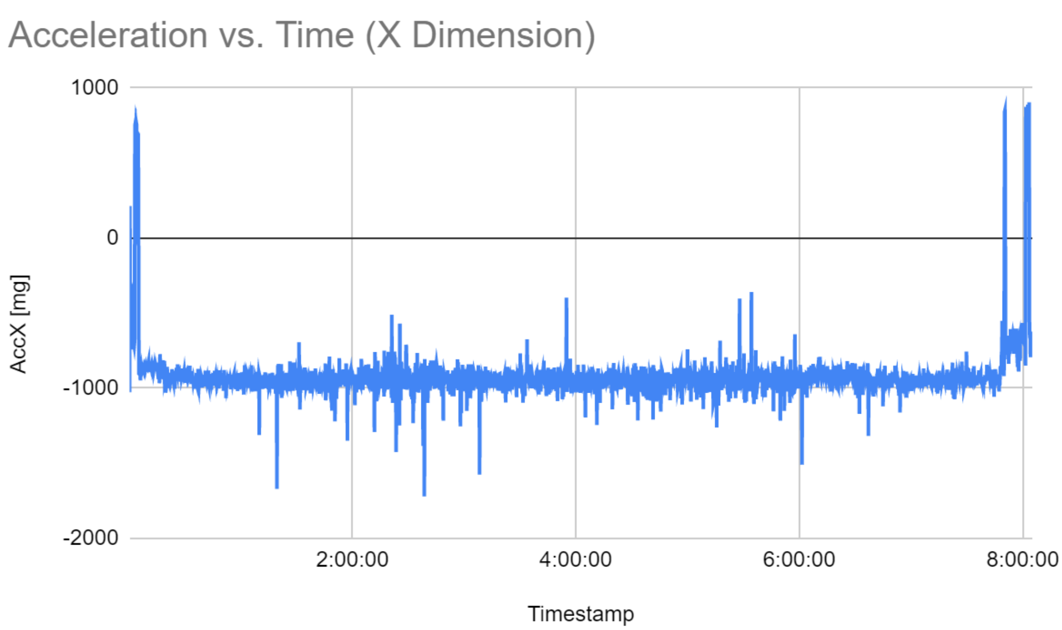

Figure 38. Side to Side Acceleration of Unclothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

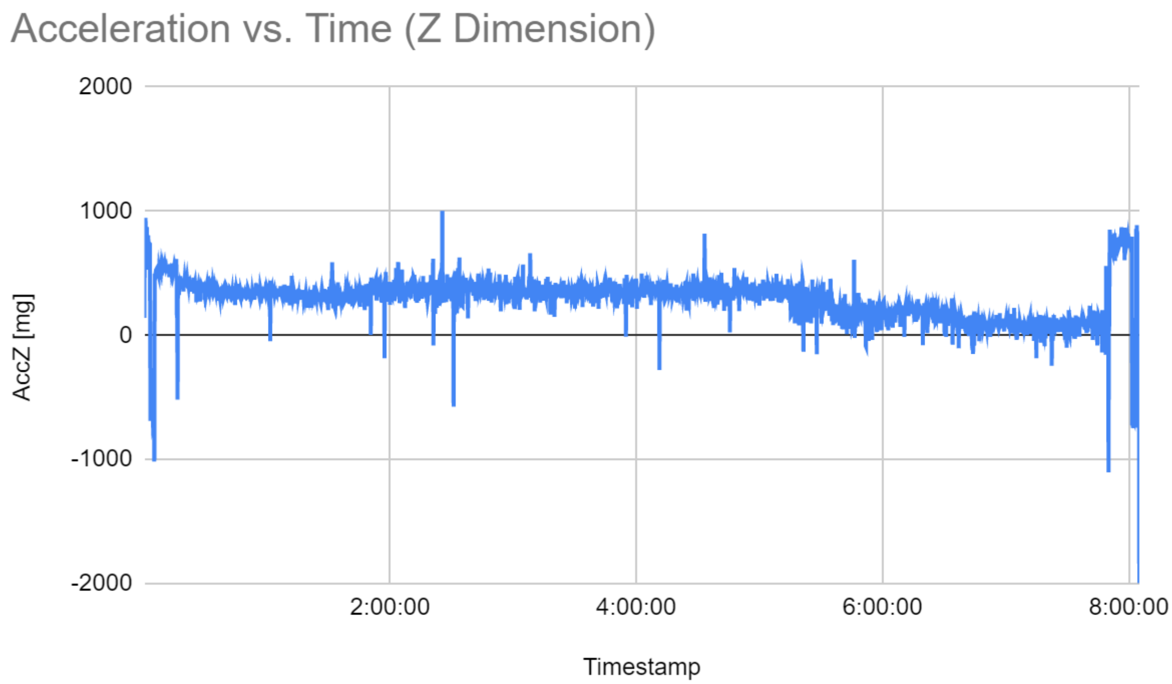

Figure 39. Cranial-Caudal Acceleration of Unclothed Manikin Over Time During 03/26/2022 Floating Trial Along Riverbank at Mizell Bluff.

manikin was found split into two halves with the torso disarticulated from the hips. The two halves of the body were separated by a large rock (pictured in Figure 40). Given that a considerable amount of force would be required to dislodge the hips from the torso, it is plausible that the manikin was repeatedly beaten into the rock by the waves until it came apart. This would explain why the sensor acceleration ratings for the clothed manikin were so high compared to the readings for the unclothed manikin.

Summary of Results

A sample of twenty-five trials analyzed the behavior of a human body-shaped object in a riverine environment and what variables might impact this behavior. Twenty of these trials tested a floating manikin, while five tested a submerged manikin. Ten of the twenty floating trials were conducted at the Fort Loudoun Dam location while the other ten were conducted at the Mizell Bluff location. Out of the twenty floating trials, ten were clothed, and ten unclothed. Additionally, out of the twenty trials, ten were placed along the riverbank and ten were placed at the center of the river. All five sunken trials were conducted unclothed, along the riverbank and at the Scottish Pike location.

A Kruskal-Wallis test indicated that the rank means for total miles traveled and average travel speed for trials were not the same between all three locations. Dunn's post hoc tests further elaborated that there was not a significant difference in ranked means for these dependent variables between trials at Mizell Bluff and Scottish Pike, but there was a statistically significant difference in ranked means between Fort Loudoun Dam and Mizell Bluff, and between Fort Loudoun Dam and Scottish Pike.

A series of Independent T-Tests were conducted to determine whether there was a statistically significant difference in means for total miles traveled and average travel speed between clothed and unclothed trials, bank and center trials, and floating and sinking trials. These t-tests indicated that there was a significant difference in total miles traveled and average travel speed between trials starting along the riverbank vs. in the center of the river at both the Fort Loudoun Dam and the Mizell Bluff locations. However, the t-tests did not indicate a significant difference in travel speed or total miles traveled between clothed and unclothed trials at either location. Finally, the t-tests conducted to compare floating vs. sinking trials indicated

Figure 40. Manikin Split Into Two Halves on Either Side of a Rock at Mizell Bluff. Hips and legs are located on the left, while the head and torso can be made out on the right.

that there is a significant difference in the amount of movement between a sunken manikin and a floating manikin. Qualitative observations indicated that the manikin's limbs would get stuck on obstacles in the river whether wearing clothing or not.

Spearman's correlation tests did not indicate any significant correlation between total miles traveled or average travel speed and rainfall, Tellico Lake reservoir level, or max wind speed at the Mizell Bluff location. At the Fort Loudoun location, the only significant correlation indicated was a negative relationship between average manikin speed and max wind speed.

Finally, sensor data could only be obtained for four out of the twenty-five trials, but indicated that changes in the manikin's acceleration were much greater and more frequent in floating trials than in sinking trials.

CHAPTER FIVE: DISCUSSION

The objective of this study was to determine whether there are consistent patterns in fluvial transport of human remains and shed light on what variables pertaining to the body itself and in the environment impact fluvial transport patterns. The variables tested included where in the river the body entered the water (in the center vs. along the riverbank), whether the body was clothed, whether the body had sunken to the bottom of a shallow part of the river or whether it was floating, what segment of the same river the body entered the water in (Fort Loudoun vs. Mizell Bluff vs. Scottish Pike), as well as environmental variables such as maximum wind speed, rainfall amount, and reservoir depth on the day of entry into the water. A better understanding of how these variables impact the distance traveled and speed of travel of a body shaped object could help investigators and recovery groups to better predict where a body might be found given the conditions under which is entered the water.

Hypothesis 1

Hypothesis 1 stated that an adult human body of average stature and weight deposited in water will follow a consistent travel path if the same environmental and taphonomic conditions are upheld for each trial. In order for this hypothesis to be upheld the manikin must have followed a consistent track through the water when placed in similar conditions (time of day, location in river, water depth etc) for multiple trials. Based on the data, this hypothesis was upheld. All trials at the Fort Loudoun Location traveled downstream, to the west of Fort Loudoun Dam. Additionally, the majority of these trials ended with the manikin getting stuck around the same bend in the river near Sugarlimb. Additionally, since there were statistically significant differences found for distance traveled and average speed of travel for bank trials vs. center of river trials at this location, the reason for variations in distance between trials does appear due to at least one discernable variable, rather than totally random. At the Mizell Bluff location, travel direction and distance were obviously different depending on whether the manikin started along the bank or in the center of the river even through qualitative analysis. However, all of the trials that began with entry at the center of the river resulted in the manikin drifting downstream to the southeast towards Baker Hollow. All trials which started along the bank at Mizell Bluff traveled distances under half a mile, if the distance was detectable at all, and their travel direction was always North, which is technically upstream. Thus, manikin path was consistent when entry into the river along the bank vs. in the center is controlled.

Hypothesis 2

Hypothesis 2 for this study stated that a body that has sunk to the riverbed in a shallow area will remain stationary or remain within a half mile from its point of entry into the river. This hypothesis was upheld. All five sinking trials had no movement that was detectable by GPS. One trial had movement that could be detected visually, but was estimated to be a distance of about five feet, well under a mile. Thus, the results of this thesis support the conclusions of past researchers that a body is unlikely to move very far, if at all, from its location once it has sunken to the bottom of the riverbed, even in relatively shallow water (Dilen 1984, Bassett & Manhein, 2002).

Hypothesis 3

Hypothesis 3 stated that a body placed on one side of the river will stay on that side of the river. This hypothesis was upheld by all trials in which the manikin was placed along the riverbank (n = 15). This supports the observations made by Bassett & Manhein (2002) based on actual cases of human remains recovered from the Mississippi River, that individuals tended to be recovered from the same side of the river that they entered. However, it should be noted that all trials along the riverbank at the Fort Loudoun location were placed on the northern bank of the river. Due to time constraints, trials could only be conducted on one side of the river rather than along both riverbanks. The north side of the river was chosen as Loudoun County Rescue volunteers voiced that this was the side of the river most drownings occur at. This means that the hypothesis was upheld for the north riverbank. However, whether it would be supported if trials were placed on the southern riverbank is unknown. Interestingly, all trials in the center of the river at the Fort Loudoun location also drifted to the north side of the river by the time of recovery. This may have been due to the way the river curves or have to do with the direction of the currents in the water. It is possible that if trials were conducted on the southern bank, the manikin would have crossed the river to the northern bank as well, disproving the hypothesis. This is a subject for further inquiry.

Hypothesis 4

Hypothesis 4 states that a body that is wearing clothing will travel a shorter distance than an unclothed body within the same period of time. This hypothesis was not supported by the trials conducted in this study. Statistical analysis did not indicate a significant difference between the mean distance traveled or average travel speed between manikins wearing clothes and not wearing clothes. Additionally, there were no obvious differences in travel path on the maps between clothed and unclothed manikins. In fact, the trial with the longest travel distance was one in which the manikin was clothed, and the shortest distance traveled was by an unclothed manikin. Based on these results, it may be that, despite the additional drag force produced by clothing, human remains are not likely to travel a shorter distance if the individual was wearing clothing vs. if they were not. However, a larger sample size is needed for a stronger analysis of the impact of clothing on fluvial transport of human remains.

An additional consideration with clothing is whether it impacts the disarticulation of the body. A very small number of the trials for this thesis resulted in disarticulation ($n = 4$). Two of these incidents occurred with an unclothed manikin while the clothed manikin released on the same day stayed intact. In one of these trials, both forearms disarticulated from the unclothed manikin at the elbow, and the right leg disarticulated at the knee. In the other trial, the unclothed manikin's left thigh and lower leg disarticulated from its hip joint, and the right leg disarticulated at the knee. The third and fourth occurrences of disarticulation occurred on the same day with one clothed manikin and one unclothed manikin, in which high winds and extremely choppy water was present. The unclothed manikin's right arm disarticulated at the elbow and was found drifting a few feet away. Additionally, the left leg disarticulated at the hip, as well as at the knee. The thigh piece was recovered from where it was lodged within an underwater rock crevice. However, the rest of the leg from the knee down could not be located. The clothed manikin was found with the lower half of the body from the hips down separated from the torso. Each half of the body was on opposite sides on a large rock. The right arm had disarticulated at the elbow but could not be located. Based on these results, it appears that disarticulation might be more likely on an unclothed body than a clothed body. However, the sample is too small in this case to accept or reject the relationship at a statistical level. Thus, clothing is clearly an issue that needs to be explored further in relation to fluvial transport of human remains.

Study Limitations and Future Recommendations

The experiments conducted as a part of this thesis were subject to the same challenges that other researchers have faced when contending with aquatic decomposition. Due to public health and ethical concerns, actual decomposing remains could not be deposited into public waterways. Though the Randy 9000 manikin served as a useful proxy with the same shape of a human body, there are several aspects of decomposition, particularly re-floating and animal scavenging, that could not be simulated. Additionally, data collection through the use of GPS and sensors was very difficult in an aquatic environment, which impacted statistical analysis of the data.

Challenges With Simulating Decomposition

Since a pre-made manikin was utilized instead of actual human remains, there were limitations as to how accurately the experiment can simulate the behavior of a decomposing human body. In order to receive more accurate results, several dynamic aspects of the decomposition process would need to be simulated. One example is the build-up of gas inside the body during the putrefaction stage of the decomposition process, which causes the body to resurface after an interval of time (Heaton, 2010). The experiments conducted for this thesis simulated two different stages of decomposition. The sinking trials were intended to test the movement of the body before decomposition has progressed to putrefaction. Conversely, the floating simulated the behavior of a body that has begun putrefaction and bloated enough to float back up to the surface. However, to get the most accurate idea of a body's path of travel in the water over time, one would need a manikin with the ability to both float and sink without being taken out of the water. In the future, building a mechanism such as an inflatable bladder within the manikin that could be remotely inflated and deflated at intervals, or programmed to do so on its own, would potentially allow for the observation of changes in fluvial transport depending on whether the body is floating or submerged. The behavior of a body sunken for a few days and then gradually re-floating to the surface could be simulated. A potential option might be an inflatable dive vest that could be triggered remotely or by a timer. Scuba divers use vests called buoyancy control devices (BCD) which allow them to rise and sink. However, the diver must operate the valves that add or decrease the air in the jacket, a task that a manikin would not be able to perform. Since the 1970s, there have been attempts to create a BCD that can change or maintain a diver's depth or velocity automatically (Valenko et al., 2016). However, none of these devices have successfully made it onto the market. Thus, the ability to remotely control floating and sinking is a challenge that has not yet been solved.

In the case that a way to remotely float and sink the manikin was created, another challenge that would need to be overcome is the estimation of how many days a body is likely to stay sunken before it re-floats in a particular river. Because the speed of decomposition is dependent on water temperature, re-floating takes a longer time in colder bodies of water than in warmer ones. For example, Bassett & Manhein (2002) analyzed cases of body recoveries in the Mississippi river and found that most of the remains had been bloated within the first nine days of entering the water. However, there were some bodies that were still found in the bloating stage after a month of being in the water (Bassett & Manhein, 2002). When observing the decomposition of pig carcasses in ponds and streams in Maple Ridge, British Columbia, Hobischak & Anderson (2002) found that bloating did not begin until days 11 – 13 of being in the water. Additionally, the bloating persisted between 23 and 37 days (Hobischak & Anderson., 2002). Because there is so much variability in the time it takes for refloating to occur, it would be necessary when simulating this process to first analyze the water-related death cases that have occurred within a particular river segment to determine the typical onset of re-floating and how long it lasts.

Another limitation of using a manikin to simulate fluvial transport of human remains is that it is made of polyethylene plastic, which is not comparable to human skin or body tissues. This means that the experiment was not able to account for the impact of animal scavenging on fluvial transport, as well as any other ways the presence of flesh on the body may impact transport patterns. Previous research on aquatic decomposition has shown that pig carcasses left in the water would become (and remain) submerged more quickly if they were heavily scavenged (Hobischak & Anderson, 2002). Another experiment found that even when remains are at a depth at which the water pressure is too great for resurfacing to occur, animal scavenging can cause the remains to be rapidly moved from their original location (Anderson & Bell, 2014). Thus, the impact of human tissue reduction and animal scavenging of remains in aquatic environments is undoubtedly important in some, if not all, environments but could not be simulated in this thesis.

Finally, a limitation of using a manikin to simulate human remains is that no one has ever carried out a controlled study comparing the behavior of a manikin in water to actual human remains. Therefore, direct comparisons between the two should be made with caution. Of course, it is difficult to prove that or disprove that a human body and manikin behave the same during fluvial transport because of the very issue that creates a need for manikins in the first place. There are ethical and environmental concerns with placing a real human body in a real aquatic environment for controlled study. For the data collected within this thesis, a good next step to determining if the data collected is accurate to real human remains would be to compare the manikin data to real cases of decedents recovered from water in the Mizell Bluff and Fort Loudoun area. This would avoid the issue of putting human remains in the water while testing whether the behavior of real cases reflects the behavior of the manikins.

Data Collection in an Aquatic Environment

Several challenges were faced throughout the duration of data collection for this project. Firstly, one of the goals of the experiments conducted was to capture small minute to minute changes in the manikin's velocity and direction of movement. However, this was impeded by issues with the STEVAL-STLCS01V1 sensor's battery use and data retention mechanism. Even attached to a battery pack, the amount of time the sensor retained a charge was extremely variable, lasting five hours some days and up to ten hours other days. Thus, there were several trials in which the sensor died before it could be retrieved. This sensor is programmed to run the processes that save the data when it is manually turned off. Thus, if the sensor loses its charge while still collecting data, the save process will not run and the data will not be written onto the SD card, resulting in data loss. Another issue with the sensor was the mechanism by which data collection was started and stopped. Recording of data by the sensor is triggered to begin and end when the sensor senses a change in acceleration. Though the sensor was Velcro-ed in place within a waterproof box, and the waterproof box was screwed in place within the manikin, the process of putting the manikin into the water still often jolted the sensor enough to make it stop recording. Because the sensor needs to be inside the manikin, which is bolted shut, in order to be protected from the water, it was not possible to tell when the sensor stopped recording during the process of placing the manikin into the water. This resulted in several trials where the SD card that was retrieved only contained the data from before the manikin was placed in the water.

Another technological limitation of the study was the maintenance of GPS signal throughout the experiment. Even while shielded from the water, the GPS within the phone would occasionally lose signal. This caused occasional gaps in the map data where location points were very far apart. An additional cause of long distances between GPS data points was when the manikin was moving too slowly or too small a distance for the GPS to recognize.

In general, data collection in an aquatic environment is very resource intensive and can be extremely expensive. In this study, volunteers from the Loudoun County Marine Rescue (LCMR) team as well as the Knox County Rescue team were heavily relied upon, as was their boat and equipment, for placement and retrieval of floating manikins. However, many of these volunteers also work in other emergency services jobs, making it even more essential to respect their time. Thus, the manikins for these trials could not be followed or watched for the entirety of the day. Though the GPS may show that a manikin stopped or started moving in the middle of the day, it does not always illustrate why this change in movement occurred. In most cases, the situation could be inferred by the context upon retrieval (i.e. if a manikin stopped moving for the day and was found caught in a fallen tree upon retrieval, it probably stopped moving because of that). However, to get the most accurate understanding possible of the fluvial transport patterns of a body shaped object, the bodies would need to be followed and observed for the entire duration of the trial. This would likely require hiring a boat captain and/or renting a boat for several full days, which costs several hundreds of dollars at minimum. Another solution that was considered to solve this issue was to attach a water-proofed go-pro camera to the manikin. However, with the visible trauma that the manikins endured in environment while in the river, it is unlikely this would have been possible without breaking the camera or losing it in the water.

Further Inquiry on Weather-Related Variables

For this thesis, several environmental variables, including maximum wind speed on the day of a trial, rainfall on the day of a trial, and water levels, were recorded and analyzed to see if any statistically significant relationship were visible between them and the distance and speed of manikin travel. With the exception of an apparent negative correlation between average manikin speed and maximum wind speed, no statistically significant relationships were found. However, it should be noted that weather conditions were relatively constant throughout all of the trials. Due to concerns for the safety of rescue personnel and other volunteers assisting in trials, no trials were conducted in any kind of extreme weather. For example, it is possible that a massive storm causing flooding would impact fluvial transport of the manikins, but this would not have been observed throughout this experiment due to these safety concerns. Additionally, the small sample size contributes to the difficultly of making any statement on the impact of weather-related variables on fluvial transport. Further fluvial transport studies should be carried out with an emphasis on collecting weather data in order to gather more data on these variables.

The Problem of Within-River Variation

When this thesis was first conceived, it was based on a desire to learn more about constants in the fluvial transport process that could be used in numerous rivers or situations to predict where a body would end up given a particular entry location. However, the results of this study illustrate that even within the same river, fluvial transport patterns can vary drastically. Fort Loudoun Dam is within the Tennessee River, and Mizell Bluff is within the Little Tennessee River, an offshoot of the Tennessee River. Though these locations are both downstream from the same river conditions and located approximately a mile and a half from each other, the paths of manikin travel were drastically different. This means that fluvial transport patterns would need to be understood within individual segments of the same river in order to use them for accurate predictions. This further complicates the problem of determining an accurate method of predicting fluvial transport of human remains. If the methods of this thesis are employed in a different river, or even in a different part of the Tennessee River, the results may vary. For example, the water at Scottish Pike, where sinking trials took place, flows relatively slowly. This was a necessary condition to ensure the trial could be completed safely. However, if a body sunk to the bottom of a rapidly moving river, could it still be expected to stay in one place or travel under a mile from its initial starting point? This is a question that cannot be answered by the data collected in this thesis. To obtain even a remote understanding of the fluvial transport of human remains, it is essentially necessary to study fluvial transport of human remains in every segment of every river individually. This is a very large and likely expensive undertaking. However, based on the results of this pilot study, it may be necessary in order to predict fluvial transport patterns of human remains with any degree of certainty.

CHAPTER SIX: CONCLUSION

The purpose of this study was to gain a better understanding of what variables pertaining to the body itself or the environment influence fluvial transport patterns of human remains. Because of how little fluvial transport of human remains is understood, law enforcement and recovery personnel are often put at risk and/or spend large amounts of money on equipment in order to locate a human body that has entered the water. Increased knowledge of the variables that influence fluvial transport of human remains may allow for more accurate prediction of the location of human remains given a particular entry point into the water. The ability to narrow the search area would increase investigators' chances of success in locating the remains and reduce the manpower and resources required. Additionally, no controlled fluvial transport study has been conducted in the Loudoun County or Knoxville, TN areas of the Tennessee River previously, so this study provided data specific to the conditions and patterns of these areas for potential use by rescue personnel.

The results supported previous research that indicated that a body that has sunken to the bottom of a riverbed is unlikely to move more than a mile from the spot it entered the water, if it moves at all (Dilen, 1984; Bassett & Manhein, 2002). In this thesis, the sunken trials were in a very shallow location where the water was only around 3 ft deep. However, given that the effect of sinking the manikin is observable even in this shallow location, it is likely that it will uphold in a deeper location where there is even more downward hydrostatic force being exerted on the body by the water. The results tentatively support Basset & Manheim's (2002) finding that a body will not cross the river and will stay along the side of the river where it entered the water. However, since trials along the riverbank were conducted only on the north side of the river in the interest of time and consistency, the behavior of a body placed on the southern riverbank past Fort Loudoun Dam is still unknown. It is possible that the hypothesis that a body will not cross from one riverbank to the other would be disproved by trials along the southern riverbank. Future research should explore this question by testing manikin travel with placements on both sides of the river.

Additionally, the results illustrated that there do appear to be consistent patterns in the travel of a body-shaped object. However, these patterns are consistent within the same river segment, not necessarily throughout the entire river. Though Mizell Bluff and Fort Loudoun Dam are very close to one another, and Mizell Bluff rests in an offshoot of the Tennessee River, the travel paths of the manikins in these locations were drastically different. This study did not find any significant difference in travel distance or speed between clothed and unclothed trials. This may indicate that clothing has little or no impact on fluvial transport distance and travel speed. However, due to the small sample size, further testing of this variable in fluvial transport should be carried out. Finally, no correlation was found with manikin distance traveled and wind speed, rainfall, or reservoir level on the day of the trial. For average manikin speed, there was a negative correlation with wind speed at the Fort Loudoun location, but not the Mizell Bluff location, and no correlation with rainfall or reservoir level. However, no tests were conducted in extreme weather to ensure the safety of volunteers carrying out the experiments. It is possible that due to this, as well as the small sample size, that there is a correlation between weather variables and fluvial transport of human remains that was not detected within this study.

The results of this study were limited by the use of a manikin in lieu of a real human body. A manikin cannot decompose, so decomposition related variables, such as whether the body is sunken or has floated due to putrefaction, could not be simulated in exactly the same manner as these processes occur in an organic human body. Additionally, animal scavenging did not occur on the plastic body and could not be simulated on the manikin. Because of the ethical and environmental problems with placing human remains in a publicly accessible water reservoir, there is no good way around this problem short of building one's own riverine environment. The next step in this fluvial transport project, as well as any other fluvial transport project using manikins as a proxy for human remains, should be to compare the results from the manikins to actual case studies involving recovery of human remains in the tested aquatic environment. In the case of this project, the results should be analyzed against actual cases of body recoveries that took place in Loudoun County west of Fort Loudoun Dam, or near Mizell Bluff. This may provide insight as to how accurate the data procured from manikin proxy studies can be expected to be compared to actual human remains.

Data collection was also difficult due to the aquatic environment. GPS signals are blocked by water, which led to the GPS for sunken trials being kept in a buoy tied to the manikin, rather than within the manikin itself, which may have led to more accurate results. Additionally, GPS technology itself is typically only accurate to several meters, which meant that minuscule changes in manikin distance from the entry point into the water could not always be detected. Collection of data with a sensor system was attempted in order to detect small changes within the manikin's position in the water. However, due to day-to-day variation in how long the sensor battery would last, many trials suffered data loss due to sensor failure before data could be recorded to the SD card. Additionally, because the recording mechanism is turned on and off when the sensor detects a large change in acceleration, there were several incidents in which the sensor was turned off inside the manikin during the process of lowering it into the water, also resulting in data loss.

Perhaps more than anything else, this project has illustrated just how complicated it is to determine fluvial transport patterns of human remains. There is clearly a need for investigators to have more reliable data to help them find human remains that are missing in water. However, data is not easily procured in an aquatic environment. Additionally, based on the results of this study, generalizations about fluvial transport patterns cannot be made across multiple rivers. In fact, they cannot even always be made across different segments or offshoots of the same river. This means that in order to understand fluvial transport patterns of human remains well enough to predict them, fluvial transport studies must be undertaken throughout multiple segments of multiple rivers throughout the country. This requires a huge amount of manpower, time, and money in order to achieve. However, this study represents a small step towards that goal.

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APPENDIX

Appendix A: Data and Maps for Individual Trials

Table 18. Summary of Trials Conducted. Total Miles Traveled calculated through ArcGIS Online. Sensor malfunction indicates that sensor did not turn on or did not record the data to the SD card properly.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
1	October 8, 2021	Unclothed	Sinking	Riverbank under railroad bridge	6 hours 37 minutes	0	Manikin did not move.
2	November 12, 2021	Clothed	Floating	Mizell Bluff – along eastern riverbank	6 hours 39 minutes	0	Not enough movement for GPS to detect. Sensor battery dead at recovery.
3	November 12, 2021	Unclothed	Floating	Mizell Bluff – along eastern riverbank	6 hours 19 minutes	0	Not enough movement for GPS to detect. Right leg disarticulated at knee and both arms disarticulated at elbow. Sensor battery dead at recovery.
4	November 19, 2021	Unclothed	Floating	Center of river parallel to Mizell Bluff	6 hours 44 minutes	0.28	Left leg disarticulated at thigh and right leg disarticulated at knee due to being caught in tree. No data present on sensor.
5	November 19, 2021	Clothed	Floating	Center of river parallel to Mizell Bluff	6 hours 4 minutes	0.43	Caught up in fallen tree. No data present on sensor.

Table 18 continued.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
6	February 2, 2022	Clothed	Floating	Mizell Bluff – along eastern riverbank	7 hours 14 minutes	0.09	Stuck in cove at 9:25AM; pulled away from bank to allow for further data collection. Sensor battery dead upon recovery.
7	February 2, 2022	Unclothed	Floating	Mizell Bluff – along eastern riverbank	6 hours 54 minutes	0.04	Sensor malfunction.
8	February 24, 2022	Unclothed	Floating	West of Fort Loudoun Dam; Center of river	7 hours 26 minutes	7.6	Stopped moving at around 12:19PM but began moving again at about 2:30PM; sensor died before recovery.
9	February 24, 2022	Clothed	Floating	West of Fort Loudoun Dam; Center of river	7 hours 35 minutes	5.8 miles	Stopped moving at about 11am; found stuck in tree limb. Sensor malfunction.

Table 18 continued.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
10	February 25, 2022	Unclothed	Floating	West of Fort Loudoun Dam; North riverbank	7 hours 30 minutes	5.4	Found tangeled in brush along river bank at retrieval time; shirt still on but some buttons ripped off; sensor died before recovery.
11	February 25, 2022	Unclothed	Floating	West of Fort Loudoun Dam; North riverbank	6 hours 47 minutes	1.66	Lost gps signal at 10:30AM but got it back at 1pm. Manikin caught along bank at recovery.
12	March 3, 2022	Clothed	Floating	West of Fort Loudoun Dam; Center of river	5 hours 15 minutes	10.8	Trial ended early due to manikin being taken out of the water by fire department. Sensor battery dead.
13	March 3, 2022	Unclothed	Floating	West of Fort Loudoun Dam; Center of river	6 hours 48 minutes	6.2	Stuck under large tree limb at recovery. Sensor malfunction.

Table 18 continued.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
14	March 4, 2022	Clothed	Floating	Center of river parallel to Mizell Bluff	6 hours 38 minutes	0.38	Still floating in middle of lake at recovery. Sensor battery died.
15	March 4, 2022	Unclothed	Floating	Center of river parallel to Mizell Bluff	6 hours 35 minutes	0.43	Drifted into cove near bluff at recovery. Sensor battery died.
16	March 11, 2022	Clothed	Floating	Downstream from Fort Loudoun Dam; Center of river	6 hours 58 minutes	6.3	Stopped moving at 12:06PM. Caught on fallen tree branch. Sensor malfunction.
17	March 11, 2022	Unclothed	Floating	Downstream from Fort Loudoun Dam; Center of river	7 hours 32 minutes	6.7	Caught on fallen tree branch. Sensor battery died.
18	March 25, 2022	Clothed	Floating	Downstream from Fort Loudoun Dam; North riverbank	7 hours 57 minutes	2.18	Stopped moving at 10:50AM. Caught on tree. Sensor malfunction.
19	March 25, 2022	Unclothed	Floating	Downstream from Fort Loudoun Dam; North riverbank	8 hours 45 minutes	6.5	Caught in pile of driftwood upon recovery. Sensor malfunction.

Table 18 continued.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
20	March 26, 2022	Clothed	Floating	Mizell Bluff – along eastern riverbank	7 hours 54 minutes	0	Water extremely choppy. Found caught between rocks at recovery. Hips disarticulated from torso. Right arm disarticulated at elbow. Could not be located. Not enough movement for GPS to detect distance.
21	March 26, 2022	Unclothed	Floating	Mizell Bluff – along eastern riverbank	7 hours 24 minutes	0	Water extremely choppy. Right arm disarticulated at elbow and found nearby in open water. Left leg disarticulated at hip with thigh lodged deep in underwater rock crevice. Left lower limb from knee down could not be located. Manikin did not move enough for GPS to detect distance.

Table 18 continued.

Trial #	Date	Prescence of Clothing	Floating or Sinking	Placement Location	Total Time in Water	Total Miles Traveled	Notes
22	April 13, 2022	Unclothed	Sinking	Riverbank under railroad bridge, Knoxville	7 hours 10 minutes	0	Manikin did not move.
23	April 21, 2022	Unclothed	Sinking	Riverbank under railroad bridge, Knoxville	7 hours 2 minutes	0	Manikin did not move.
24	April 22, 2022	Unclothed	Sinking	Riverbank under railroad bridge, Knoxville	7 hours 14 minutes	0	Not enough movement to be detected by GPS. However, visually estimated movement of about 5 feet towards the shore. Unclear if movement occurred naturally or if manikin was tampered with.
25	April 29, 2022	Unclothed	Sinking	Riverbank under railroad bridge, Knoxville	7 hours 16 minutes	0	Manikin did not move.

Figure 41. Clothed Manikin Travel Path Along Bank at Mizell Bluff on November 12, 2021.

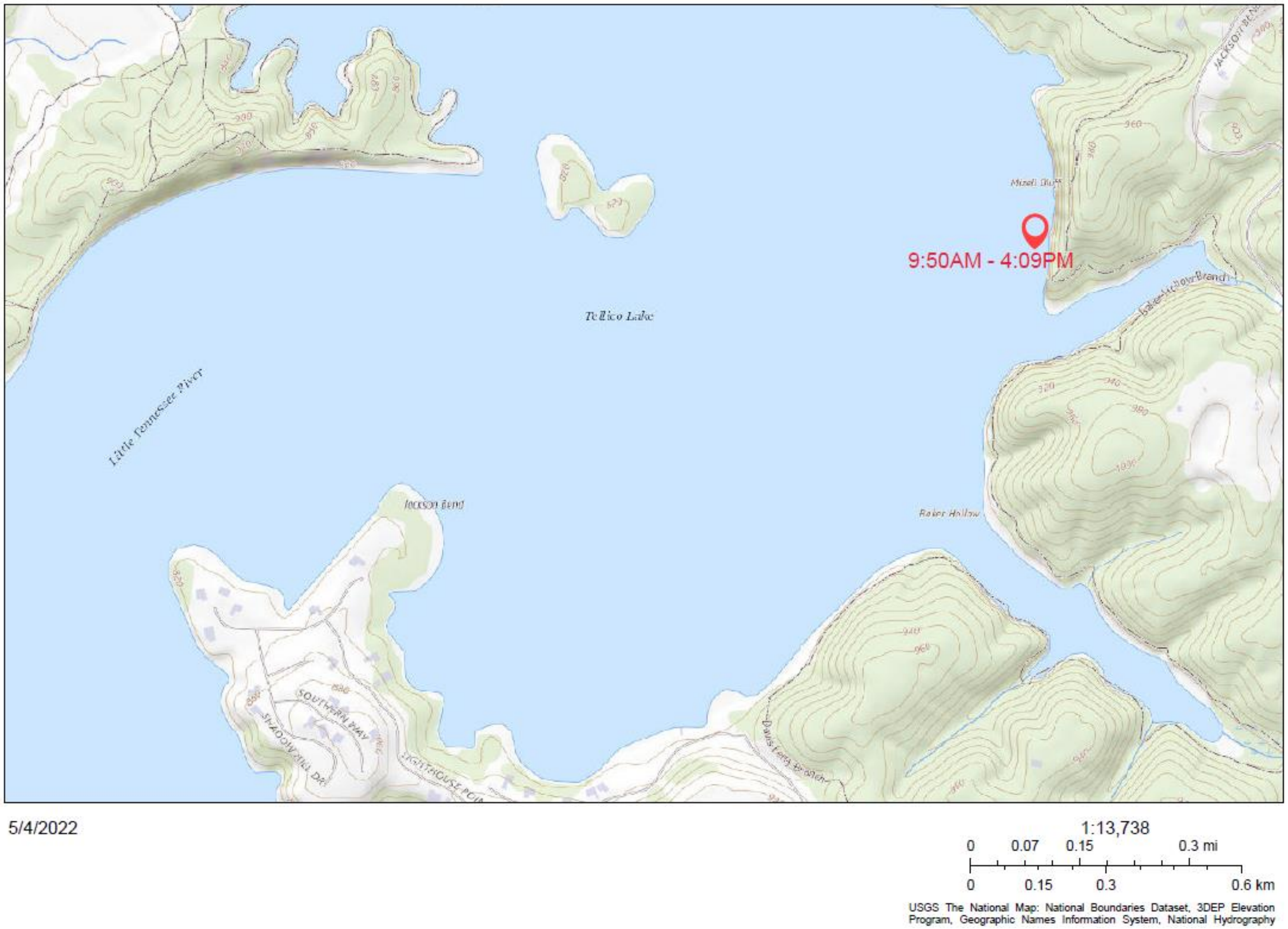


Figure 42. Unclothed Manikin Travel Path Along Riverbank at Mizell Bluff on November 12, 2021.

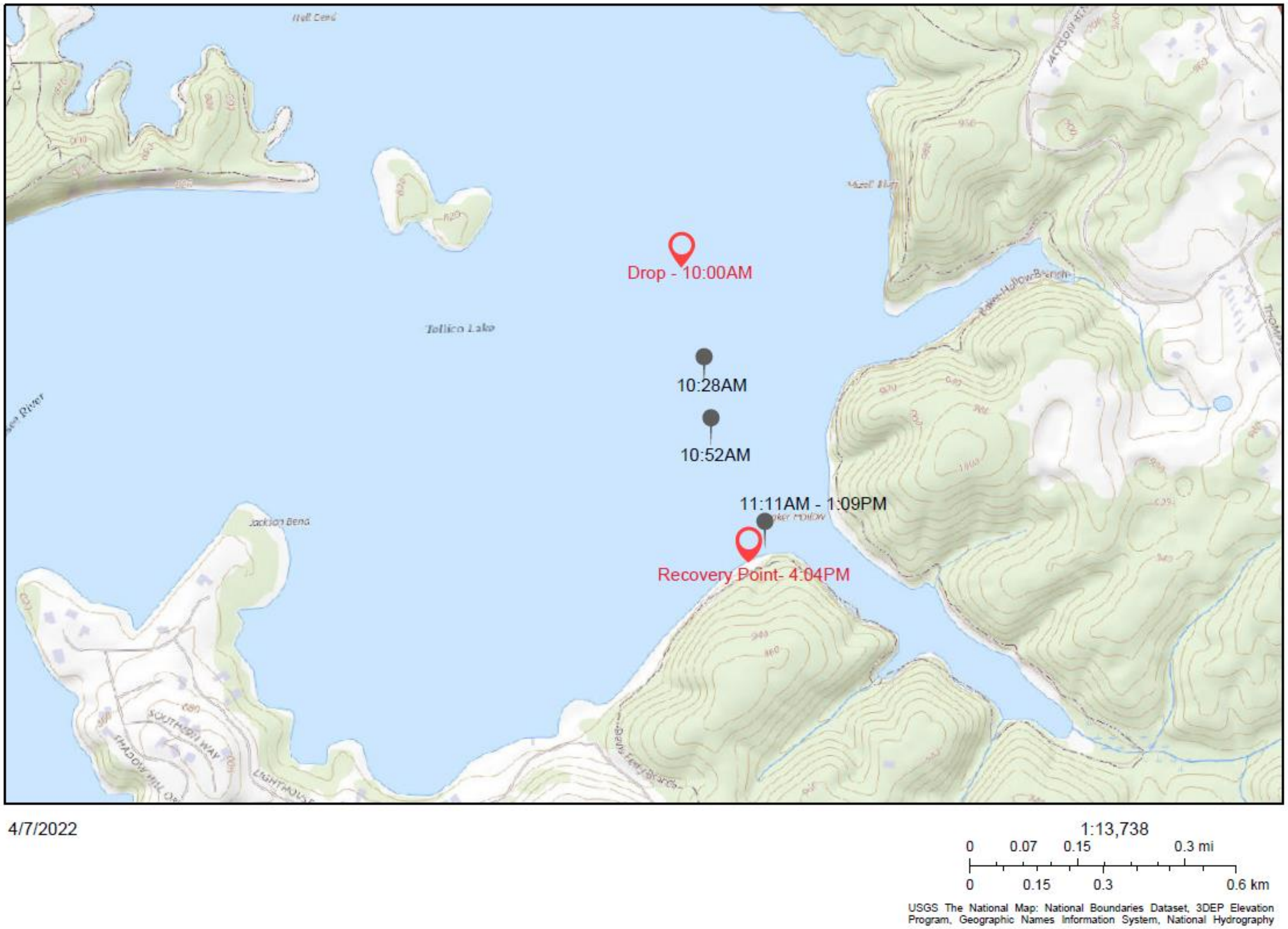


Figure 43. Clothed Manikin Travel Path in Center of the River at Mizell Bluff on November 19, 2021.

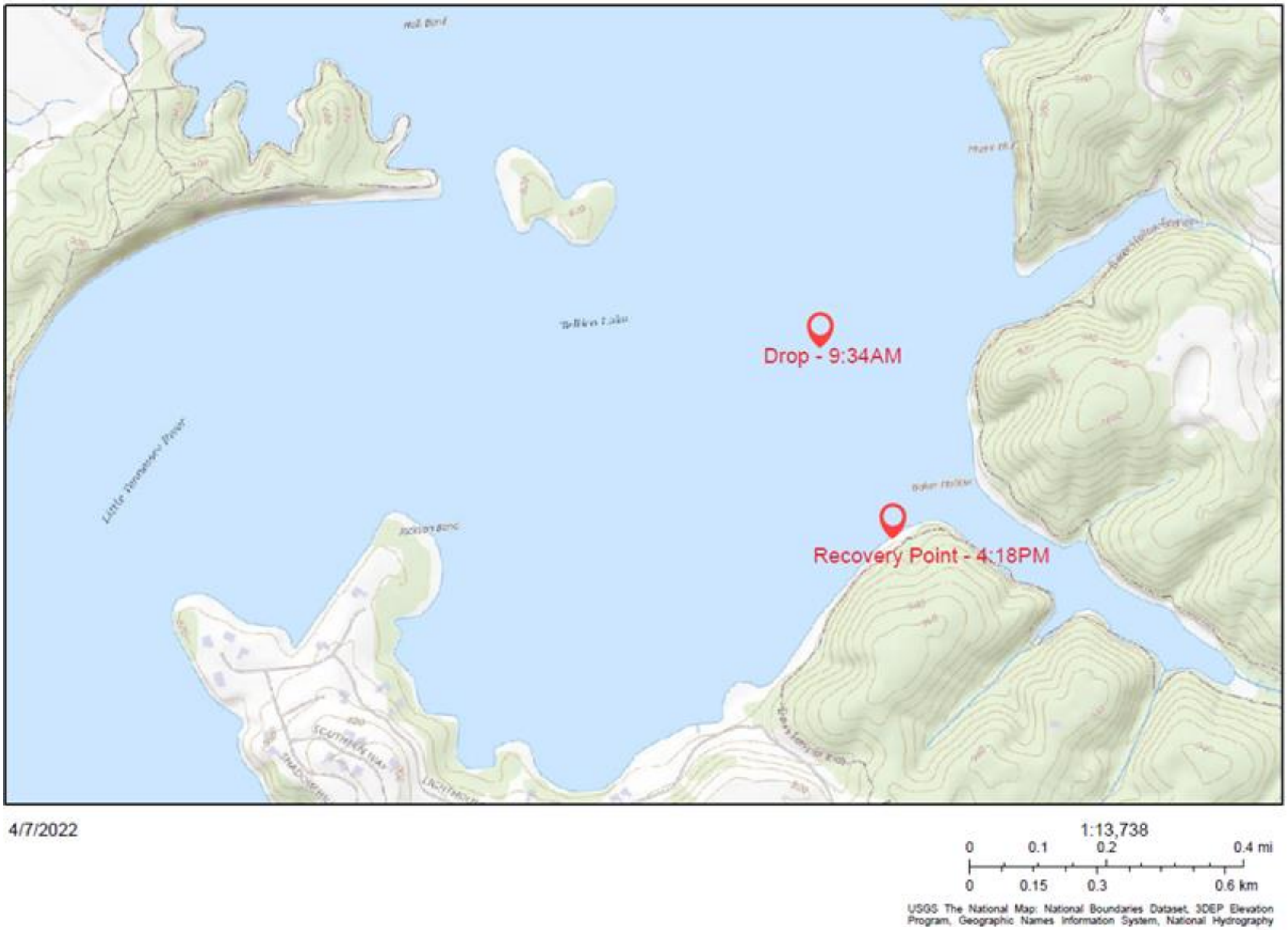


Figure 44. Unclothed Manikin Travel Path in Center of River at Mizell Bluff on November 19, 2021.

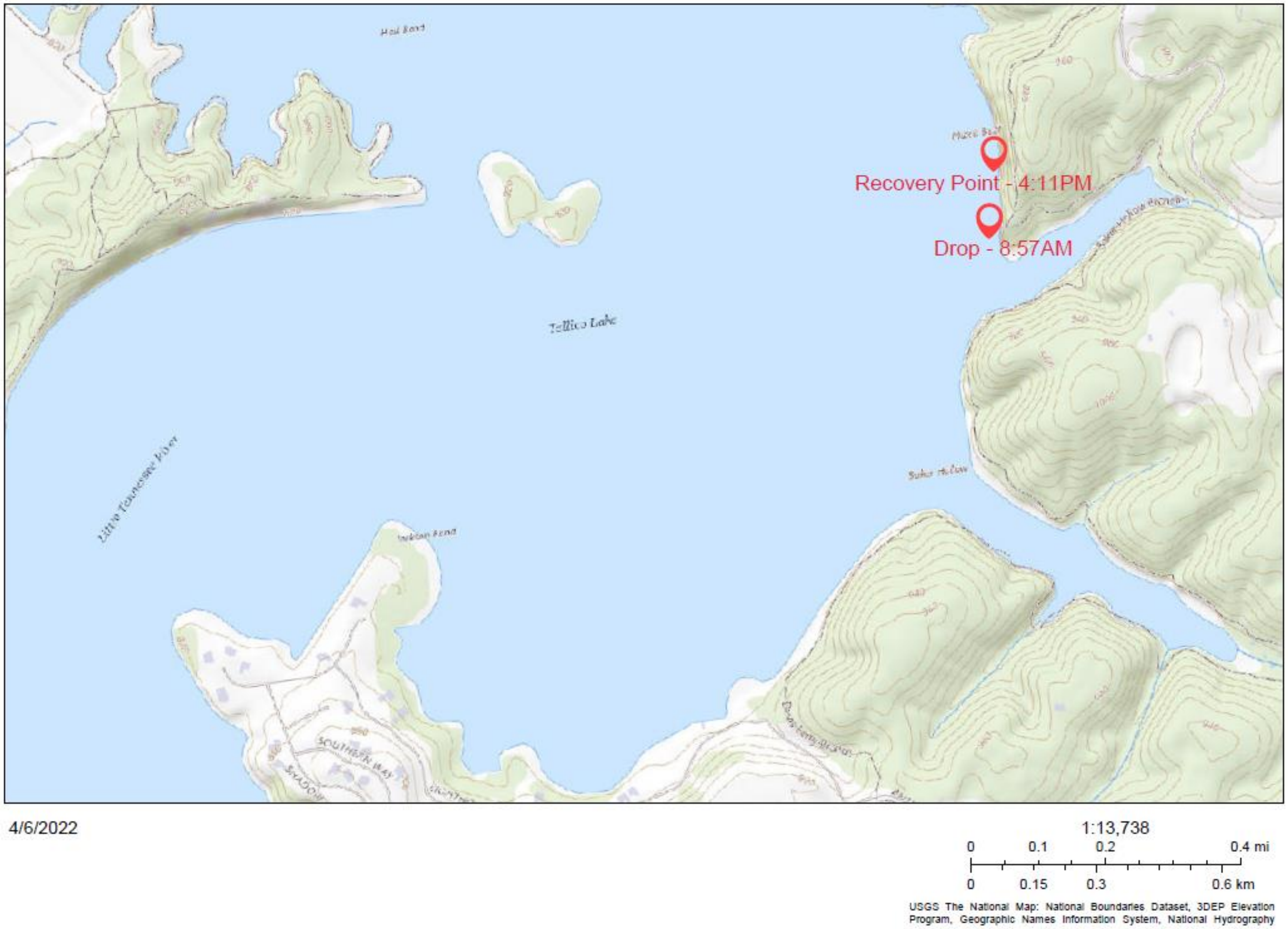


Figure 45. Clothed Manikin Travel Path Along Riverbank at Mizell Bluff on February 2, 2022.

4/6/2022

1:13,523
0 0.07 0.15 0.3 mi
0 0.15 0.3 0.6 km

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography

Figure 46. Unclothed Manikin Travel Path Along Riverbank at Mizell Bluff on February 2, 2022

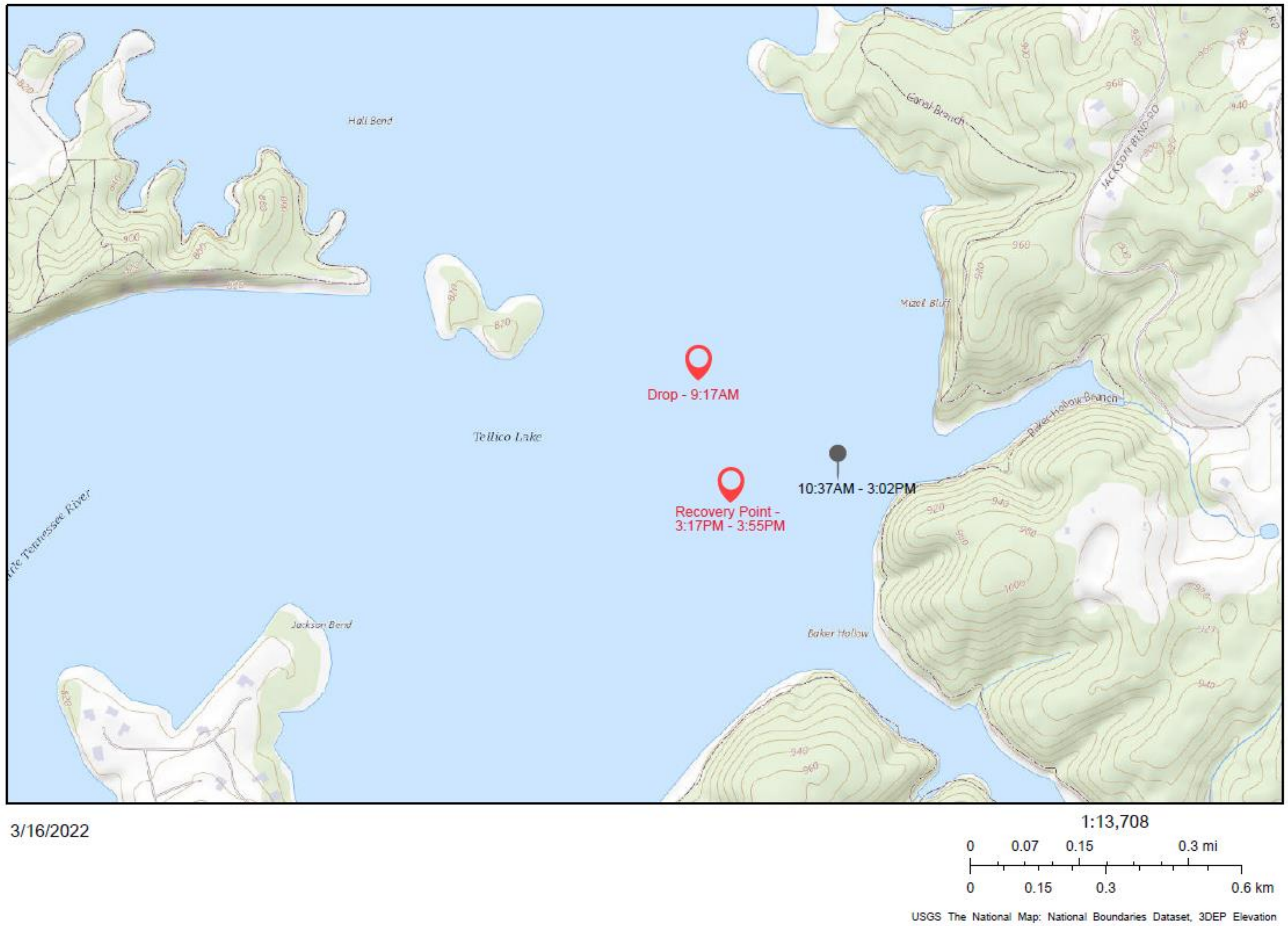


Figure 47. Clothed Manikin Travel Path in Center of River at Mizell Bluff on March 4, 2022.

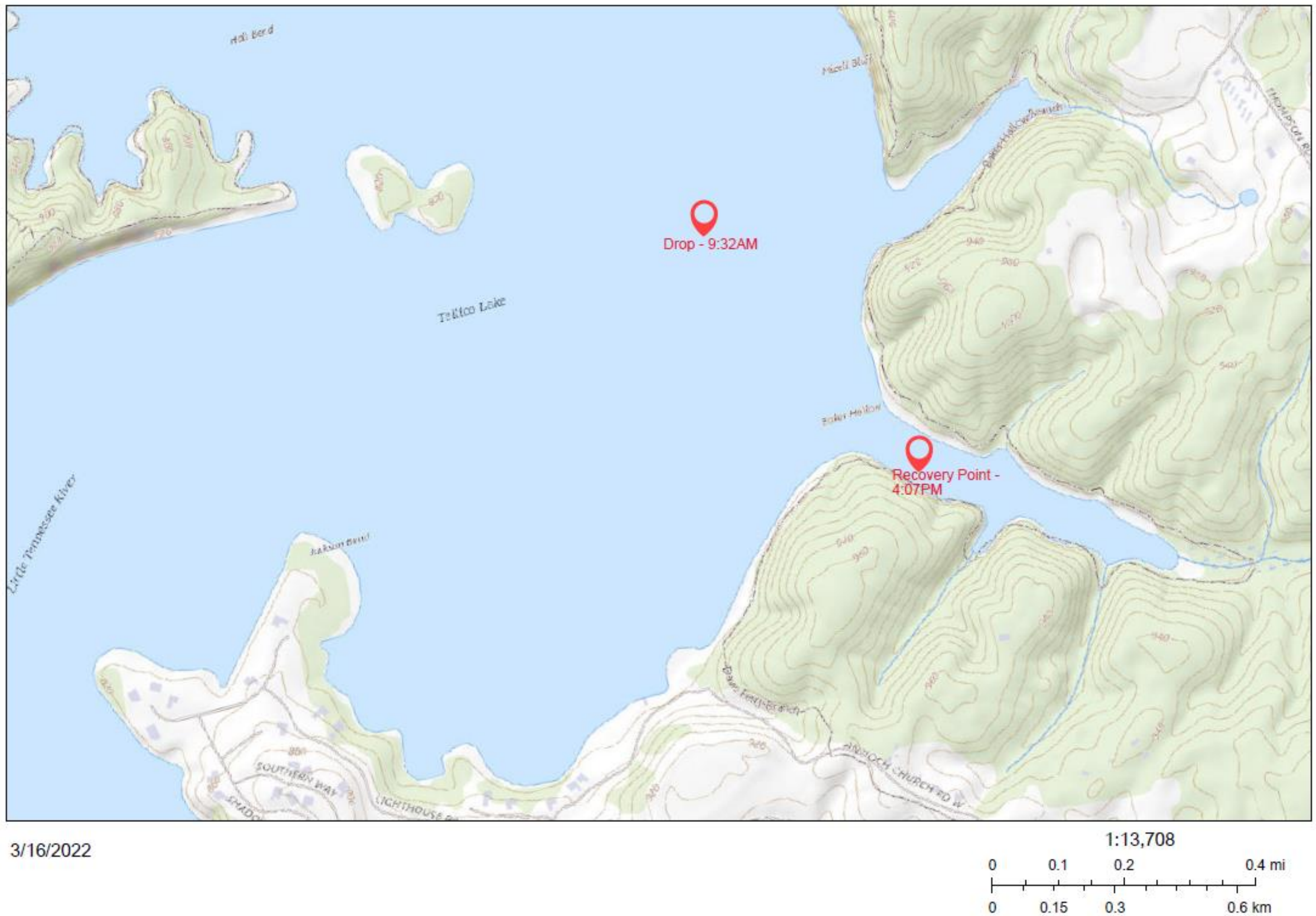


Figure 48. Unclothed Manikin Travel Path in Center of the River at Mizell Bluff on March 4, 2022.

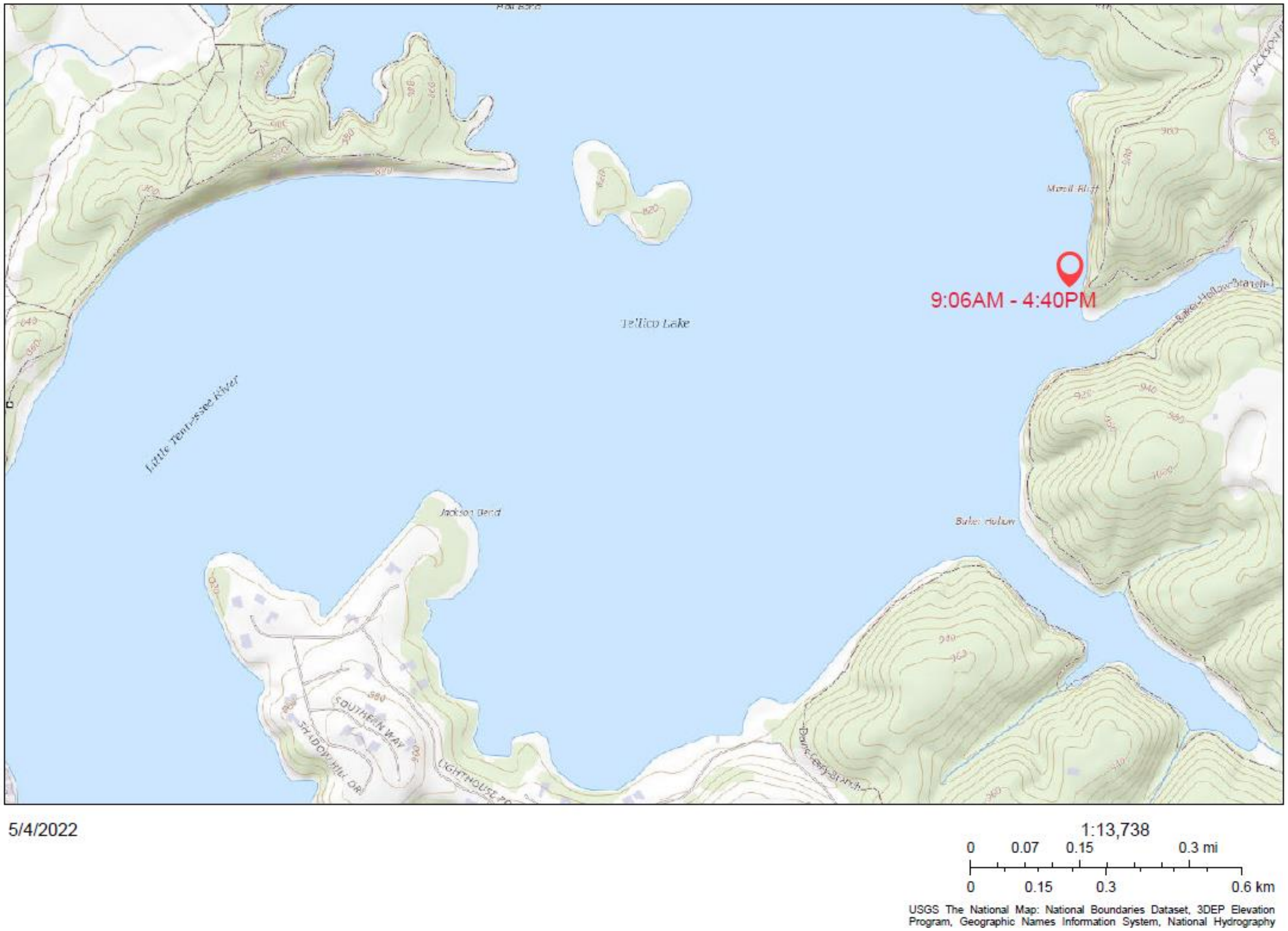


Figure 49. Clothed Manikin Travel Path Along Riverbank at Mizell Bluff on March 26, 2022.

Figure 50. Unclothed Manikin Travel Path Along Riverbank at Mizell Bluff on March 26, 2022.

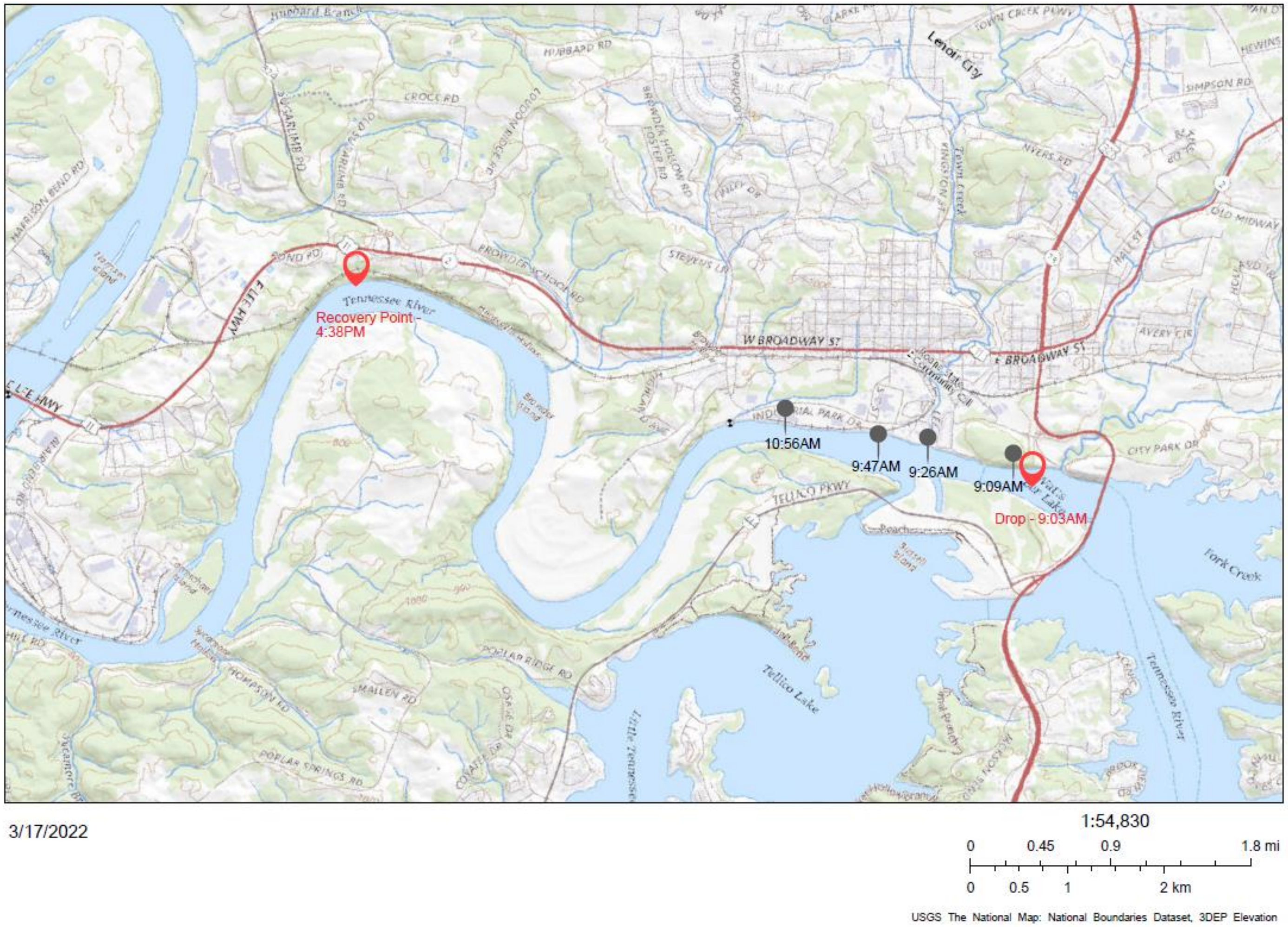


Figure 51. Clothed Manikin Travel Path in Center of River at Fort Loudoun Dam on February, 24, 2022

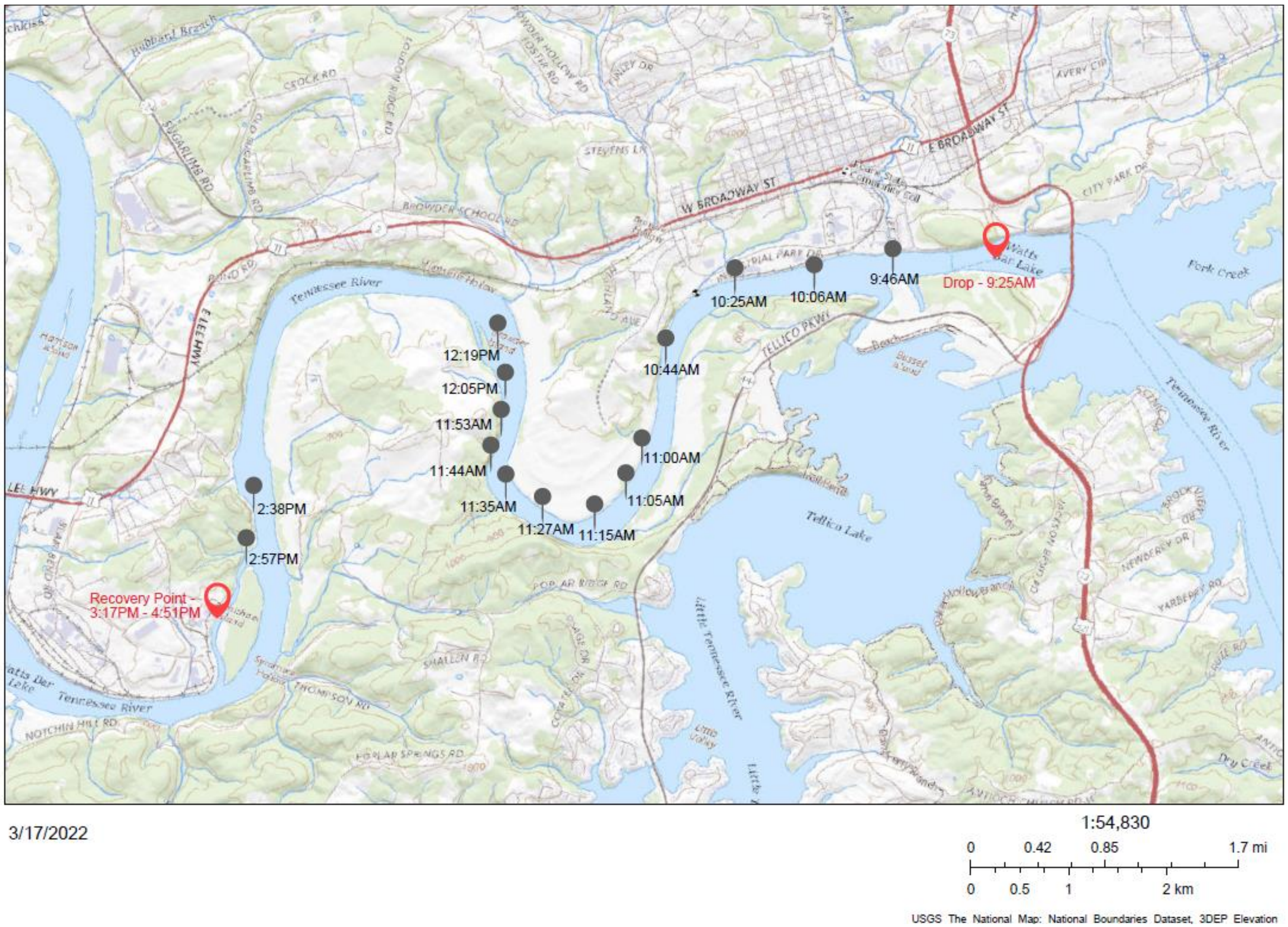


Figure 52. Unclothed Manikin Travel Path in Center of River at Fort Loudoun Dam on February, 24, 2022

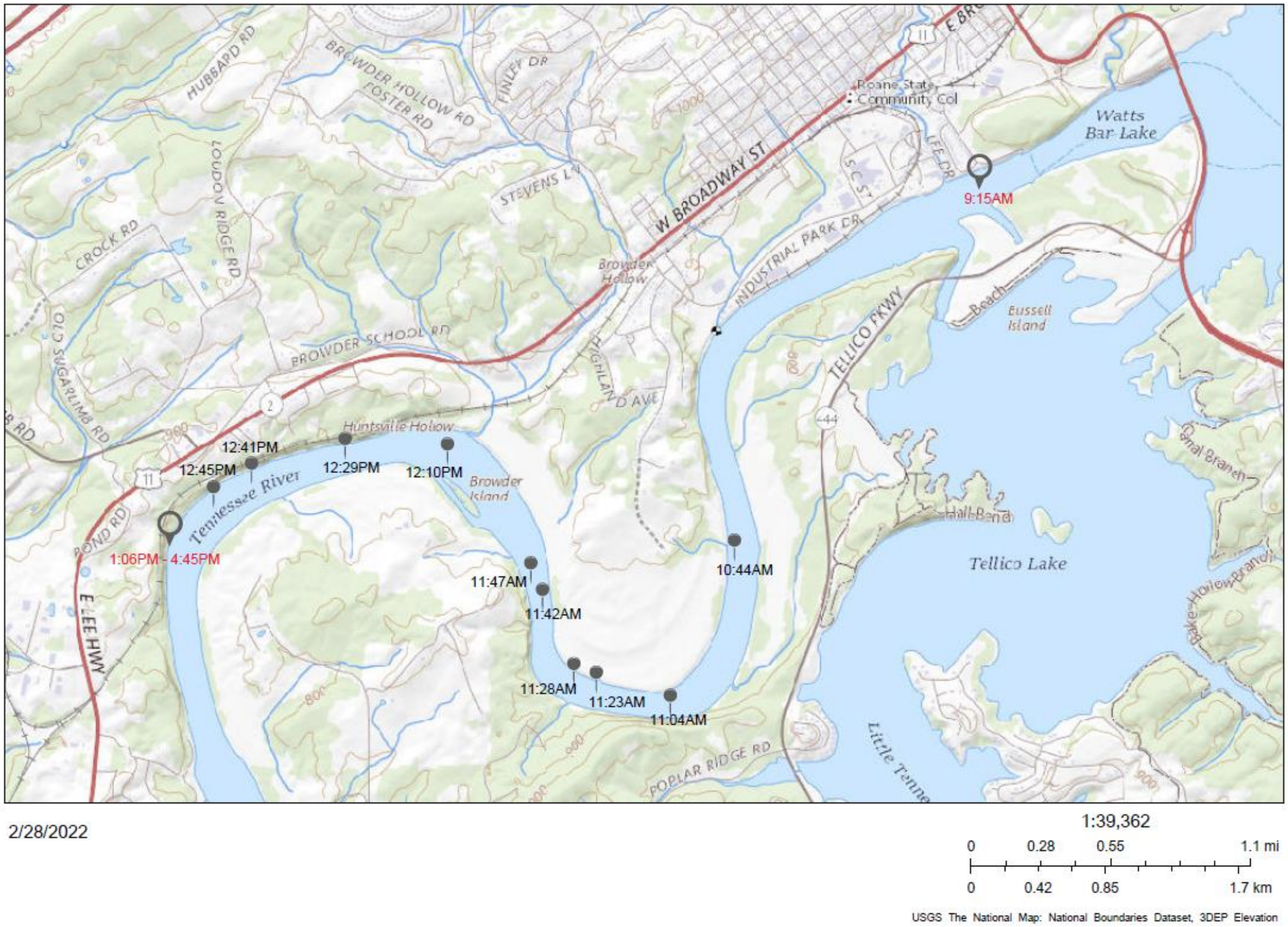


Figure 53. Clothed Manikin Travel Path Along Riverbank at Fort Loudoun Dam on February, 25, 2022

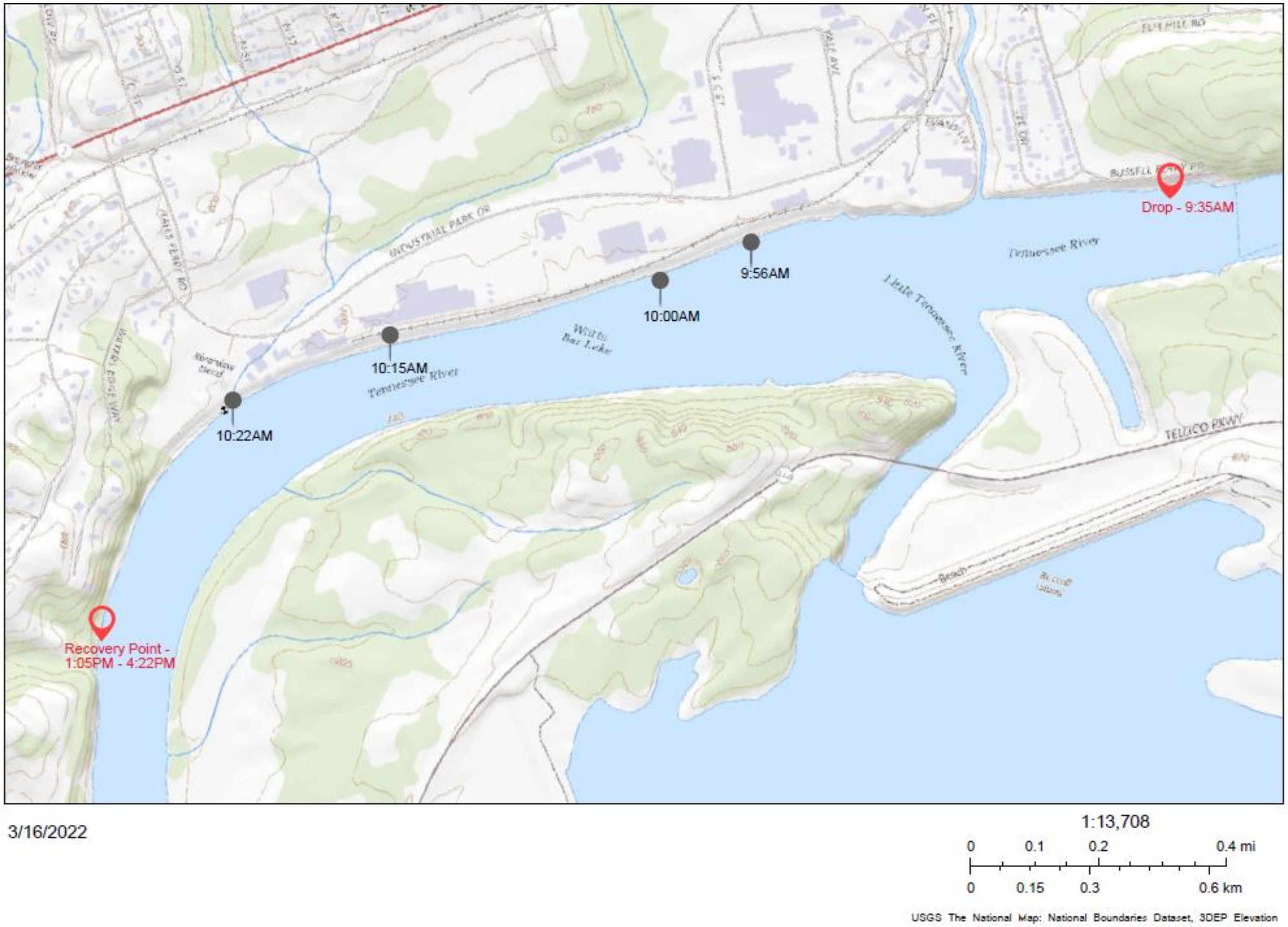
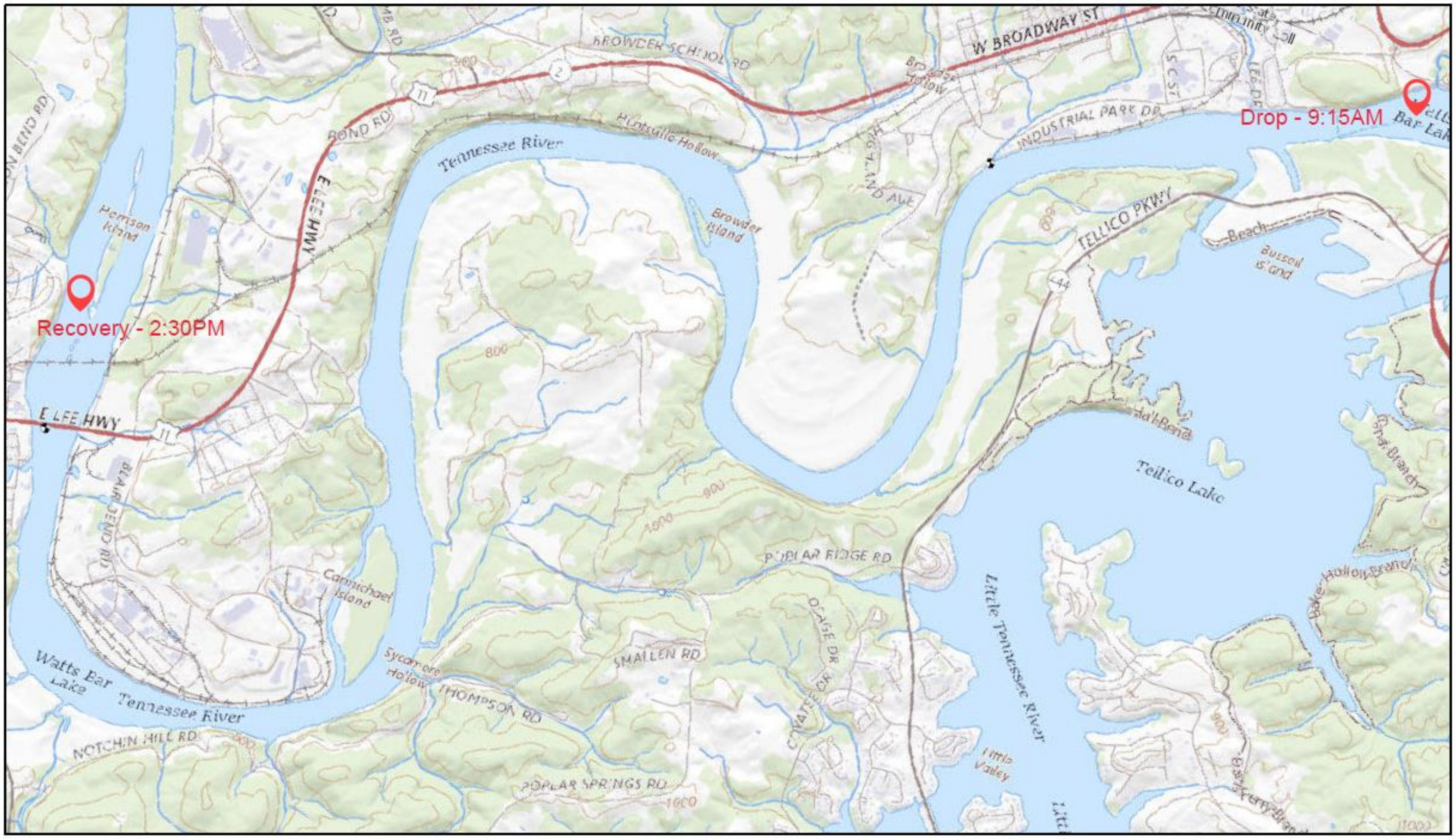


Figure 54. Unclothed Manikin Travel Path Along Riverbank at Fort Loudoun Dam on February, 25, 2022



3/10/2022

1:41,777

0 0.33 0.65 1.3 mi

0 0.5 1 2 km

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census

Figure 55. Clothed Manikin Travel Path in Center of River at Fort Loudoun Dam on March 3, 2022

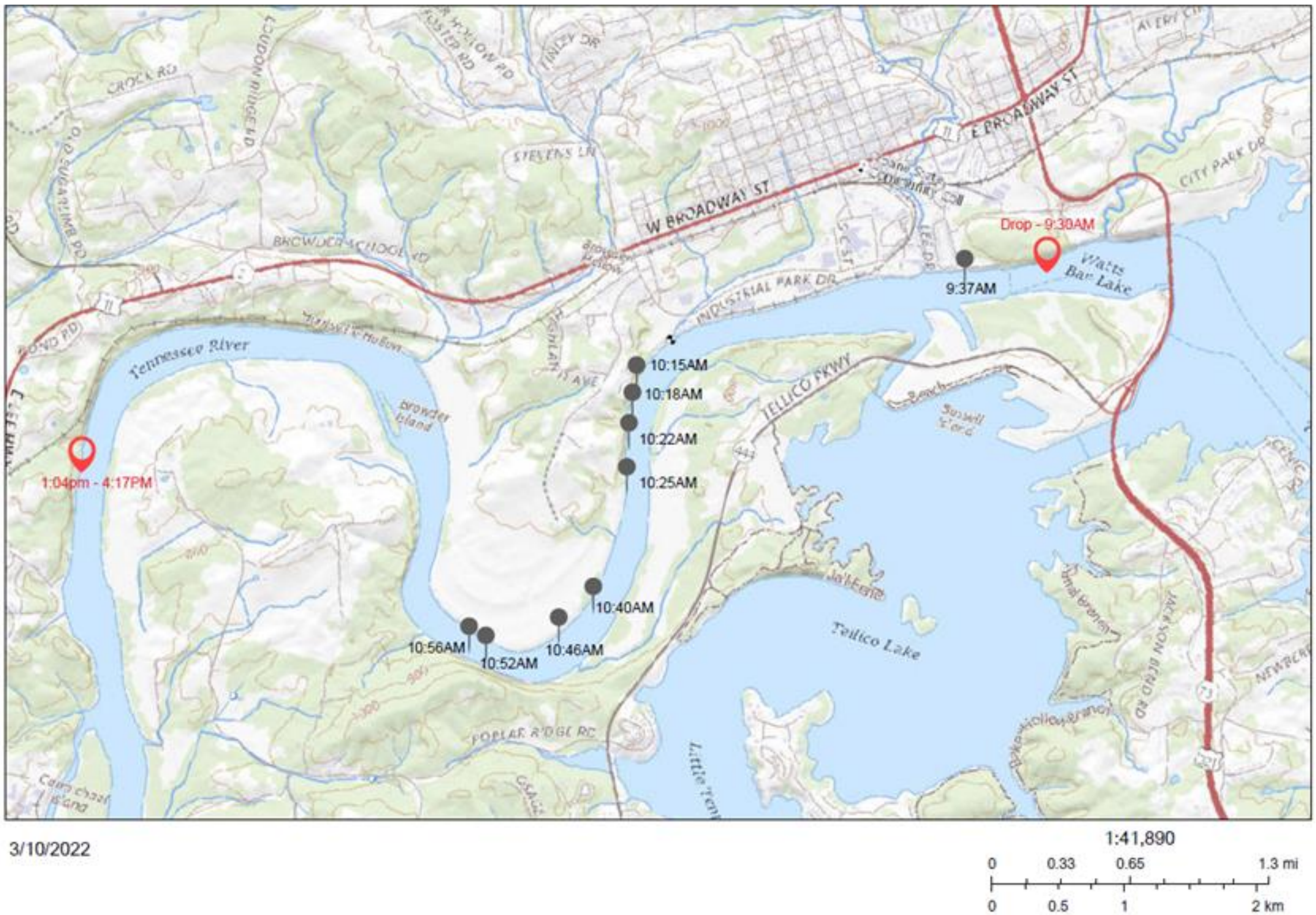


Figure 56. Unclothed Manikin Travel Path in Center of River at Fort Loudoun Dam on March 3, 2022

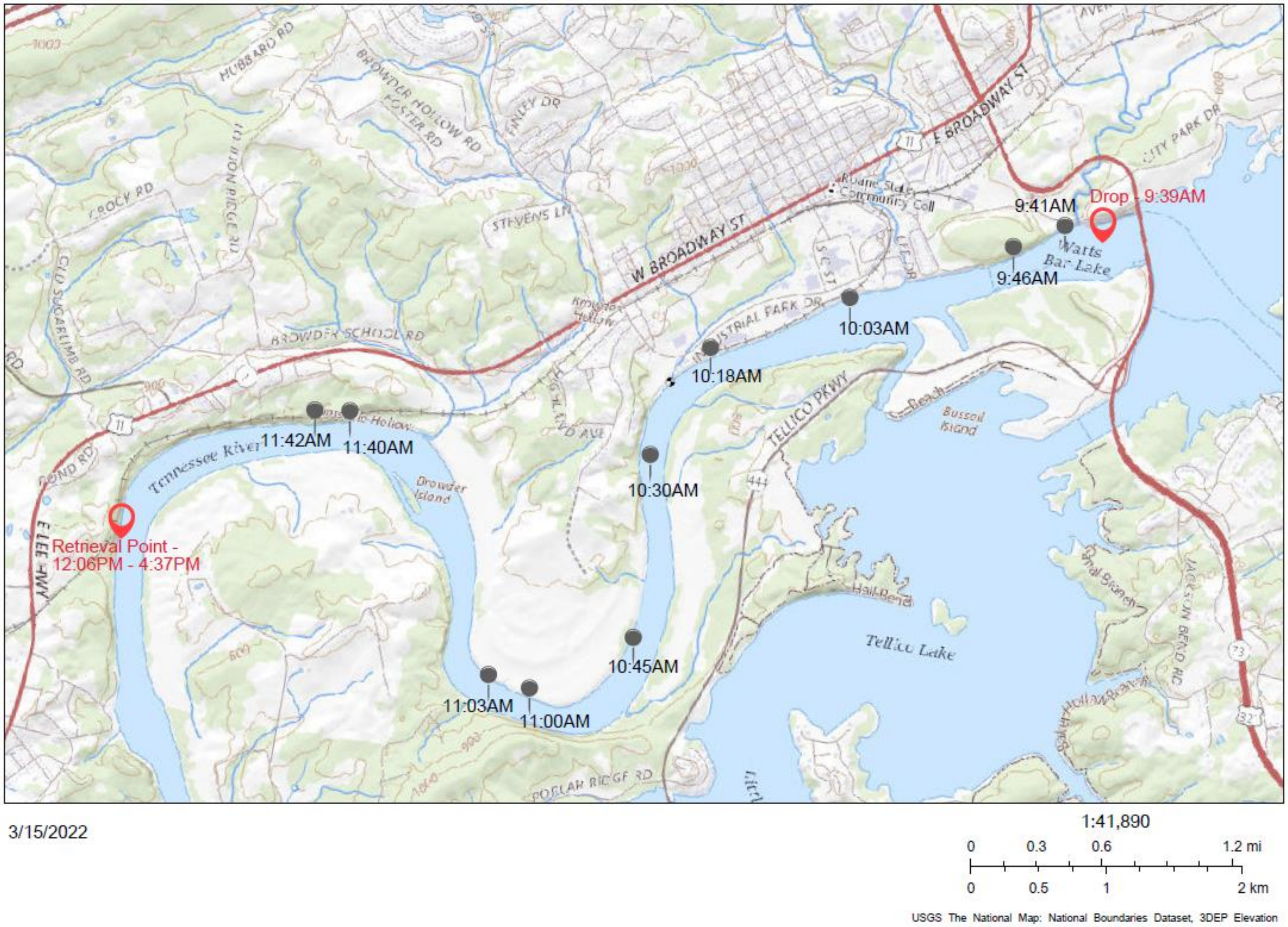


Figure 57. Clothed Manikin Travel Path in Center of River at Fort Loudoun Dam on March 11, 2022

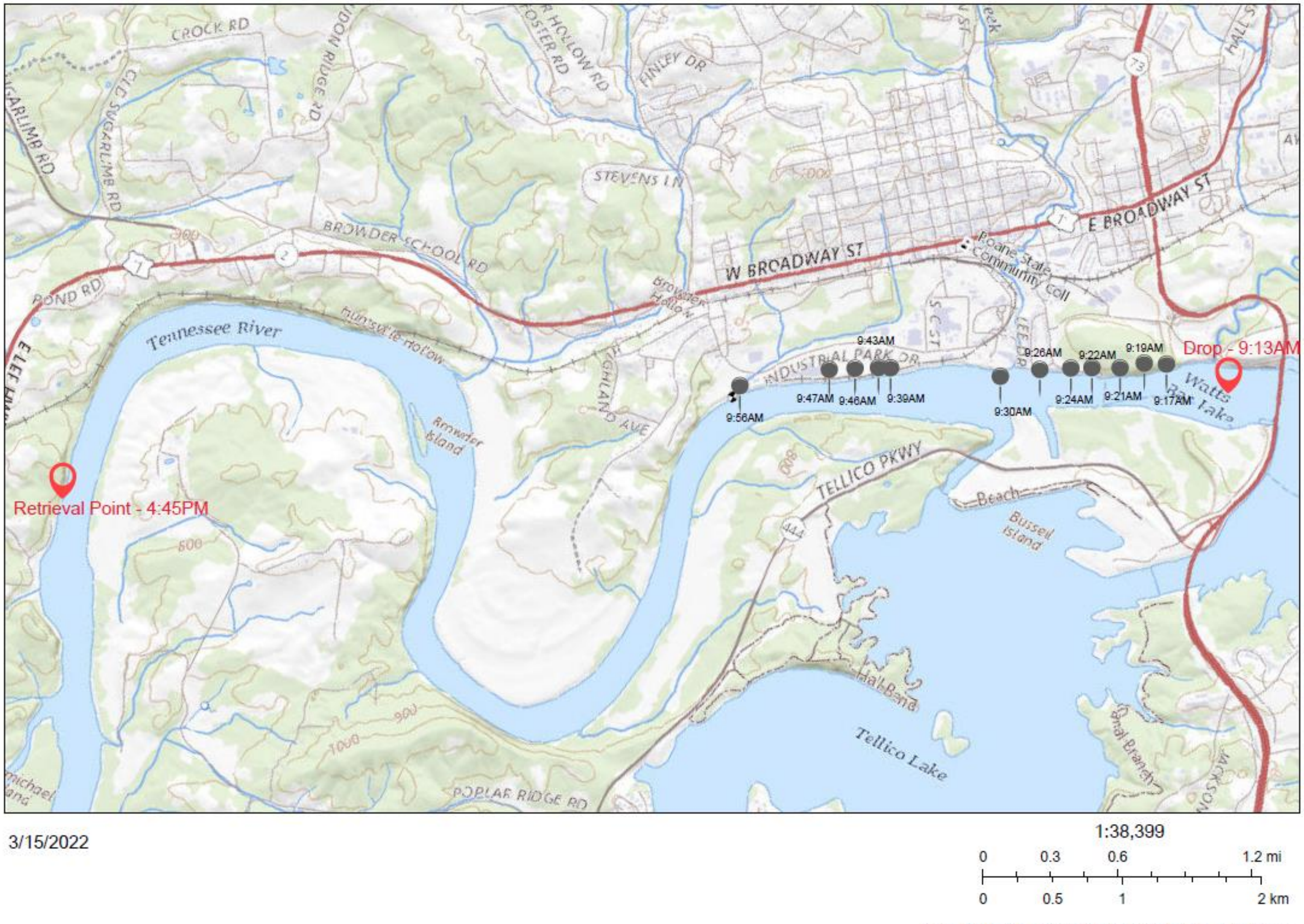


Figure 58. Unclothed Manikin Travel Path in Center of River at Fort Loudoun Dam on March 11, 2022

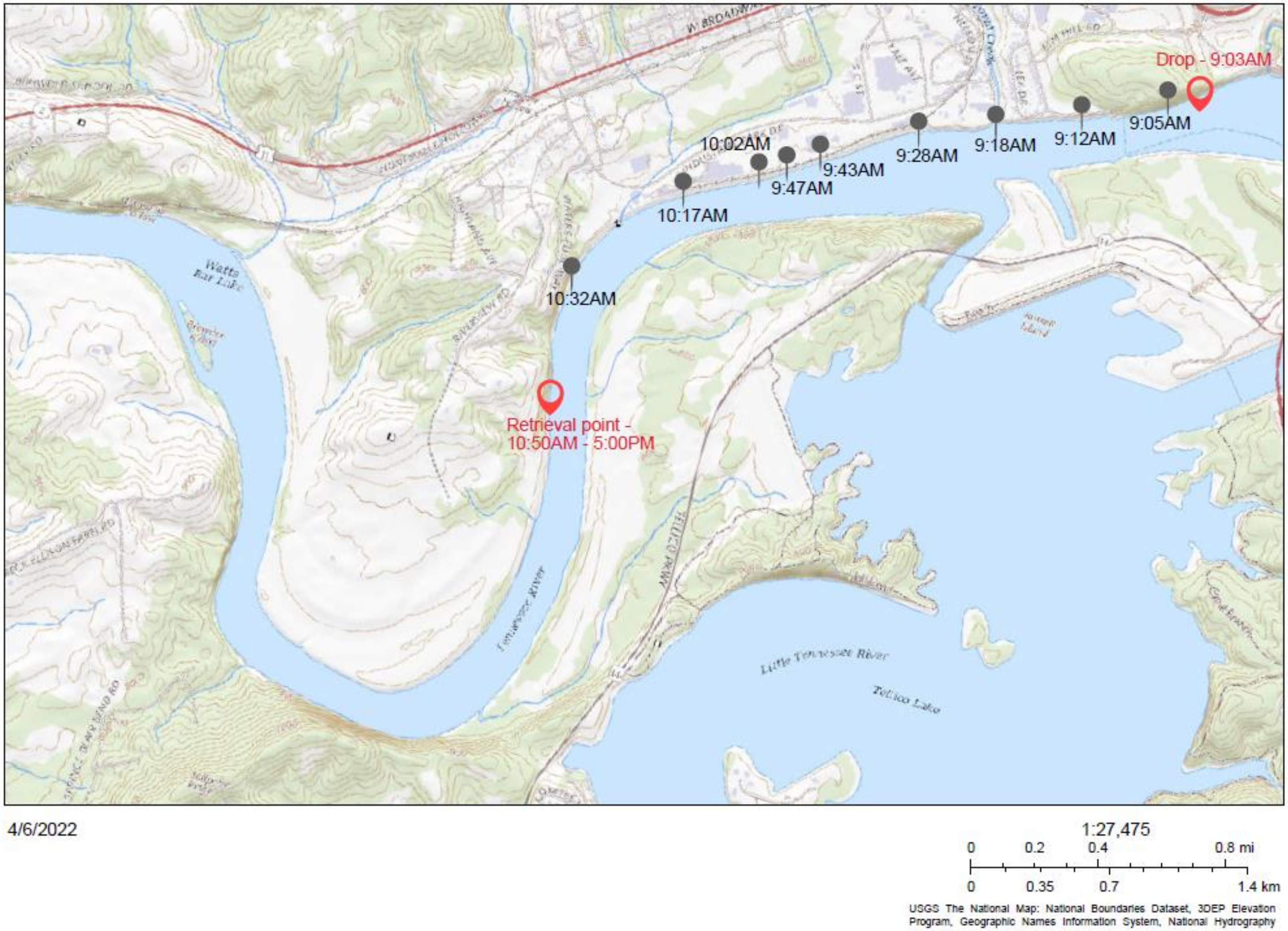
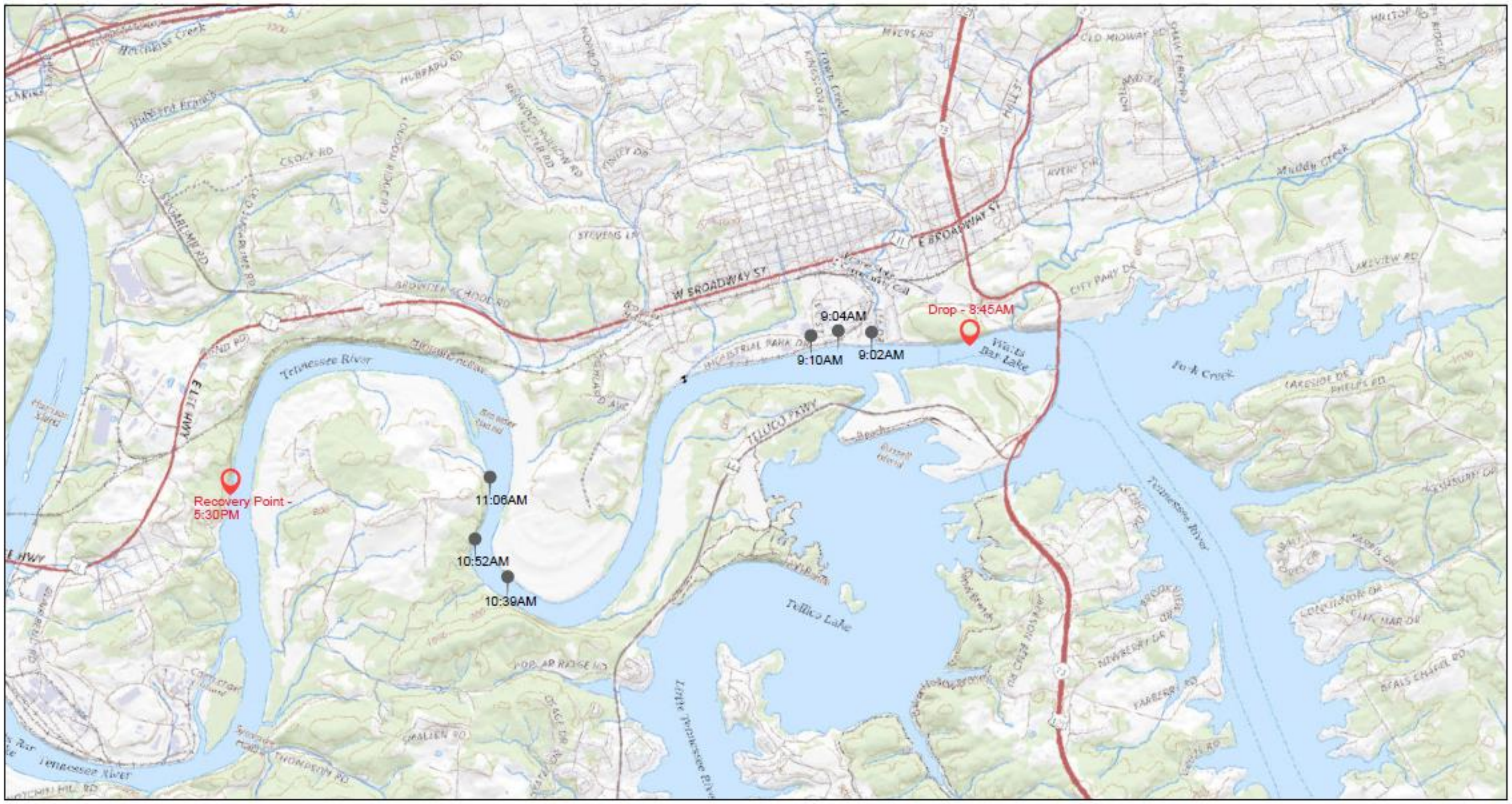


Figure 59. Clothed Manikin Travel Path Along Riverbank at Fort Loudoun Dam on March 25, 2022



4/6/2022

1:41,209

0 0.47 0.95 1.9 mi

0 0.75 1.5 3 km

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS

Figure 60. Unclothed Manikin Travel Path Along Riverbank at Fort Loudoun Dam on March 25, 2022

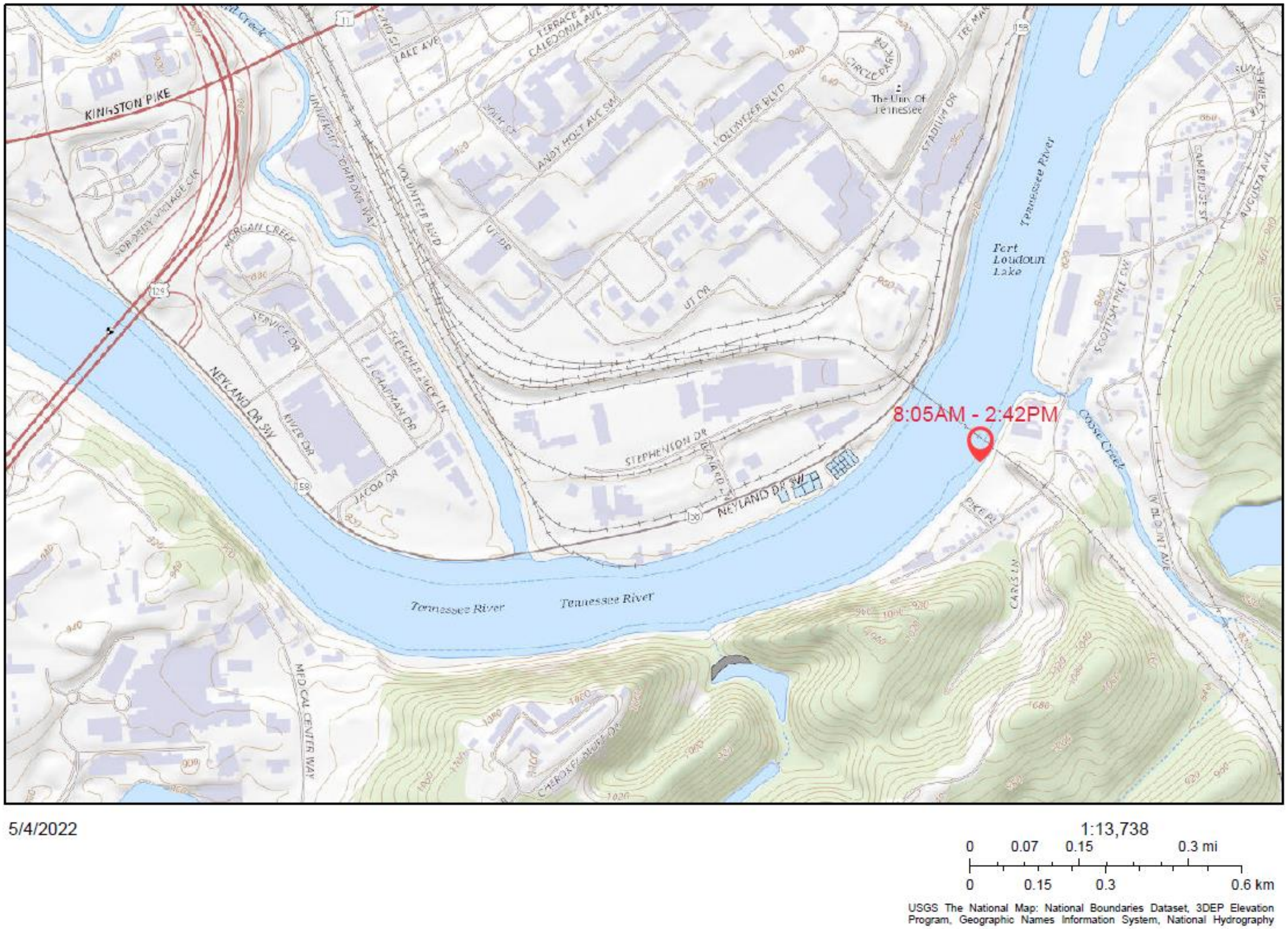


Figure 61. Travel Path of Sunken Manikin at Scottish Pike Park on October 8, 2021.

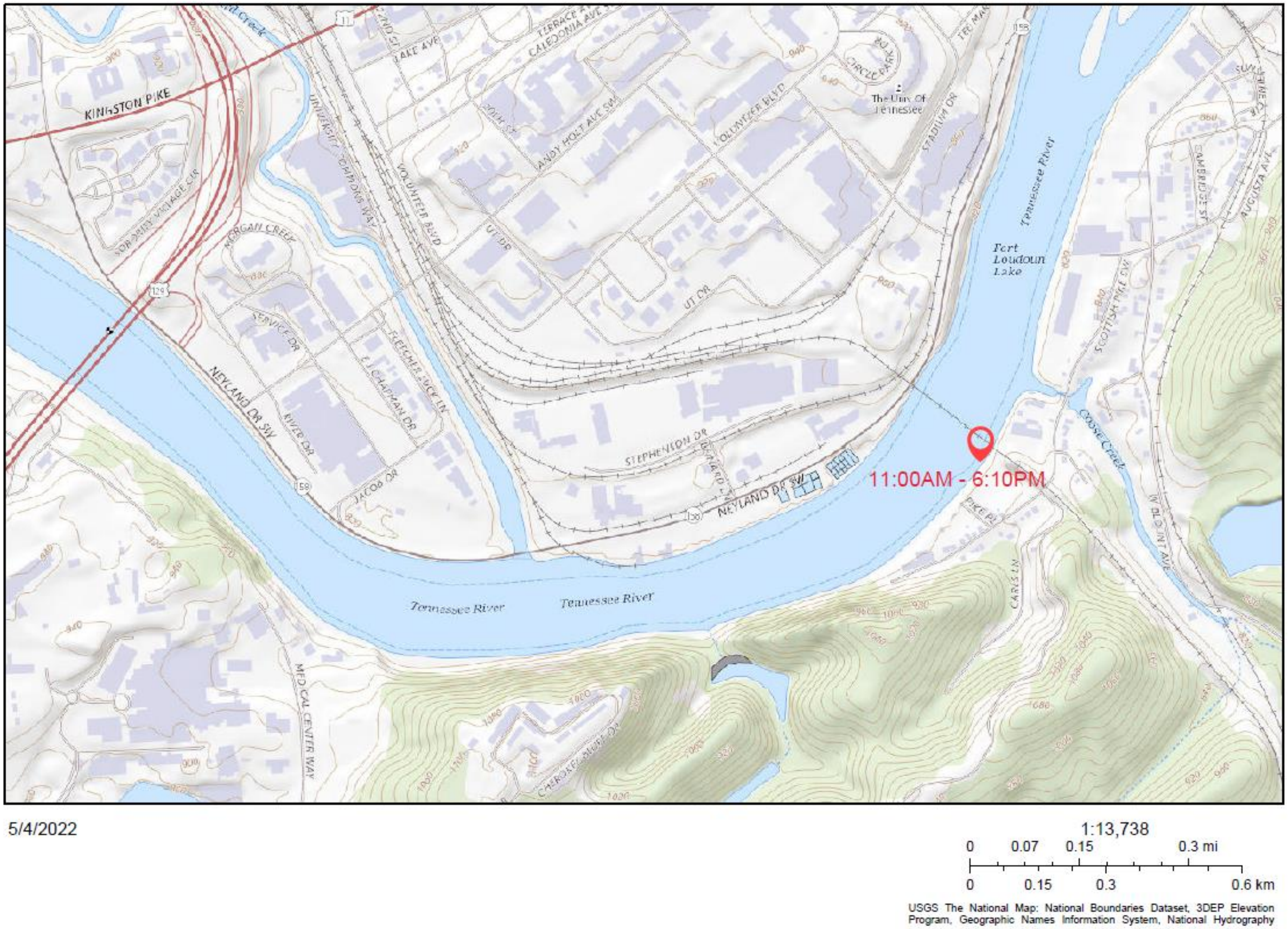


Figure 62. Travel Path of Sunken Manikin at Scottish Pike Park on April 13, 2022.

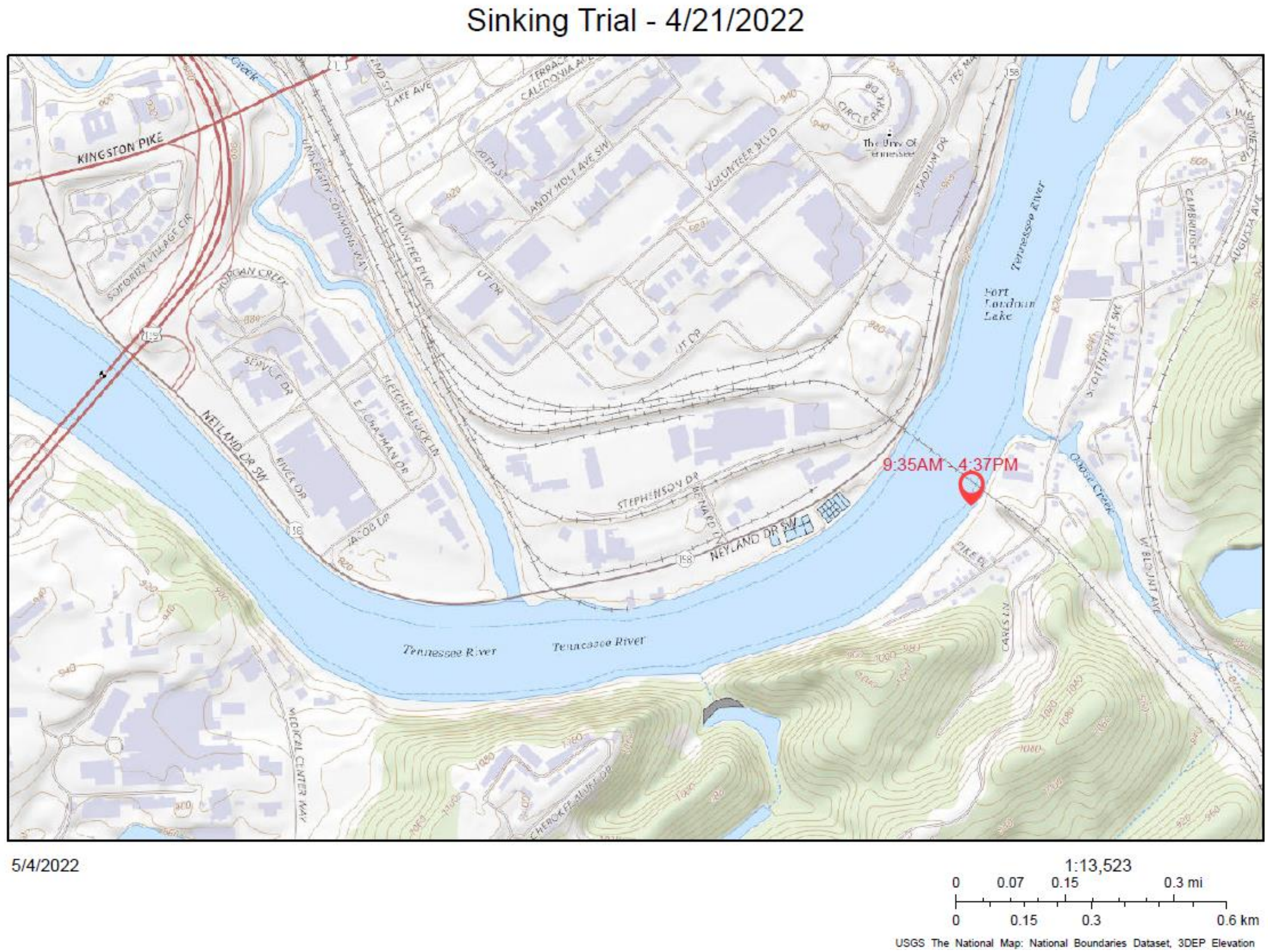


Figure 63. Travel Path of Sunken Manikin at Scottish Pike Park on April 21, 2022.

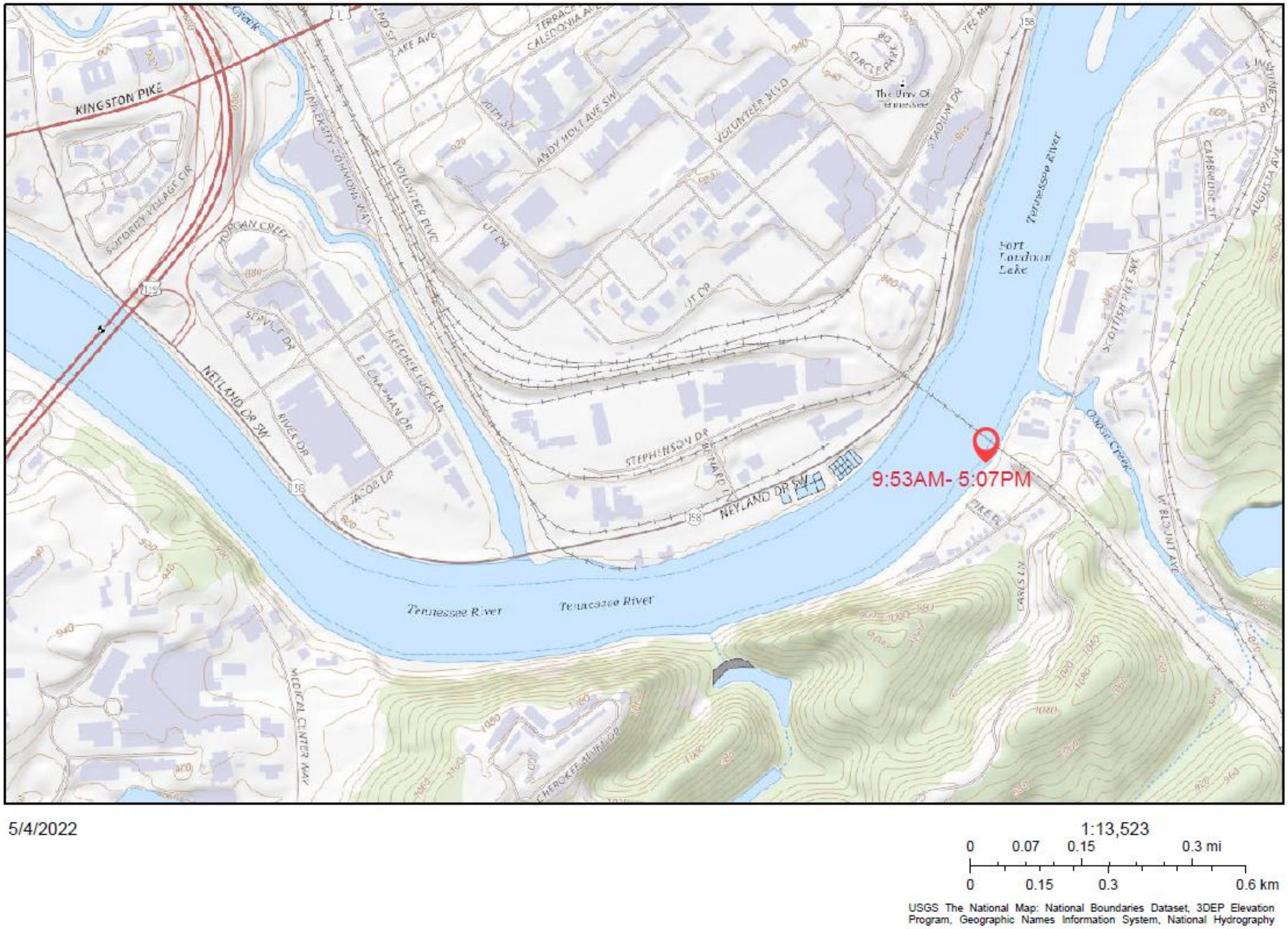
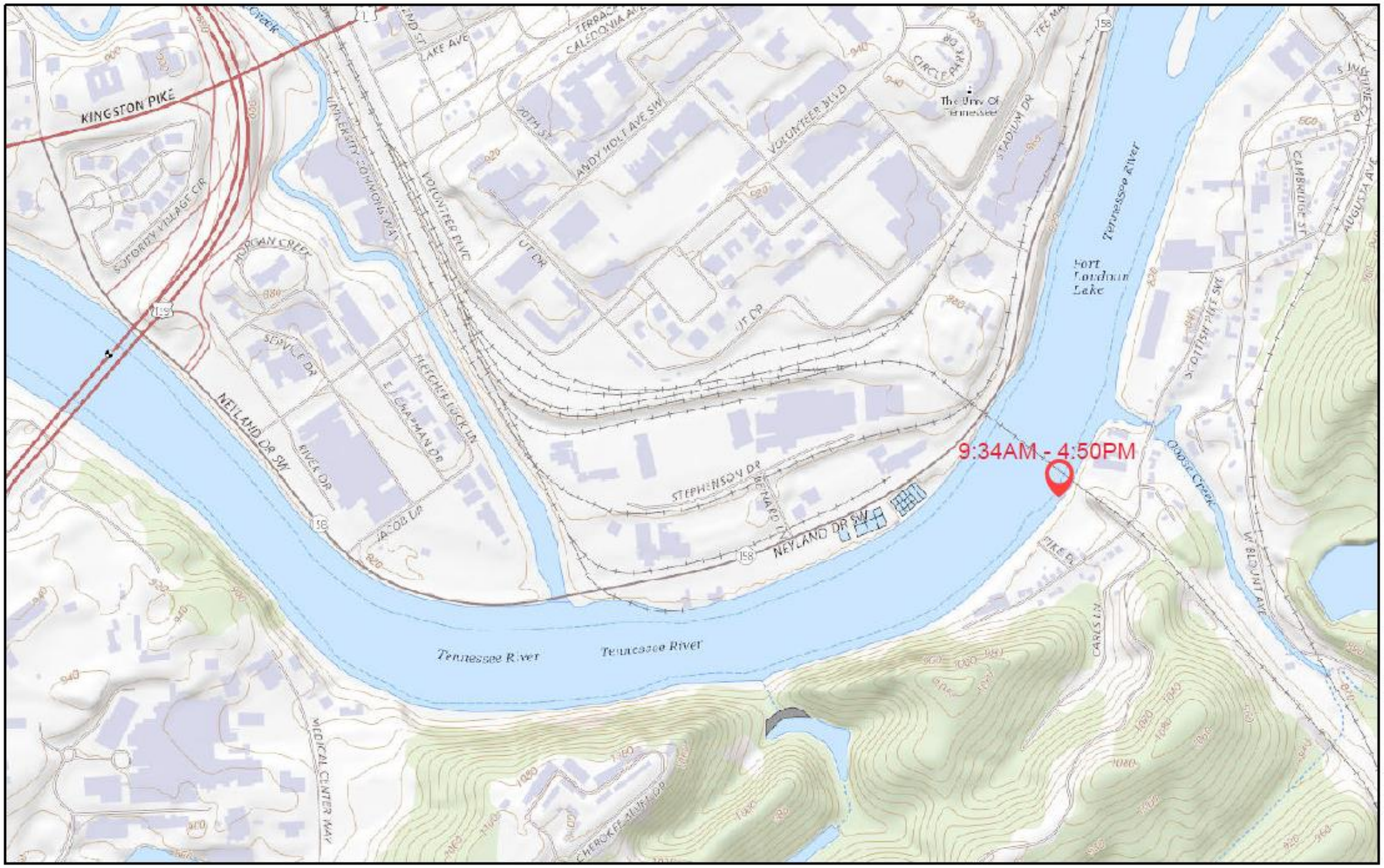


Figure 64. Travel Path of Sunken Manikin at Scottish Pike Park on April 22, 2022.



5/4/2022

1:13,523

0 0.07 0.15 0.3 mi

0 0.15 0.3 0.6 km

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography

Figure 65. Travel Path of Sunken Manikin at Scottish Pike Park on April 29, 2022

Appendix B: Lessons Learned from Test Trials

Prior to performing the official trials discussed in this thesis, several practice trials were carried out for the purpose of making sure all equipment was functional and trouble-shooting any unforeseen issues. These practice runs occurred over the summer of 2021 with the assistance of Knox County Rescue in the Knoxville area, and illustrated several patterns and obstacles that should be considered by researchers attempting to replicate the experiments performed in this thesis.

Sensor Data Storage

For the experiments discussed in this thesis, data collected by the sensor was stored on an SD card and then uploaded to a computer after each trial. However, the STEVAL-STLCS01V1 also has the capability of uploading data directly to the cloud in real-time during trials. If this method were performed, data loss from the sensor dying before running the process which saves the data to the SD card would not have been an issue. However, two issues prevented uploading data to the cloud in real-time from being a viable strategy. For one, tests performed with the manikin at the UT Aquatic Center demonstrated that, when uploading to the cloud, the sensor demonstrated the same problems inherent with GPS. If the manikin was further than two feet under the water, the signal allowing the sensor to transmit data to the internet was blocked. This made data collection using the cloud method nearly impossible for sinking trials. Either the manikin would have had to be placed in water only two feet deep, or the sensor would have had to be placed in a buoy like the phone GPS was for the sinking experiments that were carried out. The buoy method would not have provided accurate sensor data. If the sensor was placed in the buoy, it would be detecting small changes in the position of the buoy itself throughout the trials, rather than of the manikin. This made the SD card method a more viable choice for sinking trials.

Originally, floating test trials conducted on the river were still carried out using the method of uploading sensor data to the cloud. However, this illustrated another issue. Even if well populated areas of Knoxville such as near the downtown area, cell signal (and by extension, internet connection) was not available in the center of the river most of the time. This caused uploading sensor data to the cloud to be problematic during floating trials as well. Thus, the decision was made to store data on the SD card.

Conducting Trials in the Knoxville Area

Though floating trials were ultimately carried out in the Loudoun County area of the Tennessee River, several locations were tried out in the Knoxville area during test trials. Initially, floating trials began at Suttree Landing Park, which is across the river from the downtown area. It was quickly discovered that a manikin placed in this location would almost always wash up less than a mile a way into a pile of trash behind a Calhoun's restaurant. This area is also directly next to Neyland Greenway, which is highly populated by people walking, biking etc. during the summer. This exposed the manikin to a high chance of being seen and moved either by curious pedestrians, or by staff from Calhoun's (which actually occurred). Thus, it was determined that floating the manikin too close to the downtown area would be risky, and that it should be placed further downstream. A location that worked much better when attempted was placing the manikin near Sequoyah Park. In this location, river flows next to several less populated parks and private properties and was less at risk of being trifled with. Though official trials for this project ended up being performed in Loudoun County, this may be an interesting location to investigate in the future.

Importance of Labeling Manikins and Notifying Dispatch

Finally, both test trials and the actual trials demonstrated the importance of taking two precautionary measures: dispatch (or at least the rescue crew in the area) should always be notified of when a trial is being conducted, and manikins should always be labeled when placed in the water. Boaters, fishermen, and pedestrians will absolutely call emergency services when they see a body-shaped object in the water. Many people will often not want to take a closer look to make sure it is indeed a real body, and will simply call it in. For example, during one test run with Knox County Rescue in Knoxville, an individual saw a trial being carried out and reported to dispatch "a pontoon boat dragging a naked dead body behind it." Dispatch was able to radio the boat and confirm it was simply the experiment they had been notified of. However, if they had not been notified in advance that the trial was being conducted, they probably would have thought it was an actual emergency.

Additionally, the manikin should be painted or have some other relatively waterproof label on it when placed for a trial. During this experiment, “Property of UTK Anthropology; Do Not Touch” was painted on both the back and the front of the manikin’s torso in large letters. The words were written on with a Sharpie paint marker and then touched up with a layer of boat paint. These warning labels must be re-touched around every five trials or once they are obviously getting scratched/washed off to the point they are illegible. Not only do they remind emergency personnel of the experiment if they do get called out to check; these labels also can prevent the manikin from being stolen. For one of the trials at Fort Loudon Dam, a group of boaters found the manikin and wanted to place him on their boat deck as a decoration but called the fire department instead once they saw that the manikin belonged to the university. Of course, in the event that someone did take the manikin home with them, the GPS tracker would show its location, but retrieving the manikin in that case would certainly be awkward for all involved. Thus, the importance of labeling the manikin should not be overlooked.

VITA

Karli Palmer is originally from Connecticut and received her Bachelor of Science in Anthropology from Southern Connecticut State University in May 2019. She then chose to attend the University of Tennessee, Knoxville to pursue a Master of Arts degree in Anthropology with a concentration in Biological Anthropology. Her primary research interests include, human decomposition in aquatic environments, human gross anatomy, bioarchaeology, zooarchaeology, taphonomy, paleopathology and mass grave excavations, particularly in the context of genocide and other human rights violations.