TRACKING MILITARY MANEUVER TRAINING DISTURBANCE WITH LOW COST GPS DEVICES

by

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Abstract

Military training lands are a vital resource for national security and provide crucial habitat for a number of threatened and endangered species. Military land managers must manage the land in accordance with federal environmental policy and regulation, while simultaneously providing the lands needed for training military forces. Off road maneuver training can cause significant environmental damage including removal of vegetation, compaction of soils, increased erosion, loss of habitat, and degradation of the landscape to a point of not being useful for continued military training.

Various techniques have been developed to help the military land managers determine a sustainable training level for the landscape. Many of these techniques have limitations in the spatial resolution of data collected and the ability to provide timely and accurate assessments of training disturbance. Advancements in GPS and GIS technology over the past two decades have shown the potential to fill this knowledge gap.

In this study low cost civilian off the shelf (COTS) GPS devices were accuracy tested to determine their capability to provide reliable and accurate military vehicle locations during training (1.93 m CEP, 4.625m 2dRMS). The GPS data collected from COTS devices on three battalion training exercises at Fort Riley, KS were processed in a GIS and statistically analyzed to compare and contrast several off road maneuver metrics (speed, turning radius, distance traveled) by vehicle type tracked, and by platoon in order to determine if units or vehicle types could reliably explain the variation in these metrics. Lastly, a method of mapping the relative environmental disturbance was developed and mapped for the same data sets. Wheel sinkage was used as a measure of disturbance, it was calculated at each GPS point based on vehicle type and soil conditions then mapped in using a fishnet grid for Fort Riley, Kansas.

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Dedication

This work is dedicated to the special women in my life. With the support of my wife, mother, and daughters I have been able to accomplish far more than I would have on my own limited abilities.

Preface

The thesis is an original unpublished work by the author, Phillip Denker. As an active duty US Army Officer I have brought knowledge of military systems that are unfamiliar to many of the researchers working in this field currently. Prior to starting this research I had spent the last eight years as a platoon leader, executive officer, and company commander for U.S. Army maneuver units at Fort Hood, Texas, Fort Riley, Kansas, and various locations in Iraq. My military experience has been relied on heavily in drawing conclusions and recommendations, but are only personal experiences, and should not be assumed to be wholly representative of knowledge on U.S. Army maneuver or maneuver training.

My deepest appreciation and admiration is given to those who have worked so diligently furthering our knowledge of environmental conditions specifically maneuver disturbance on military lands and my conclusions and recommendations while conflicting with some previous ideas are meant to help facilitate our understanding, not disparage previous work.

Chapter 1 - Introduction

The U.S. Department of Defense (DoD) requires a variety of landscapes to allow military units to conduct a broad spectrum training to prepare for ongoing and future missions. The DoD “manages and protects over 425 federally-listed species and over 500 species at risk” on roughly 28 million acres across 370 military installations (Department of Defense, 2011). The U.S. Army alone is responsible for nearly half of the total land (12 million acres). Much of the land used by the Army for training is susceptible to damage as a result of off-road maneuver training. There is a direct correlation between off-road military training and environmental conditions on military lands. Disturbance by military vehicles includes increased soil compaction, reduced soil moisture, reduced soil carbon, reduced vegetative cover, restricted root development, increased erosion, spreading of invasive species and gully formation (Althoff et al., 2007; 2010; Anderson et al., 2005; Diersing et al., 1988; Goran et al., 1983). The damage caused by off-road training can reduce the viability of the land for conducting future training and can result in injuries to soldiers attempting to maneuver on areas with unexpected gullies and increased likelihood of flash flooding. This study will test the effectiveness of low cost commercially available technology to collect data on off-road military maneuvers.

The Military Mission

The lone mission of the DoD is “to provide the military forces needed to deter war and to protect the security of our country” (Department of Defense, 2013). Under this overarching mission there are a variety of mission sets directed to each military service to ensure the DoD meets its mission. While each service has a separate mission they all have similarities in mission constraints. One large constraint placed on the services as they strive to be successful in their missions is resource availability. The services are all limited by economic and natural resources. The budgets of each of the services are continuously stretched to meet demands, and natural resources are limited and must be used in a sustainable manner in order to meet future needs.

Department of Defense Land Management

The DoD Natural Resources Program is designed to support the military mission by providing "continued access to realistic habitat conditions, while simultaneously working to ensure the long-term sustainability of our nation's priceless natural heritage" (Department of Defense, 2011). According to the 2012 Department of Defense Report to Congress on Sustainable Ranges:

"…sustaining a diverse set of range resources is critical to ensuring readiness and military effectiveness. Using realistic training ranges allows DoD to:

1. Foster the development and maintenance of operational proficiency and mission readiness
2. Enable increased force operational survivability and mission success
3. Provide realistic environments needed for the development of tactical operational and strategic concepts, as well as tactics, techniques, and procedures (TTPs)
4. Support the testing, evaluation, and improvement of system maneuverability, reliability, and effectiveness in the range environment outside of the laboratory or development facility."

Within the framework of DoD land management there are two main stakeholders. The first are the military land managers who are tasked with ensuring the sustainability of the resources and compliance with environmental regulations. The second are the service members who train on the DoD lands. These two groups have historically had very different perspectives on the nature of the land and its use.

Military Training Lands: A Natural Resources Management Approach

Military lands usage varies significantly from other land use types. Some lands are heavily impacted by intense off road training, while other lands on an installation may only be subject to projectile impact from weapons, but see no other use. The intermittent use of military lands for training, and the desire of military leaders to have multiple landscapes for training different types of units and mission scenarios, has resulted in military training lands that are often more representative of historic natural conditions than adjacent lands. Military lands are often not developed or placed in agricultural usage to the degree of many other lands. As military lands have been preserved they often provide substantial habitat for diverse flora and fauna along with substantial cultural and archeologically significant sites (Stein et al., 2008). Army lands often are over represented in numbers of endangered species and species of concern (Stein et al. 2008), which makes it even more important for land managers to adequately manage the resource. Land managers have the task of managing these species and meeting other government policy and regulation while balancing the military mission requirement. The mission of military land managers is to provide the lands needed for training of military units while simultaneously managing the lands for ecological sustainability. The DoD has specified that each military installation with significant environmental and cultural resources will develop and maintain an Integrated Natural Resources Management Plan (INRMP) (U.S. Department of the Army, 2005).

Military Training Lands: A Warfighter's Approach

To best meet the warfighter's mission they must train in realistic environments and under a variety of environmental conditions. The warfighter's approach to training lands in the short term may come into direct conflict with ecological best management practices. For example, from an environmental standpoint it may be best to avoid training during intense rain as it could remove vegetation and increase erosion, but from a warfighter's standpoint, training during various environmental conditions prepares the warfighter for the conditions that may be faced in battle and is paramount to mission success. This concept is furthered by a common adage in Army training "if it ain't rainin', you ain't trainin." The warfighter's view of military land is as a tool to be used during training for future real world missions. This is not to say that the warfighter's approach does not consider sustainability and ecologic diversity, quite to the contrary, the newest environmental strategy for the Army for example is "Sustain the Mission – Secure the Future". The premise of this strategy is that in order for the Army to continue its mission of providing land forces necessary to meet the mission, it must use sustainable business and environmental practices in order to have the resources needed to train now and into the future (U.S. Army, 2004).

There are at least three main areas where the condition of the environment directly impacts the military mission: training area availability, economic costs of training lands, and safety when operating on the landscape.

Training Area Availability

Training area availability is of primary concern to the military user. If the continued use of training lands is unsustainable, lands will become unavailable thereby limiting opportunities for realistic training. Overuse of training lands can lead to training areas that do not meet the needs of the user such as areas devoid of vegetation, areas with substantial gully formation, or flood prone areas. Military users may also see reduced training area availability if training areas are being rested to allow for recovery after severe disturbance. As some areas are overused and become less desirable or unavailable for training, the remaining lands could see higher training intensities thereby creating an unsustainable training intensity feedback loop resulting in a degradation of all quality training areas.

Cost Associated with Maintaining Relevant Training Sites

There are considerable costs associated with maintaining quality training lands for military use. The overall environmental funding for the Army for FY 2010 was $1.48 billion and $1.10 billion in FY 2011, of which nearly 50% went to restoration programs (Department of Defense 2012).

Training Area Safety

The safety of soldiers is paramount to military success. Soldiers are often required to conduct dangerous missions, but military leadership at all levels is focused on soldier safety. Soldiers are injured during training each year; some of those injuries can be directly attributed to training lands that are not managed properly. The US Army Sustainability Report for 2012 indicated that on duty ground accidents were between 2.236 and 2.827 per 1000 Soldiers between fiscal years 2009 and 2011, with fatalities occurring at a rate of 0.040 to 0.052 (U.S. Department of the Army, 2012). While some of these accidents are not occurring due to unsafe conditions on training areas, a small percentage of them are.

*During the course of this research, two training area related accidents occurred within the three tracked units resulting in soldiers receiving medical attention at a military hospital.

Study Motivation

This study was designed to demonstrate a cost effective means to provide valuable spatial, tactical and ecological information to various stakeholders engaged in the use and sustainability of DOD lands.

There currently is a void in knowledge that exists between the land managers and military land users that may be able to be bridged with low cost existing technology. The void consists of a lack of understanding of where, when and how the land is being impacted by military users. Land managers armed with this knowledge would be better prepared to provide sustainable, safe, quality training lands for the military users. Military land users with this information could better understand the costs associated with their actions and adjust accordingly.

Using low cost readily available passive GPS devices to track military off-road vehicle maneuver and then analyzing and processing it in GIS could provide valuable data needed by both land managers and land users at all levels. Some examples of ways the data could be used are:

- Environmental impact assessments
- Endangered species conflict assessments

- Military maneuver After Action Reviews (AAR)
- Development of military simulations
- Understanding of tactical land use requirements
- Land use intensity mapping
- LRAM project identification
- Help in identification of proper land types for existing and future training requirements
- After accident investigations & safety training assessments

This study will test a selected low cost civilian produced GPS device for accuracy, ability to collect relevant data, ease of data processing and applicability to the needs of land managers and land users.

Chapter 2 - Background

Military training lands are often degraded by select training activities. The degradation of the lands is dependent upon the type of training being conducted, the condition of the land prior to the training and the existing climatic conditions at the time of training. The department of defense employs military training land managers, engineers and environmental managers who have the role of ensuring military lands comply with federal environmental regulations and also provide sustainable lands that meet the military's continuing need for training lands. This literature review will first discuss how military maneuvers cause disturbance, then discuss current methods being used by land managers to estimate training related disturbance, and finally conclude with a review of GPS technology's introduction into the study of military maneuver disturbance.

Military Maneuver Disturbance

In order for military land management professionals to determine the best management practices and possible impacts from future training they must understand the interactions between specific training events and the landscape. Some military training disturbance regimes may be localized allowing easy assessments of the impact on the landscape such as the impact of the use of a small arms range over several acres of land or the direct impact of a vehicle crossing a stream. Other military training disturbances may be spread over large portions of the landscape with varying degrees of use such as noise pollution from aircraft or impacts of large munitions. The main focus of this research is on the impact of off road maneuver training on the landscape which often falls in the category of large wide spread disturbance. In order to understand the impacts of military training over these large scale disturbance regimes, land management professionals and researchers must have knowledge of what kind of disturbance is occurring as a result of the training.

Environmental Effects of Off Road Maneuver Training

Numerous studies have been conducted to determine military maneuver training disturbance. Direct impact from off road travel by military vehicles has detrimental effects on environmental conditions. Researchers have shown various degraded environmental conditions resulting from off road military vehicle training (Althoff et al. 2007; Althoff et al. 2010; Ayers 1994; Fehmi et al. 2001; Goran et al. 1983; Leis et al. 2005; Lindsey and Selim 2012; Milchunas et al. 1999). Changes to soil properties, flora and fauna as a result of off road military maneuver training are reviewed below.

Maneuver Impacts on Soil Physical Properties

Off-road vehicle traffic has the ability to change soil physical properties (Alakuku et al. 2003; Althoff et al. 2007; Althoff et al. 2010; Thurow et al. 1993). Soil compaction is an immediate, measureable and long lasting impact of off-road vehicle traffic (Abu-Hamdeh et al. 2000). Of all impacts of off road vehicle traffic, changes to soil properties are likely the most significant due to the impact soil changes have on other factors of ecological function. For that reason, more time will be spent in this thesis on this topic than any of the other impacts of off-road maneuver.

Military vehicles interact with the soil both at the surface and at depth through stress strain relationships. At shallow depths, studies have shown that military vehicles remove soil layers thru shear stresses caused by the slipping of the wheel lugs or tracks against the surface of the soil (Althoff et al. 2010; Ayers 1994; Haugen et al. 2003a).

Machinery induced subsoil compaction has also been shown in multiple studies (Abu-Hamdeh et al. 2000; Alakukku 1996; Althoff et al. 2007; Ampoorter et al. 2010; Brais and Camire 1997).

According to Hillel (2004) compaction is the densification of an unsaturated soil by the reduction of the fractional air volume. Lal and Shukla (2004) further refine the definition to "a process leading to compression of a mass of soil into a smaller volume and deformation resulting in decrease in total and macroporosity and reduction in water transmission and gaseous exchange." Compaction of soils results primarily in the loss of air filled volume in the soil, as the soil particles and water are under normally observed stresses incompressible (Lal and Shukla 2004).

The initial soil characteristics have a large effect on subsequent soil compaction. Of the initial soil characteristics, soil moisture is arguably the most important factor in the determination of compactibility of the soil (Althoff et al. 2010). Althoff et al. (2010) found areas that had higher moisture showed significantly more damage than areas that were drier at the time of tracking by an M1A1 Abrams tank. With little water present in a soil, the dry soil particles are in direct contact and the force required to overcome the particle to particle contact is greater than the force required to overcome a particle to water contact (Hillel 2004). While moist soils may deform more easily, very dry soils can be compacted by destruction of the soil aggregates and breaking of soil particles (Danilova 1996). Some moisture in the soil increases the compactibility of the soil through a lubricating effect on the soil particles (Hillel 2004). There is a peak water content for a given soil when the lubrication effect is maximized but the pore filling effect has not reduced the compactibility of the soil greatly (Raper and Kirby 2006).

Lindsey and Selim (2012) list the water content at which a soil is at risk for the highest compactibility to be near the soils lower plastic limit.

Soil texture also has a relationship to maneuver training disturbance. Ampoorter et al. (2010) state “soils with a clay or silt texture are more sensitive to soil compaction than sandy soils.” This is due to the fact that larger soil particles have much less surface area and less cohesive bonds between particles. The larger particles tend to have larger pores that are highly permeable and are therefore normally found in a consolidated state. Furthermore, the larger particles have a lower overall porosity than fine grained particles reducing the total compressibility (Hillel 2004). Althoff and Thien (2005) found increased bulk density, and decreased porosity on a silt loam soil, but no significant changes to bulk density on silty clay loam.

Bulk density is the relationship of the mass of the solids within a soil to the total volume of the soil. Bulk density within a soil “determines the magnitude of particle to particle contacts” (Lal and Shukla 2004). As soils become more compacted they have more particle to particle contacts as the water and other void spaces within the soil are reduced. As the bulk density of a soil goes up the soil shear strength is increased due to more cohesion between particles and a higher internal friction angle (Mouazen et al. 2002). Bulk density of soils can be impacted by compaction, but like other compaction impacted elements, the soil characteristics at the time of the compaction impact how bulk density is affected. If a soil is dry at the time of compaction there is very little change in the soil’s bulk density. Thurow et al. (1993) found no difference in the bulk density of a dry soil tracked 10 times by a M2 Bradley fighting vehicle, but found a statistically significant increase in the bulk density of a soil tracked while wet, with the most impacted soils found in the upper 50 mm of soil. Additionally, Brais and Camire (1997) found that the bulk density increase with relation to traffic intensity was logarithmic. Althoff and Thien (2005) found increased bulk density under an M1A1 Abrams tank on a silt loam, but found no significant change in bulk density on a silty clay loam on Fort Riley.

An additional factor to consider in the disturbance of soils under off road traffic is the intensity or repetition of the force being applied to the ground. It has been found that one pass of a vehicle over a point can cause compaction; "single tracking on a compactible soil by a vehicle that is over the bearing capacity of the soil can significantly reduce the total porosity to a depth of 50 cm" (Abu-Hamdeh et al. 2000), and that the first few times the force is applied cause the most disturbance (Ampoorter et al. 2010; Raper and Kirby 2006). It has also been found that multiple vehicle passes causes increased compaction of the soil (Althoff and Thien 2005; Ampoorter et al. 2010; Raper and Kirby 2006). Once a soil has been compacted it becomes more difficult to compact further. Brais and Camire (1997) found that over 50% of all soil compaction resulted from the first three passes on course soils and first two passes on fine soils. Lindsey et al. (2012) found soil compaction of as much as 80% of maximum occurring during the first tracking by a vehicle with each additional pass over the same location causing progressively less compaction. Thus more traffic by the same stress will have a limited additional impact.

After disturbance there is a change in the hydraulic conductivity of the soil as the relict pores are no longer able to provide significant pathways for water movement through the soil reducing the ability of the water to move in saturated conditions (Halvorson et al. 2003). Infiltration has been found to be significantly reduced by compaction (Abu-Hamdeh et al. 2000; Assouline 1997; Danilova 1996; Richard et al. 2001; Thurow et al. 1993). Halvorson et al. (2003) noted that small increases in soil bulk density from compaction can result in disproportionally large decreases in infiltration. Soil moisture at the time of compaction can have an impact on the subsequent reduction in infiltration rate. Soils with very low soil moisture levels during compaction were not seen to have significantly reduced infiltration rate on one study (Thurow et al. 1993). Infiltration rate was also found to be impacted by the number of vehicle passes, with more vehicle passes resulting in further reduction in infiltration rates (Thurow et al. 1993).

As maneuver training reduces infiltration, it subsequently increases runoff and significantly increases erosion (Alakukku 1996; Halvorson et al. 2003; Thurow et al. 1993). Thurow et al. 1993 noted no increase in interill erosion following compaction as the surface particles were held firmly in place by the surface compaction, but after several months the particles were loosened by shrinking and swelling and the erosion at two months was greatly increased.

Vegetation Response to Military Maneuver Disturbance

The first impact of off road vehicles on vegetation is the immediate damage to the plants themselves from the stresses caused by the vehicles (Dickson et al. 2008; Diersing et al. 1988). Plants may be crushed or uprooted by off road vehicle traffic (Diersing et al. 1988; Goran et al. 1983; Milchunas et al. 1999). In addition to the direct plant vehicle interaction, the soil changes caused by off road vehicle use can alter vegetation in numerous ways. Reduced infiltration can limit the plant available moisture in the upper soil profile (Goran et al. 1983). Subsoil disturbance from training reduces larger pores thus limiting the ability of plant roots to penetrate (Goran et al. 1983). The soil air regime is also impacted by compaction and can hamper plant growth (Danilova 1996). The compacted surface layers may also limit the ability of seedlings to reestablish after vegetation is removed by initial trafficking (Goran et al. 1983). These changes have manifested in reduced vegetative biomass after disturbance (Dickson et al. 2008; Goran et al. 1983; Thurow et al. 1993). Military vehicle disturbance can also alter the vegetative species composition as species that are able to reestablish or tolerate the direct impacts of crushing in the more disturbed areas may be able to survive where pre-disturbance species may not. Milchunas et al. (1999) found that taller forms of woody plants, and long lived perennials were reduced in some plant communities, while short lived perennials, annuals and exotics were increased in abundance with higher levels of disturbance. Goran et al. (1983) found that grasses were often replaced by forbs. Dickson et al. (2008) found that vegetative response to an M1A1 Abrams tank at Fort Riley, Kansas was different based on the initial vegetative composition, with C_3 grasses more susceptible to damage than native vegetation. While high disturbance regimes from military training have been found detrimental to vegetation by nearly all research, Leis et al. (2005) found that within systems that evolved with higher than normal disturbance there may be some benefit to natural vegetation from an intermediate level of military disturbance.

Fauna Response to Military Maneuvers

The response of fauna to disturbance is quite varied. Intense constant training on an area tends to result in “largely denuded landscapes supporting only seasonal populations of disturbance tolerant flora and fauna” (Goran et al. 1983).

While high intensity training results in reductions in fauna, Goran et al. (1983) found varying results of mammal relationship to training intensity. Some small mammal species were found to decline, whereas other species increased in abundance with off road vehicle usage on some landscapes. Goran et al. (1983) found a "shift in species compositions (at Fort Riley), with decreases in prairie voles and western harvest mice and increase in white footed mice in areas of intensive military activity." They also found populations of small mammals 50 times greater on the installation than on the highly agricultural lands surrounding the installation (Goran et al. 1983). This creates what could be a counterintuitive relationship of fauna to military training. While intense military training may be detrimental to many species, the preservation of the landscape on military grounds may still be far more habitable than those lands off the installations which have been converted to agricultural and urban uses.

Other fauna have shown a more direct relationship to training that that of small mammals. Avian populations demonstrated a more linear relationship with significant biomass reduction (Goran et al. 1983). Althoff et al. (2007) found reduced quantities of nematodes in areas that were more intensely disturbed by an M1A1 Abrams tank, with earthworm abundance reduced by 82% in soils that were wet when disturbed.

Persistence of Disturbance

The persistence of maneuver training disturbance on a site is dependent on many factors: level of initial disturbance, depth of compaction, rainfall, freeze/thaw cycles, and soil flora and fauna. While surface compaction can begin recovery relatively quickly (Althoff et al. 2010; Brais and Camire 1997) it can take 20–30 years before recovery is complete, depending on the soil type (Ampoorter et al. 2010). Schäffer (2005) found that

30–40 years were not adequate for complete recovery of gas diffusion and fine root densities under wheel tracks. Braise and Camire (1997) found “bulk density was 8% higher at 10-20 cm and 11% higher at 20 to 40 cm depths after 12 years post compaction” in their study, but the upper 10 cm had no compaction effects measured after 6 to 12 years. Lindsey and Selim (2012) measured increased soil penetrometer resistance (PR) 14-16 months after tank trafficking compared to controls, with the highest PR on those soils that had higher moisture at the time of initial tank trafficking.

Many compacted soils will have some degree of restoration naturally over time. Danilova (1996) found that on soils with strong shrink swell cycles, there was quick recovery in the top soil layers. In contrast, “in the case of severe compaction to the point that compaction passes a critical threshold, nearly all the pores are destroyed and water is unable to move throughout the soil, even mechanical loosening may not be sufficient to restore the soil to pre-compaction levels” (Danilova 1996). Althoff et al. (2010) found that tallgrass prairie soils, such as those on Fort Riley, recover much quicker post disturbance compared to many other soils.

Methods of Maneuver Disturbance Estimation

Researchers and land managers have devised numerous methods to collect the data required to determine when, where and how military off road training is impacting the landscape, but many of the current techniques have limitations that can limit the ability of decision makers. Some of the proposed and tested methods of data collection include plot studies or transects, models that estimated impacts based on doctrinal or subject matter expert guidance, remote sensing of changes to military lands, and GPS tracking of vehicles during maneuvers (Anderson 2002; Department of the Army 2012; Diersing et al. 1988; Koch et al. 2012).

Army Sustainable Range Program

Army Regulation 350-19 "The Army Sustainable Range Program" provides policy to military leaders and land managers for the sustainable use of military lands (U.S. Department of the Army 2005). This regulation establishes the Integrated Training Area Management (ITAM) program and the subordinate Range and Training Land Assessment (RTLA) program to monitor and provide continued range support to the Army.

Range and Training Land Assessment (RTLA) Program

It is part of the mission of the RTLA program to understand where training is occurring on an installation, what the environmental effects of the training are, estimate the allowable training load, and identify projects in need of repair for the Army's Land Rehabilitation and Maintenance (LRAM) program (U.S. Department of the Army 2005). The RTLA program has developed from earlier attempts to monitor environmental conditions on Army Training Lands.

The earliest attempts made by the Army to understand maneuver impacts were physical studies of disturbance using plots or transects. Plots or transects provided evidence of environmental conditions and were tied to an estimation of training intensity at the site to determine the effects of maneuver disturbance (Diersing et al. 1988). These studies have provided much of the current understanding of the types of environmental degradation that results from military maneuver and controlled paired plots continue to provide significant findings in the discipline. The plot and transect level program of monitoring on Army lands came to be known as the Land Condition Trend Analysis (LCTA) program (Anderson 2002). This program established in the late 1980s and continuing annually for over 10 years included plots and transects on over 50 installations (Anderson 2002). Fort Riley alone had established 160 x 100 meter long permanent transects on Fort Riley in 1989 (Althoff et al. 2007). These transects or plots alone do not provide an estimate of vehicular disturbance until a method of estimating the number of vehicles that crossed the transect or plot could be made. As the field portions of these studies are conducted annually it is difficult to determine the time and conditions and actual maneuver intensity that occurred on each study site (Koch et al. 2012). Methods to estimate the training intensity and tie it back to the plot level studies include techniques to estimate the training intensity by identifying the use on the site through track identification and also thru analysis of military training records. Anderson et al. 2005 used LTCA transects for determining vegetative cover changes from maneuver training by using military records to determine the Tracked Vehicle Days (TVD) and Tracked Vehicle Equivalents (TVE) to estimate disturbance levels. Using this technique they were able to determine "military training was a significant factor in disturbance, with 58% of disturbance explained by TVE and 48% of disturbance explained by the number of battalions on the installation at a given time" (Anderson et al. 2005b). Transect and plot studies continue as part of the RTLA program on many installations.

Using Army Doctrine to Estimate Training Disturbance

The current method used by RTLA to estimate training load is the Army Training and Testing Area Carrying Capacity (ATTACC) method (U.S. Department of the Army 2005). ATTACC training estimates of off road maneuver are based on Army doctrine directly or based on the DoD Range Facility Management Support System (RFMSS) (U.S. Army Environmental Center 1999). RFMSS is a system of record for scheduling and recording military ranges and training lands. This system bases training load on estimates of how much off road training should be associated with a specific type of unit conducting a specific type of training rather than any real maneuver recordings (U.S. Army Environmental Center 1999). The training estimates used for ATTACC can be directly from military unit input into RFMSS, or from a combination of unit input in RFMSS, range schedules, and army doctrine (U.S. Army Environmental Center 1999). The ATTACC methodology uses the estimated training load from doctrine or RFMSS to determine the Maneuver Impact Miles (MIMs) for the training event (U.S. Army Environmental Center 1999). The MIM is the equivalent maneuver disturbance to that of a M1A2 Abrams tank operating during an armor battalion field training exercise for one mile (Sullivan and Anderson 2000). The MIM calculation does not account for ecological settings where training occurs, and as such an "armor unit conducting a BN FTX will have a MIM value of 20,250 regardless of where the event occurs" (U.S. Army Environmental Center 1999). This system provides land managers with training loads and can be used to estimate disturbance, but the spatial scale of the estimates is only at the maneuver area level (Koch et al. 2012).

A study by Herl et al. (2005) attempted to further support the ability of Army doctrine to support estimation of training maneuver on training of US forces at Grafenwoehr Training Area in Germany. Herl, a trained military engineer and geographer used the military doctrinal tool known as the Modified Combined Obstacle Overlay (MCOO) which is used by military leaders to determine the best tactical terrain for maneuver. Herl used this technique on an installation that is designed for large scale military exercises that should include maneuver assessments by the units in their training maneuvers. Even under these favorable conditions for this technique to work, results of spatial distribution of military maneuver disturbance based on doctrine was not significant (Herl et al. 2005).

GPS Tracking Of Maneuver Training

Due to the limitations of physical and doctrinal methods of determining military maneuver, Global Positioning System (GPS) technology has been tested and effectively used to monitor military vehicle maneuver (Ayers et al. 2000a; Ayers et al. 2005; Haugen 2002; Haugen et al. 2003a; Koch et al. 2012; Li et al. 2007a; Li et al. 2007b; Rice 2006; U.S. Department of Defense 2012). GPS technology provides the capability to not only know where vehicles have conducted maneuver training, but to also provide information on vehicle dynamic properties at the time of disturbance, and provide highly accurate temporal data that can be used to better understand the environmental conditions at the time of disturbance.

Use of GPS Devices to Track Military Maneuver

Tracking of military maneuver training using GPS devices was first introduced by Ayers et al. (2000). This research used differentially corrected GPS (DGPS) systems to demonstrate the ability to accurately track military vehicles, and provided methods for determining dynamic vehicle properties from the GPS data (Ayers et al. 2000a). Ayers et al. (2000) work provided the first demonstration of not only the ability of GPS to track vehicles but also to estimate the intensity of the training based on the vehicle dynamic properties.

Vehicle Tracking System (VTS)

The Vehicle Tracking System (VTS) was designed by the same group of researchers that provided the first DGPS recording on military training, and was first reported by Hagen 2002. Haugen et al. (2003) used the VTS device to track wheeled and tracked vehicles at Yakima Training Center, WA, for a 10 day training exercise. The data from this was able to be used to characterize vehicle movements including the location, velocity, and turning radius. Comparisons of different types of training missions and the amounts of time vehicle spent on vs. off road were conducted. Accuracy assessments were conducted on the device with a reported accuracy of 2.4 m 50% of the time and 6.9 m 95% of the time (Haugen et al. 2003a).

Vehicle Dynamics Monitoring and Tracking System (VDM/VDMTS)

The Vehicle Dynamics Monitor and Tracking System (VDMTS) was designed by the Army Corps of Engineers Construction Engineering Research Laboratory (CERL) in collaboration with Dr. Ayers of the University of Tennessee, and Cybernet Systems Corp (Koch et al. 2012). It is similar to the VTS DGPS device described above but also included an integrated inertial sensor to track movement when GPS signal is not available. The VDMTS was designed specifically for tracking military maneuver training. The VDMTS was operated on Fort Riley, KS, Fort Benning, GA and Pohakuloa Training Area, HI and tested to meet or exceed the capabilities of the VTS (Koch et al. 2012).

GPS Disturbance Measurements

Rice (2006) used an upgraded variant of the same device as Haugen to estimate multiple vehicle passes over the same location and to attempt to determine training formation types from GPS data. Ayers et al. (2005) and Wu et al. (2007) used the same GPS data sets from Rice and Haugen and analyzed them in a GIS to identify potential roads. The same data sets collected from VTS GPS devices from the research above was also also used to estimate the "vehicular traffic intensity" based on the number of vehicle passes using a 10 meter search radius (Wu et al. 2008). Li et al. (2007a & 2007b) developed models that incorporated dynamic vehicle properties collected from GPS tracking of military maneuvers to estimate disturbed width and impact severity based on turning radius and velocity. Li et al. (2007a & 2007b) found higher disturbance with increased (tighter) turning radius, especially turning radius less than 30 meters. Koch et al. (2012) used the VDMTS to determine the amount of time military units were training near critical habitat.

Tactical Tracking Systems

GPS devices were initially designed for military use, and the Army currently has several GPS variants in use on some ground vehicles. None of these systems have been reported in research as having been tested for use in training related disturbance measurements. This section is included to provide background information on these systems from a military perspective as the author has substantial experience with these systems both in training and combat situations which may provide insight to their possible use for maneuver disturbance tracking.

The Blue Force Tracking (BFT) or a new variant Joint Capabilities Release BFT (JCR BFT) is a military system that uses a Defense Advanced GPS Receiver (DAGR) positioning device along with GIS software and satellite communication to provide near real time spatial information to military units (Schwerin 2011). The system is used by all branches of service and is installed in ground and air vehicles. Both the BFT and JCR systems employ a GPS device and a GIS based system for determining and mapping locations of the vehicle it is on, and of friendly units on the battlefield. The system is in wide use and at times is the most reliable communication platform for units spread across large areas. It was first placed in service with units deploying to Afghanistan in 2002 and in Iraq in 2003 (Dunn 2003). There are currently over 100,000 BFT units in the DoD (Schwerin 2011).

While these systems provide excellent situational awareness to the military users they have proven to be of limited use to land managers. There are at least four major problems associated with using these devices for land management or research purposes.

The first problem with trying to use the BFT/JCR for land management maneuver tracking is the devices are in a limited number of vehicles. These systems, while becoming more common within military vehicles are not pervasive in training vehicles. System deployment across training vehicles may be less than one BFT/JCR per three to five vehicles within a given unit, and may not be spread across the military formation in a manner conducive to collecting information for land managers/researchers. In some units the percent of vehicles outfitted with BFT systems may be less than 10%. The distribution of BFT/JCR within a unit is not even. Large offensive weapon platforms such as tanks and infantry fighting vehicles are often outfitted at a very high rate, while many wheeled vehicles have very few devices, and some classes of wheeled vehicles do not have any BFT/JCR devices.

A second key problem with using the BFT/JCR for maneuver training tracking is that the training requirements of units dictate what training is conducted and what systems are used for various training exercises. Often adding more technical components to a training event may reduce the overall effectiveness of the training. For example, a unit conducting off road drivers training on a vehicle platform may be focused on the most elementary tasks of how to operate the vehicle and incorporation of the BFT/JCR system into the training could detract from the required training. Also, during early stages of unit training there may be limited personnel capable of using the system limiting the reliability of the system to collect training related data. Units are also often training in situations called "force on force training" where one element from the same unit may be conducting training versus another element from the unit. For this force on force training it would often be detrimental to the training if units were using the BFT/JCR as they would know where the opposing element was at. Therefore in many training situations the units would purposely need to leave the BFT/JCR devices turned off. For these reasons, many off-road training events are conducted without the use of the BFT/JCR reducing its effectiveness as a tool for tracking maneuver training.

The next issue with using the BFT as a multi–role data collection device is the difficulty of data acquisition. The system itself operates on a classified network which significantly limits the data availability, researchers and land managers would all have to have clearance to access the data, and due to the classified nature of the data, research could suffer from difficulty in publishing. Another hardship with data acquisition beyond the clearance is the data logging of the device. These devices are designed for units to have better situational awareness at a given time; this translates to a map that shows where vehicles are at presently, not where they have been. The current systems are operated in such a manner as to display current position and the position of other friendly units, not to collect and log GPS data. Although the systems may have the capability to log data, they are not designed for easy data download with a removable flash drive or SD card as the other devices tested in this research are.

Lastly, the data collection and update rate of the BFT/JCR system does not lend itself well to use as a land management device. These devices are designed for military situational awareness, and as such they are not designed with a refresh rate of one Hertz like the other devices tested are. The BFT positional refresh rate had historically been a matter of minutes but with the new JCR release it has been reduced a matter of several seconds (Slabodkin 2011). The reduced refresh rate does bring the system more in line with the needs of land managers, but reported rates are still well in excess of the one hertz rate that has been proven successful for calculation of vehicle dynamic properties required by land managers.

New military GPS based tracking systems have been proposed and are in developmental stages at the time of this study. One of the most well documented new systems is the U.S. Army Nett Warrior system. This system uses commercial off the shelf products (primarily smart phone technology) combined with several other army systems of record to provide GPS positioning and communication down to the individual soldier level (Gourley 2013). Nett Warrior and similar systems may have the capability to meet the needs of military land users and land managers, but system design and implementation to date provide inconclusive evidence they will fill the knowledge gap. Also, new systems may fail to overcome the security clearance and percent of training time in use issues that are associated with the BFT currently.

Chapter 3 - Objectives

Objective 1: Comparison of Previously Tested Maneuver Tracking GPS Devices to Low Cost COTs GPS Device

This objective was designed to determine if a low cost civilian off the shelf (COTS) GPS device could be used to track military vehicles. To meet this objective a COTS GPS device was selected and tested for accuracy under military maneuver like conditions. The COTS device was then directly compared in side by side tests with two types of GPS devices specifically designed and currently in use for tracking military maneuver disturbance. This objective is covered in chapter 4 below.

Objective 2: Estimate Metrics of Maneuver Training Events based on COTS Data through Case Studies

This objective was designed to test the COTS GPS device in actual military maneuver training. The COTS devices tracked three maneuver battalions as they trained. The data was then used to analyze the variability in off road disturbance between units and vehicle types during like training events. This objective is reported in detail in chapter 5 below.

Objective 3: Development of a GIS Based Model for Depicting Maneuver Training Intensity Based on COTS GPS Data

The third objective was to develop a new way of mapping GPS data collected during military training events in a manner that would be consistent for a long term disturbance monitoring program. Chapter 6 below discusses how an intensity map of Fort Riley was created using COTS GPS data from the three training events tracked.

This chapter also details current intensity mapping methods and demonstrates some of the weaknesses inherent in current mapping methods.

Chapter 4 - Comparison of Previously Tested Maneuver Tracking GPS Devices to Low Cost Civilian off the Shelf (COTS) Devices

Introduction

Tracking the movement of military vehicles during training provides much needed knowledge to researchers, environmental and training area managers. Several GPS (Global Positioning System) devices have been used previously to track military vehicle movements (Ayers et al. 2000b; Ayers et al. 2005; Haugen et al. 2003a; Koch et al. 2012; Li et al. 2007a; Li et al. 2007b). As with many areas of technology, advancements in the field of GPS has both created technologically better devices and significantly reduced the cost and size of the older technology. Survey grade GPS devices are commonly in use by researchers, planners and engineers, with high enough accuracy to report locations within several centimeters. Low cost GPS modules have made it feasible to have GPS devices in small portable devices like automotive navigation systems and smartphones.

The aim of this research was not to test the newest technology within the field, but to instead test the capability of devices that are now more cost effective and have become more ubiquitous within society. As GPS devices have been included in many modern vehicles and in many new mobile devices, the costs have been reduced to a point that it may be possible to reliably and cost effectively track a large proportion of maneuver training on military installations. This would provide researchers a better understanding of where, when and how military training maneuver is impacting the landscape.

Tracking of training disturbance has been successfully accomplished using GPS devices by numerous researchers (Ayers et al. 2000b; Ayers et al. 2005; Haugen et al. 2003a; Koch et al. 2012). The two primary systems used in previous research are the Vehicle Dynamic Monitor (VDM) also called the Vehicle Dynamic Monitor and Tracking System (VDMTS), and the Vehicle Tracking System (VTS) (Ayers et al. 2000b; Ayers et al. 2005; Haugen et al. 2003a; Koch et al. 2012). These previously tested devices have shown the ability to record the necessary data to determine where, when and how military training is occurring (Ayers et al. 2000; Ayers et al. 2005; Haugen et al. 2003; Koch et al. 2012). These devices have several advantages over the device tested in this research and several disadvantages. The primary advantages of the VDMTS and VTS includes the existing literature showing their effectiveness, the existing data set from numerous military installations, developed data handling procedures, and large batteries allowing for long intervals of data collection without researcher involvement. The disadvantages of these devices are the initial costs (in excess of $2500.00 per device), large size/weight (each device weights in excess of 10kgs), a user training requirement that exceeds simpler devices, and due to external connections, there exists the possibility to have missed recording times due to loose connections.

An objective of this research was to determine if a low cost Commercial Off The Shelf (COTS) GPS device can adequately collect the data needed for military land managers and researchers. In order to determine if a low cost COTS GPS device could provide the needed data, tests were conducted to determine the accuracy, data collection capability, and functionality of one COTS device and compare it to the currently used devices (VDMTS/VTS). Accuracy tests were conducted to determine the capability of the COTS device in relation to the other devices. In addition some direct comparison tests were conducted to see if the devices were capable of collecting data in the same operating environment as the existing devices.

GPS Device Description

GPS technology has increased dramatically since military vehicles first used satellites for navigation with the US Navy's Transit program was designed to help ballistic missile submarines navigate in the early to mid-1960s (Powers and Parkinson 2010). Early systems took 10 to 16 minutes of stationary data collection to give a two dimensional accuracy of approximately 25 meters (Powers and Parkinson 2010). Current GPS devices have the capability to provide sub-meter accuracy based on satellite and terrestrial support platforms (Coyne et al. 2003; Juniper Systems Inc. 2013). This research focuses on the primary systems used to track military vehicles for land management programs/research, the VDMTS/VTS (description below), and a selected COTS device. As mentioned in chapter 2 the BFT/JCR system could be used to collect GPS data for military maneuver training, but the hardships involved do not make it a good choice for land managers and is therefore left out of this comparison testing.

Vehicle Tracking System (VTS)

The Vehicle Tracking System (VTS) has been used in numerous previous military maneuver tracking studies (Ayers et al. 2002; Ayers et al. 2005; Haugen et al. 2003) with some upgrades to the system as new technology became available. The system in its current design uses a Garmin GPS18-PC GPS receiver, an Acumen Serial Data Recorder, a 64 or 128MB Compact Flash card, and two Odyssey dry cell 12 volt batteries connected in parallel in a water resistant hard case. The Garmin GPS18-PC is a WAAS enabled

Differential Global Positioning System (DGPS) receiver. It can track 12 satellites and the manufacturer data indicates a DGPS accuracy <3 meter 2DRMS with appropriate signal (Garmin 2005). It has a cold acquisition time of approximately 45 seconds, warm acquisition time of approximately 15 seconds and a data collection rate of 1hertz (Garmin 2005). Paired with the data recorder and the batteries in serial the system can record four days data (64MB card) and eight days of data (128MB card) (Rice 2006).

Vehicle Dynamics Monitor (VDM or VDMTS)

The VDM/VDMTS is a similarly designed system to that of the VTS. The system consists of one Odyssey dry cell battery, a data recorder (using one SD card), and an U-blox DGPS antenna. This system also has the added capability of being able to record positional accuracy when the vehicle is not in motion using a micro electro mechanical systems (MEMS) based inertial sensor (Koch et al. 2012). Testing of this device demonstrated error of less than 3.7meters 2DRMS (Koch et al. 2012).

COTS Device

There are numerous GPS devices on the civilian market that could have been used in this study. These devices range in cost from less than $50.00 to thousands of dollars. A list of criteria was established to narrow the search for a test device. The criteria in order of priority were 1) current availability, 2) manufacturer accuracy estimates (less than 10m CEP), 3) capability to store at least one weeks' worth of training data, 4) battery life (lower limit estimate 1 week battery life with estimated 2 hour operating time per day), 5) passive GPS tracking, 6) 1 second data logging, 7) low cost (upper limit established $200.00), 8) size (availability to mount on various vehicle platforms), and 9) simplicity of design. The first six design criteria were to have capabilities similar to that of the units currently in use (VTS and VDM); the last three criteria were established in order to help overcome limitations of the VTS and VDM for widespread implementation.

The COTS device selected for this research was the LandAirSea LAS-1505 Tracking Key Vehicle GPS tracking System by LandAirSea Systems Inc. The device is based on a U-blox Antaris 4 GPS RCB-4H module. This GPS module is passive and operates on the L1 frequency with 16 channels. Its reported accuracy is 2.5m CEP with acquisition from cold start of 34 seconds, warm start of 33 seconds, and a hot start of less than 3.5 seconds and operating temperatures from -26 to 85 degrees C. The GPS module is incorporated in the LAS-1505 Tracking Key with an ABS housing, an attached magnet, and housing for 2 AAA batteries. The dimensions of the entire unit are 96.5mm long, 37.1mm wide, by 34mm high. The device total weight in operation with batteries is approximately 110 grams. Power draw is 49mA while tracking and 0.072mA in sleep mode. Based on the power draw, the manufacturer estimates battery life of 2 weeks for 2 hours of tracking per day, and 1 week for 4 hours of tracking per day. The data storage capacity of the device is capable of holding 360,000 seconds of logged data (100 hours) using NMEA 0183 protocol with a data logging rate of one coordinate logged each second. The device is equipped with Past Track software which allows for unit download and some simple mapping functions and also for data export into a .txt file for further processing. The device only records data when moving, entering a sleep mode after 2 minutes of no movement. The device is also active immediately once the batteries are installed; there are no buttons of any type on the device, simplifying operation.

Figure 4-1 LandAirSea LAS-1505 Tracking Key Side View

Figure 4-2 LandAirSea LAS-1505 Tracking Key Bottom View

Archer

In order to establish a “true” location, a higher order GPS device was selected. The Archer Field PC with Hemisphere GPS XF101 from Juniper Systems, Inc. was selected for its ease of use (no required base station and internal ESRI ArcPad application) and high level of accuracy. With DGPS using the XF101 in a good multipath environment with adequate satellites in view this GPS has a reported horizontal accuracy of <0.4 meters (Juniper Systems Inc. 2013). While survey grade GPS devices could have provided an accuracy level of sub-centimeter, the nature of the comparison receivers does not require that level of accuracy.

Figure 4-3 Archer Field PC with Hemisphere XF101

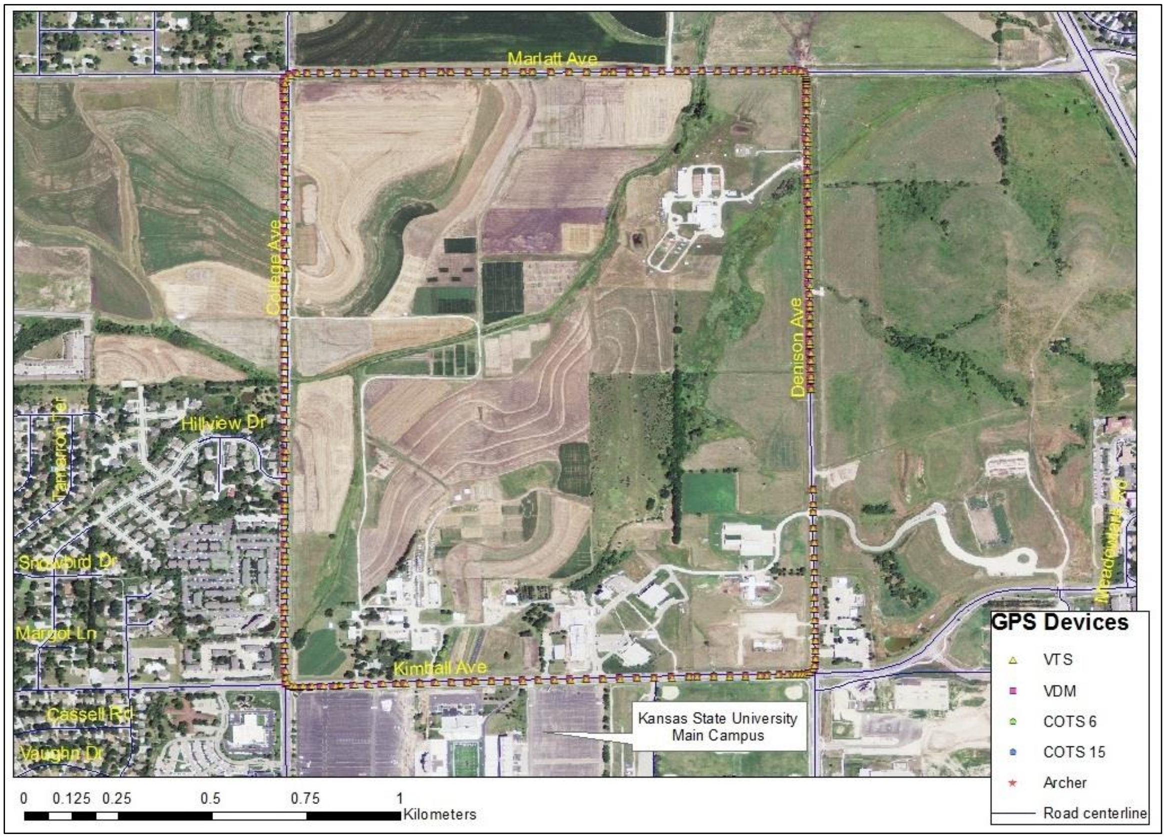
Site Description

There were two main sites were the comparison tests occurred. Accuracy tests were conducted on the North Campus of Kansas state university, and operating environment comparison tests were conducted on Fort Benning, GA.

North Campus

Accuracy tests were conducted at Kansas State University, Manhattan, Kansas just north of the university main campus. A portion of the campus extends north of the main campus and is used for agricultural research. The area has very little topography and is open with few overhead obstructions allowing clear satellite signal. All accuracy testing was conducted on surface streets on the north campus following all local traffic laws. The streets used in this test are Denison Avenue on the east, Marlatt Avenue on the north, College Avenue on the west, and Kimball Avenue on the south.

Figure 4-4 GPS Accuracy Assessment Test Track



Fort Benning, GA

Fort Benning, GA is an U.S. Army installation located south of the city of Columbus, GA on the west central portion of the state. The installation covers approximately 182,000 acres with 140,000 acres being managed forestland crossing two different ecological zones, the Piedmont and the Coastal Plain. The installation has 5 federally protected species and 91 other species of conservation concern (Fort Benning Directorate of Public Works 2006).

Fort Benning is an U.S. Army Training and Doctrine Command (TRADOC) installation with a primary mission of maneuver forces training. It is the home of the

Army's Maneuver Center of Excellence (MCoE) with the mission to "provide trained, agile, adaptive and read Soldiers and Leaders for an Army at war, while developing capabilities for the Maneuver Force and the individual Solider and providing world-class quality of life for Soldiers, Civilians and Army Families" (http://www.benning.army.mil). The installation is the primary training installation for Infantry and Armor Soldiers from the rank of Private thru Colonel.

GPS tests on Fort Benning were completed in cooperation with the United States Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) and the Fort Benning Environmental Management Division. CERL and the Fort Benning Environmental management division have been partnering over several years to track the movement of maneuver vehicles and their use near red-cockaded woodpecker habitat using the VTS and VDM GPS devices. For comparison purposes COTS devices were placed alongside the VTS/VDM devices as they continued monitoring.

Methods

The comparisons tests were conducted as two separate tests; one comparing accuracy levels of the three different devices (VTS, VDM, and COTS) vs. a higher order GPS device (Archer Hemisphere), and a second operating environment test comparing the COTS to VTS and VDM devices in actual field study conditions.

GPS Accuracy Assessment

GPS accuracy testing often consists of several tests; the first test is often a static test where the device is operated in a known location for an extended period of time and the location of all plotted points are then compared to the known location to determine the ability of the device to accurately and precisely record its location (Coyne et al.

2003). This test is often used to define the accuracy of a GPS device. The design of the COTS device and the underlying software are incompatible with this kind of test. The device does not log any points when stopped therefore static accuracy tests with this device would result in zero registered points. Contact with the manufacturer was made in an attempt to find a solution, but the device manufacturer was unable to provide a means to allow the device to record points for a static position test.

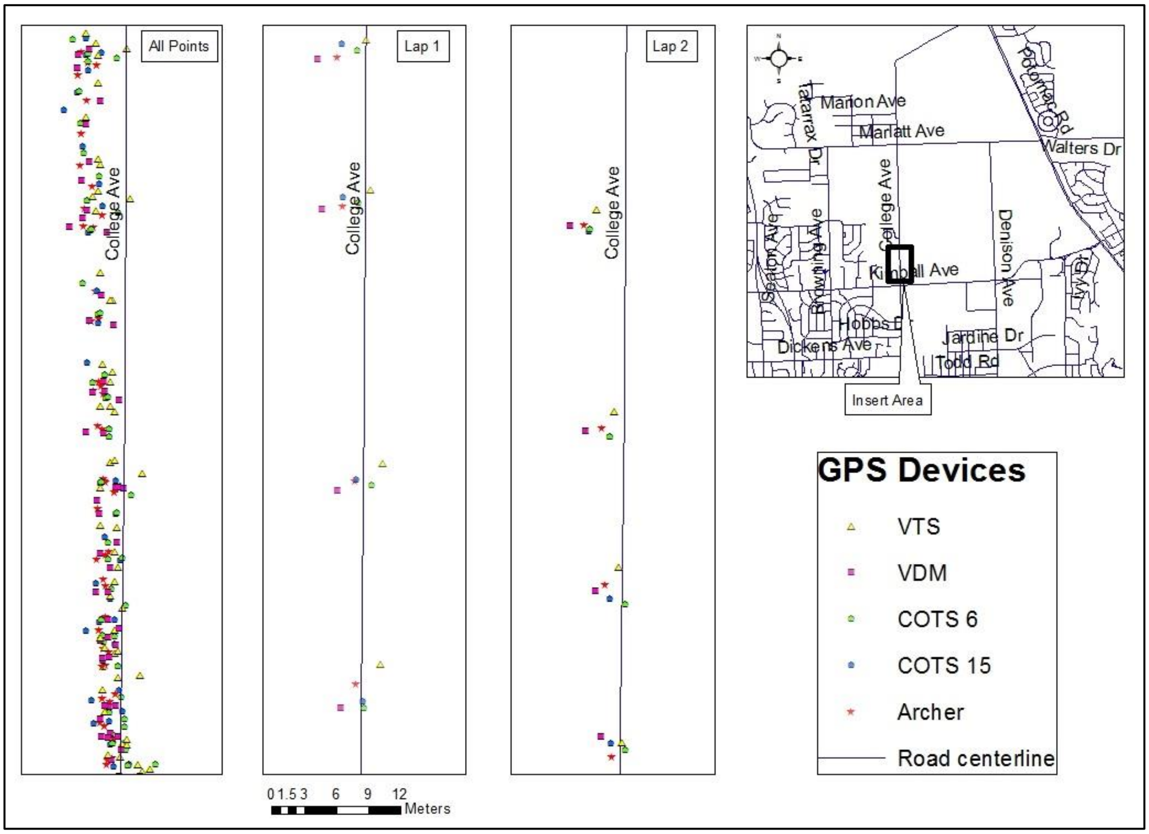
A second test is often conducted to determine GPS accuracy while a device is in motion; this type of test is called a dynamic accuracy test. This type of test was conducted with the COTS device and reported as the overall accuracy of the device. Static accuracy tests results are more controlled and are likely to produce higher accuracy than dynamic accuracy tests, but as these devices are designed only to log data when moving a dynamic accuracy test is more relevant.

In order to conduct the dynamic accuracy tests, a higher order GPS (Juniper Systems Inc. 2013) device was needed. The higher order GPS device records data that for the purpose of the test is considered to be the "true" coordinates of the point. The Archer XF101 coordinates at each position were compared to the coordinates recorded by each of the other devices. A determination of distance of the coordinates of the test device to the coordinates of the Archer XF101 provided the error for that particular point. For the dynamic test, one Archer XF101, one VTS, one VDM, and two COTS devices were located in close proximity around a central point (the Archer XF101 being the centermost device) on the roof of a vehicle where no obstructions from the vehicle would interfere with satellite signal. The test vehicle was moved to a position on a test track. All GPS devices were turned on and allowed time to acquire satellite signal (a 15 minute time interval was given as only the Archer has a display that allows the user to know when satellite lock is achieved). Once all devices were assumed to have achieved satellite signal acquisition, the test vehicle proceeded to traverse the test track observing posted speed limits.

The test track consisted of a 5.38 kilometer loop on surface streets on the north portion of the Kansas State University campus. Repeated loops of the test track were conducted over two hours with all devices conducting simultaneous logging on 16 August 2013. The devices were set to record points on a 1 second interval throughout the testing period. When testing was complete, all devices were turned off and recorded data was downloaded from each device.

The GPS data was converted into ESRI shapefiles in ArcGIS and mapped. The data for each device was broken down into separate laps for each time around the test track so points from each device would be compared only to points of the other devices on the same lap and not confused with between lap comparisons (Figure 4-4). The Archer device only recorded points when minimum accuracy thresholds were met thereby not having a point at each one second time interval. The remaining four devices' data were reduced to only contain points that matched temporally with the Archer points, reducing the overall number of recorded points to 3710 points for all five devices for comparison. All of the GPS devises recorded data in a decimal degree format and, for ease of data comparison, ArcGIS was used to project all points to the local UTM (Universal Transverse Mercator) coordinate system (UTM zone 14N). The UTM coordinates of each device for the same time interval were then used for comparison of each device to the "true" value recorded by the Archer device.

Figure 4-5 Separation of Accuracy Data into Laps for Data Comparison



Accuracy Calculations

There are numerous different methods for reporting GPS accuracy used by different GPS manufactures and researchers, for this research Circular Error Probability (CEP) and Two-Distance Root Mean Squared (2DRMS) were selected for reporting as these measurements have been previously used to report the accuracy of the VTS and VDM (Koch et al. 2012; Haugen, 2002). CEP is the measurement of GPS positional error that includes 50% of the data points whereas 2DRMS is the measurement of error that includes 95% of data points (Koch et al. 2012). In order to determine the CEP and 2DRMS for each device, the longitude (x value) of each GPS device at each data point was compared to the longitude of the "true" x value at that data point (the Archer longitude), the same was done for the latitudes values at each point. Equation 4-1 provides the method used to determine error at a given GPS point.

Equation 4-1

$$Error = \sqrt{(X_{GPS} - X_{True})^2 + (Y_{GPS} - Y_{True})^2}$$

Where:

X_{GPS} = tested GPS device UTM Longitude

X_{True} = Archer XF101 "true" UTM Longitude

Y_{GPS} = tested GPS device UTM Latitude

Y_{True} = Archer XF101 "true" UTM Latitude

Accuracy Assessment Results

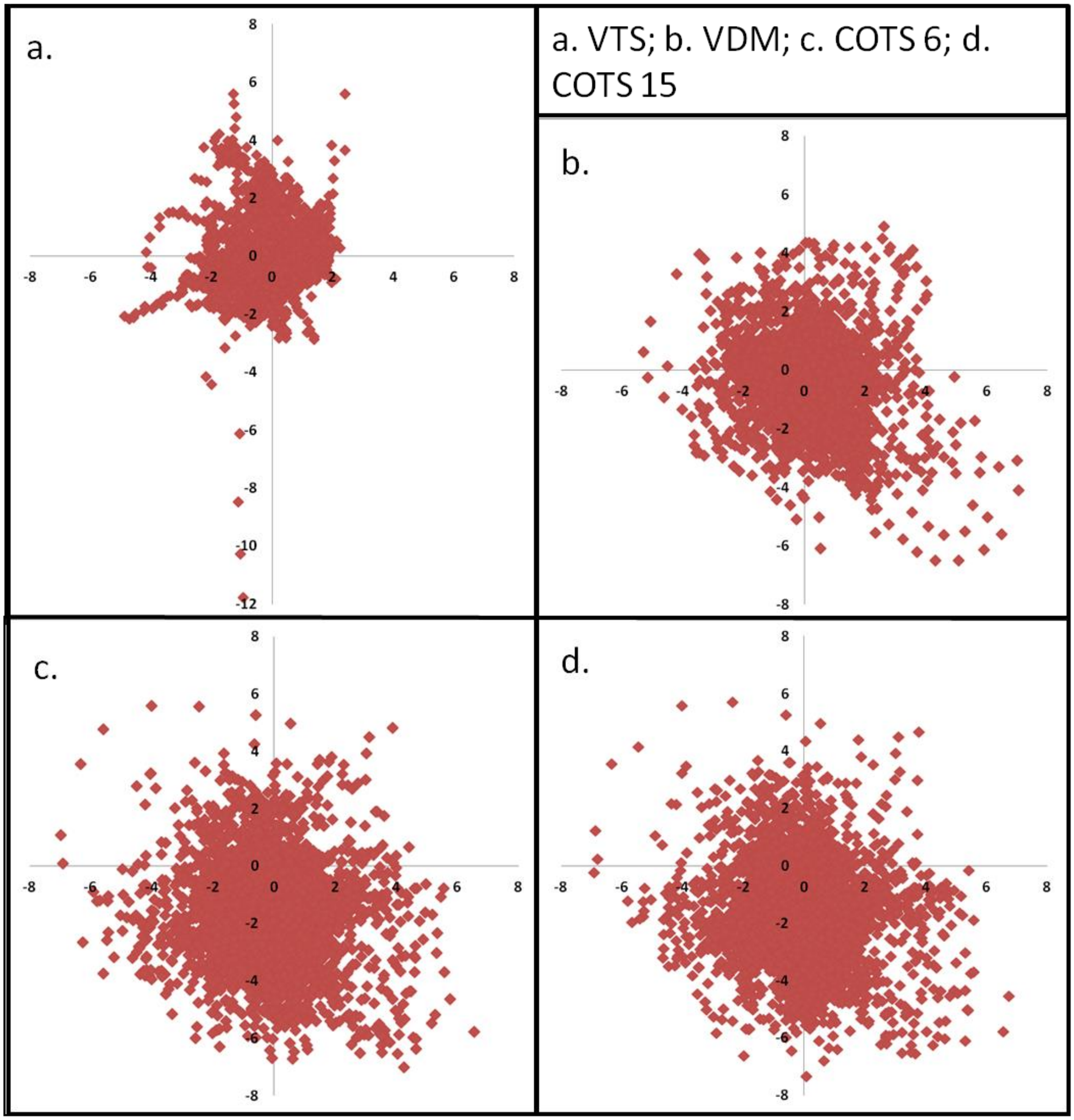
The 2DRMS and CEP data for the devices indicates that the tested VTS was the most accurate device tested with a 2DRMS of 3.09 meters, followed by the VDM (3.78 meters), then the COTS devices (4.57 to 4.68 meters). All devices had a CEP of less than 2.0 meters (COTS devices exceeded the manufacturers accuracy statement of 2.5 meters CEP). The VTS, while being the overall most accurate based on CEP and 2DRMS, had the largest single point error (11.24 meters).

Table 4-1 Dynamic Accuracy Test Results for All Points

	Average # Sateilights Used	Average HDOP	Average Diference in X	Maximum Difference in X	STD X	Average Difference in Y	Maximum Difference in Y	STD Y	CEP	2DRMS
Archer	9.39	0.69								
VST			-0.23	4.86	0.99	0.15	11.24	1.19	1.29	3.09
VDM	10.99	0.82	0.26	7.06	1.32	-0.44	6.51	1.35	1.58	3.78
COTS6			-0.12	6.98	1.57	-1.59	7.02	1.73	1.95	4.68
COTS15			-0.03	6.92	1.55	-1.49	7.33	1.68	1.91	4.57

Positional error was not uniform in all devices; the error of the COTS devices was the least uniform between longitude and latitude. The average longitude point error for the COTS devices (0.075 meters combined) was less than the error associated with the VTS (0.23 meters) or VDM (0.26 meters). Conversely, the average latitude point error for the COTS devices (1.54 meters) was much larger than the VTS or VDM latitude point errors and also much larger than the COTS longitudinal point errors. Figure 4-6 shows the error distribution of all tested devices for all points. Both the VTS and VDM error is centered near the origin, whereas the COTS device data indicate a southern trend in the data centered near 1.5 meters south of the true point.

Figure 4-6 Error Distribution of Tested GPS Devices (meters)



Using the same data set, filters were placed to compare several different series. The first filter removed all GPS points when the VTS device recorded the vehicle conducting a turn. In order to complete this test, all points with a calculated turning radius of less than 150 meters (based on methods described by Haugen 2002) were removed from the data set and accuracies were recalculated. The straight point analysis

(Table 4-2) indicated that for all GPS devices tested, the GPS of the straight points are similar to the overall GPS accuracy.

Table 4-2 Dynamic Accuracy Test Results for Straight Points

	Average # Sateilights Used	Average HDOP	Average Diference in X	Maximum Diff X	STD X	Average Difference in Y	Maximum Difference in Y	STD Y	CEP	2DRMS
Archer	9.39	0.69								
VST			-0.24	4.89	0.98	0.15	11.76	1.21	1.30	3.12
VDM	10.99	0.82	0.25	7.06	1.22	-0.45	6.51	1.28	1.48	3.54
COTS6			-0.14	6.56	1.49	-1.63	7.02	1.69	1.89	4.52
COTS15			-0.04	6.56	1.46	-1.53	7.33	1.64	1.83	4.39

Another analysis of the data set was conducted on only the points with a turning radius of less than 150 meters (Table 4-3). The CEP and 2DRMS of the VDM and COTS devices indicate a reduced accuracy when turning when compared to the all points data. The COTS devices are comparable to the VDM device (6.03 meter vs. 5.63 meter 2DRMS respectively), but the VTS device accuracy is influenced much less by turning radius (Table 4-3).

Table 4-3 Dynamic Accuracy Test Results for Turning Points

	Average # Sateilights Used	Average HDOP	Average Diference in X	Maximum Diff X	STD X	Average Difference in Y	Maximum Difference in Y	STD Y	CEP	2DRMS
Archer	9.22	0.83								
VST			-0.12	2.90	1.05	0.14	2.96	0.95	1.18	2.84
VDM	11.09	0.84	0.40	7.02	2.05	-0.34	5.62	1.93	2.35	5.63
COTS6			0.03	6.98	2.18	-1.21	6.24	2.05	2.50	6.00
COTS15			0.09	6.75	2.29	-1.17	5.72	1.99	2.51	6.06

Further analysis on the data set was conducted to approximate the conditions under which the GPS devices will commonly be used during military maneuver tracking. Using the same data set, additional parameters (speed and turning radius) were used to sort and filter the data to estimate the dynamic accuracy of the selected GPS devices under various conditions. Of particular interest is the accuracy of the devices under conditions similar to those that will often be encountered when tracking military maneuver. The average speeds of military vehicles in training are not as high as the average speed of the overall accuracy assessment, therefore data were filtered to estimate accuracy at below 6.5 meters per second (the mean total speed of all vehicles tracked during other the other research objectives of this study), below 3.05 meters per second (average off-road speed observed during other research objectives of this study), and when the turning radius was below 30 m (approximate point of increase in disturbance from other research (Haugen 2002; Li et al. 2007b; Liu et al. 2009)). Results of filtered accuracy comparisons indicate that the COTS devices display similar errors to the VDM/VTS when speeds are below 6.5m/sec (2DRMS: VTS 3.38m, VDM 4.15m, COTS average 3.85m) and at estimated off road speeds of 3.05 m/sec (2DRMS: VTS 3.15m, VDM 3.29m, COTS 2.79m average). When turning radius is included with speed restrictions all four devices have an average 2DRMS less than 5m. Estimating off road speeds at the most damaging turning radius (less than 30m), the average COTS error is marginally less than that of the VTS or VDM (Table 4-4).

Table 4-4 Error Estimates Based on Speed and Turning Radius

		VTS	VDM	COTS 6	COTS 15	COTS Average
Speed <6.5m/sec	CEP (meters)	1.40	1.74	1.67	1.54	1.61
	2DRMS (meters)	3.38	4.15	4.00	3.71	3.86
Speed <6.5m/sec and Turning Radius >=150m	CEP (meters)	1.47	1.55	1.58	1.37	1.47
	2DRMS (meters)	3.51	3.72	3.80	3.28	3.54
Speed <6.5m/sec and Turning Radius <30M	CEP (meters)	1.25	1.84	1.81	1.69	1.75
	2DRMS (meters)	3.03	4.40	4.34	4.07	4.21
Speed <3.05m/sec	CEP (meters)	1.32	1.38	1.24	1.05	1.15
	2DRMS (meters)	3.15	3.29	3.05	2.52	2.78
Speed <3.05m/sec and Turning Radius <30m*	CEP (meters)	1.30	1.32	1.19	0.91	1.05
	2DRMS (meters)	3.11	3.16	2.94	2.20	2.57

*Only 18 points used in

COTS Operational Performance Assessment (Fort Benning)

In order to compare the efficacy of the COTS device to the previously tested devices (VDM and VTS) a side by side field comparison was conducted. The previous accuracy tests compared the COTS device to the VDM and VTS under ideal conditions with open sky views and continuous operation. Military maneuvers will often occur with frequent stops and starts and under vegetative cover limiting direct lines of site to GPS satellites. In order to compare the devices under operational circumstances the COTS devices were mounted next to VDM and VTS devices while conducting research on maneuver impacts of red- cockaded woodpecker habitat at Fort Benning, GA. The VTS and VDM device have been used to determine the amount of time military maneuver is spent in red-cockaded woodpecker habitat for over one year.

In order to compare the devices, the standard procedures were followed for the placement of the VTS and VDM devices on military vehicles that would be possibly operating in red-cockaded wookpecker habitat and the COTS devices were mounted to the same vehicles. Most vehicles used in this comparison were M1152 High Mobility Multipurpose Wheeled Vehicles (HMMWV) of several variants, along with three M1126 Stryker vehicles. The M1152s were of similar design, but the rear deck where the VDM/VTS GPS antenna were located was of several different designs. Some of the M1152s had cargo strap mounting brackets near the VDM/VTS GPS antenna mounts, some had no brackets. On M1152s with cargo strap brackets the COTS devices were able to be secured to the brackets near the VDM/VTS GPS antenna. On other M1152s with smooth cargo compartment hatches there was not a mounting position for the COTS device near the VDM/VTS antenna. On the M1152s without a good mounting position the COTS devices were installed inside the armored cabins of the vehicles (although this could limit satellite reception).

Overall 10 vehicles (including three M1126 Strykers) were mounted with the COTS devices outside near the VDM/VTS GPS antenna position, and 16 COTS devices were mounted inside the HMMWV passenger compartments. As covering GPS devices has been shown to reduce accuracy only vehicles with COTS device externally mounted were of primary concern in this comparison (although data from one internally mounted device is included below due to relative availability of data).

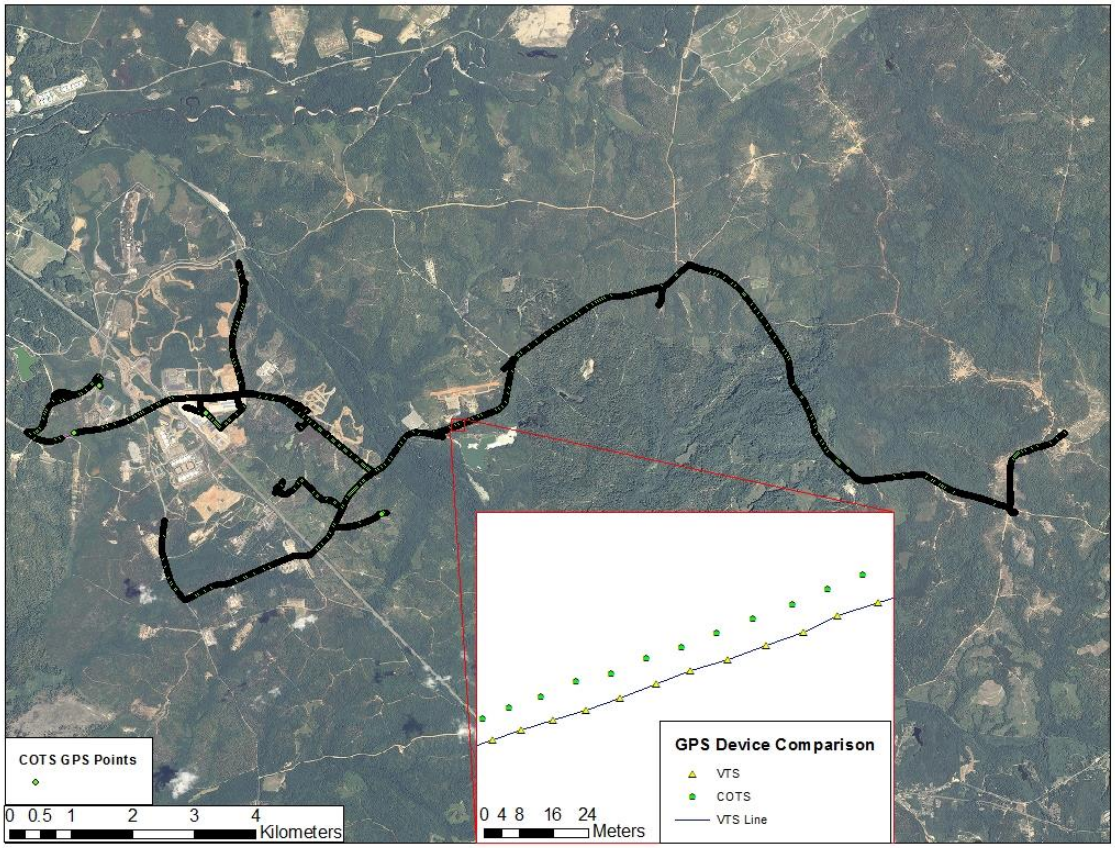
Of the ten COTS device externally mounted, there were numerous corrupt data sets between the COTS, VDM and VTS devices. As this was the first implementation of the COTS device in a field environment, there were several lessons learned from the COTS installation. The mounting of all devices was on a short time frame before vehicle movement by the unit causing some installation rushing. Data collection error occurred as two COTS devices were returned with the battery override strips still in place (no data collected), and two COTS devices were returned with loose batteries which were likely loosened when the battery override strips were removed and corrections were not made to correctly seat the batteries (no data collected).

Only four of the remaining outside COTS installations were returned with quality GPS recording data (numerous COTS devices were returned with quality data gathered from recording inside the vehicle crew compartment, but only one of those data sets was reviewed for the side by side comparison (LW202)). The COTS devices mounted outside vehicles that had both good VDM/VTS and COTS data sets were on HMMWV numbers LW152, LW154, LW202, and Stryker number STR09. LW202 had a COTS device mounted externally and internally so the internal COTS device was also analyzed.

Analysis of the comparative data sets was conducted differently than the standard accuracy testing. As the VDM/VTS were not of a demonstrably higher accuracy order than that of the COTS device neither the VDM nor VTS was considered the “true” location, instead a determination of distance between the recording of the VDM//VTS and COTS device was made, with the understanding that at a given point any of the three devices could have been closer to the true geographic location. In order to compare the devices, the coordinates of all points were plotted in a GIS and a line was drawn through the points of one GPS system. The comparison device location was compared to the line to determine the distance a point was plotted from the line. For all comparisons the VDM/VTS device points were used to create the line, and the COTS device points were subsequently compared to the line to determine point distance from the line.

Before comparisons could be made between VDM/VTS data sets and the COTS data sets, a representative data set was created. The VDM and VTS had battery life that far exceeded the battery life of the COTS device for the testing period. In order to have representative data sets the VDM/VTS data sets were trimmed to the time frame captured by the COTS device. This allowed the COTS device to be compared to only the VDM/VTS coordinates that were recorded at the same time as the COTS device data. The GPS tracking data was also broken up into segments so there was not overlapping data during comparison (to reduce the likelihood that points of different time recordings were compared to the incurred line). Figure 4-8 shows one GPS track of a VTS device (on HMMWV LW154) trimmed to the COTS device recording length then used for comparison. The insert shows a line through the VTS GPS points. An ESRI tool (near) was used to compare the distance in meters that the COTS device differed from the VTS line. This technique does not provide an absolute GPS unit accuracy, but does provide data for the like kind comparability of the two devices.

Figure 4-7 Comparison of COTS GPS Points to VDM Line at Fort Benning, GA



While the overall data set was less than desirable, there were four vehicles that had externally mounted COTS devices with both a complete COTS data set and a complete VDM or VTS data set (vehicles LW152, LW154, LW202, and STR09). Figures 4-8 thru 4-11 show the overall GPS points of each tracked vehicle based on the COTS device battery life and a selected insert to demonstrate the separation of the COTS device from the line created through the VDM/VTS data.

Figure 4-8 Comparison Data Sets for HMMWV LW154

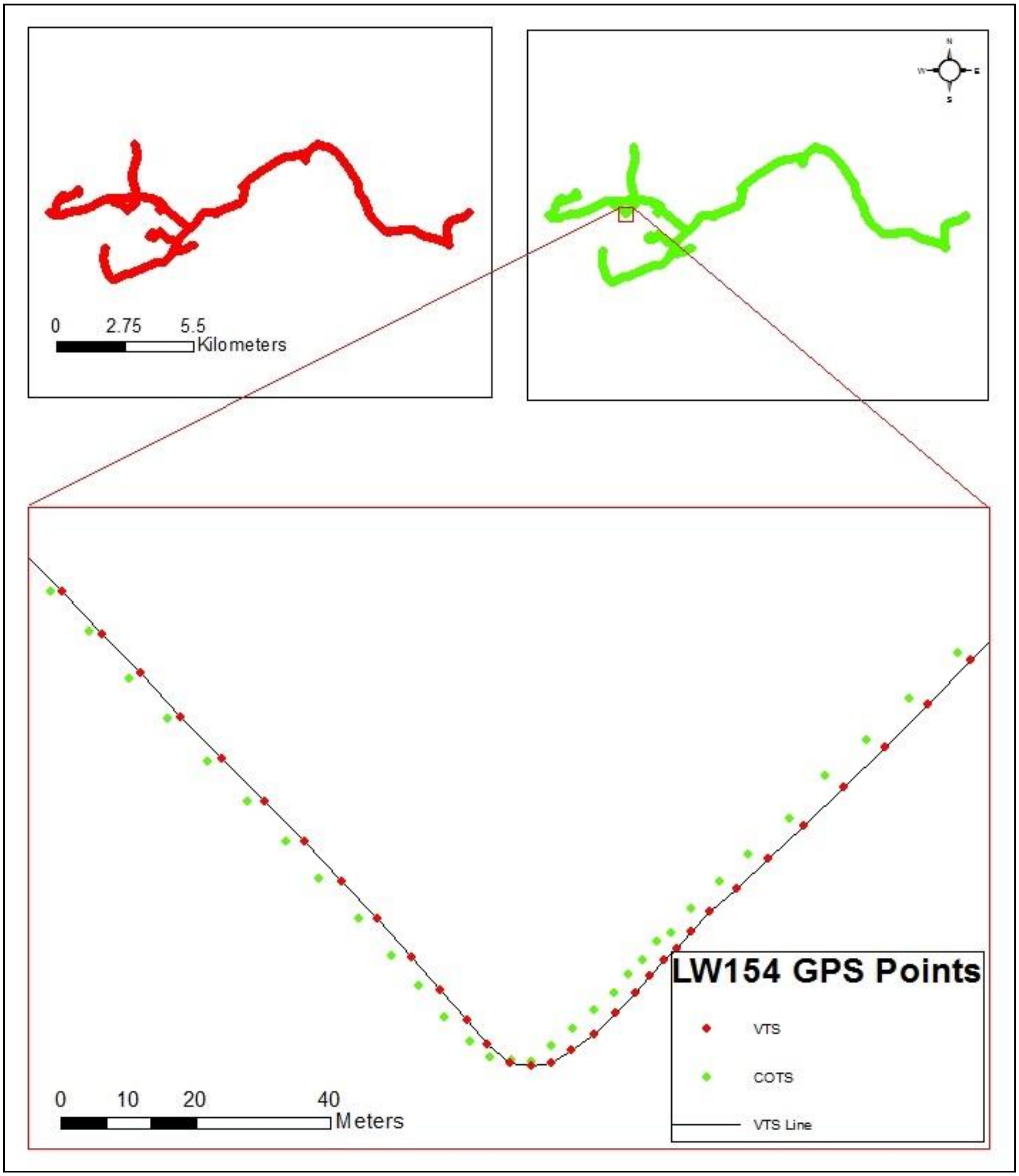


Figure 4-9 Comparison Data Sets for HMMWV LW202

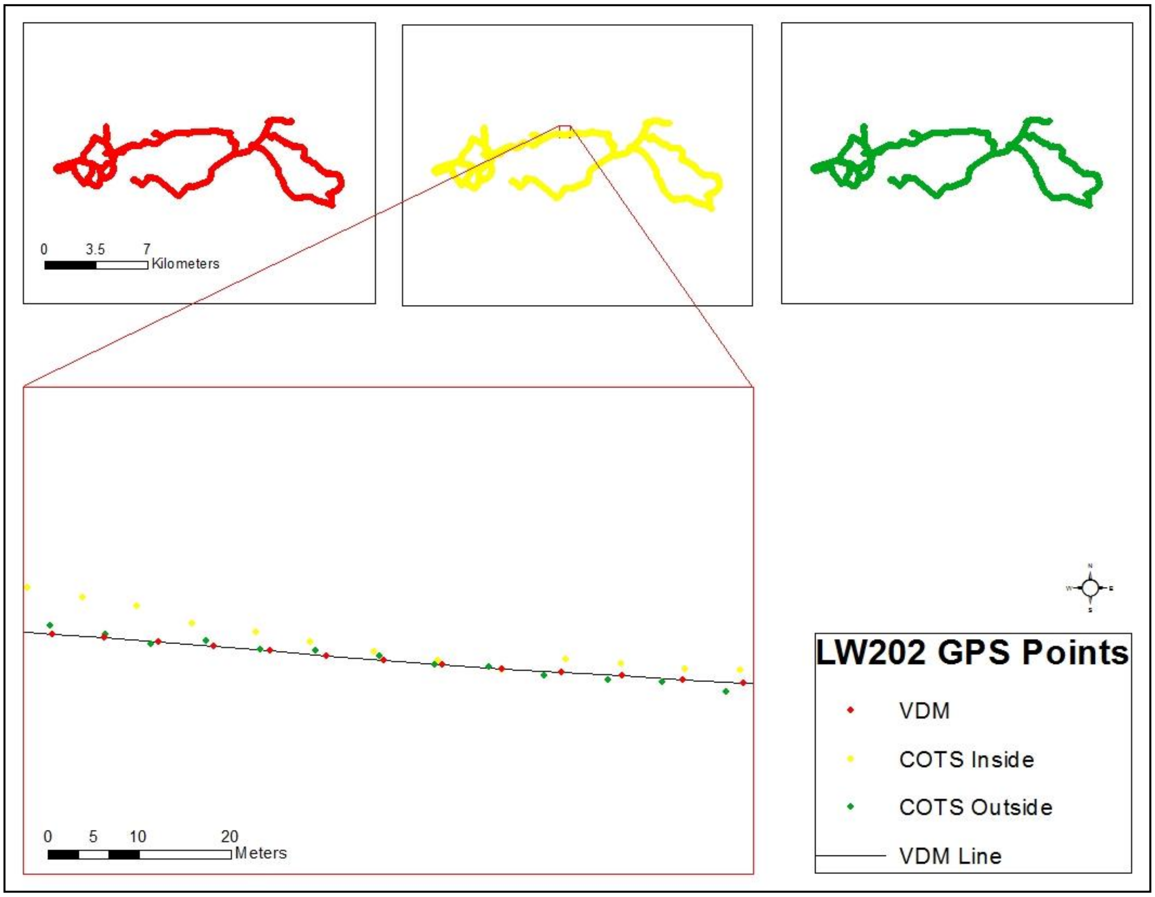


Figure 4-10 Comparison Data Sets for Stryker 13

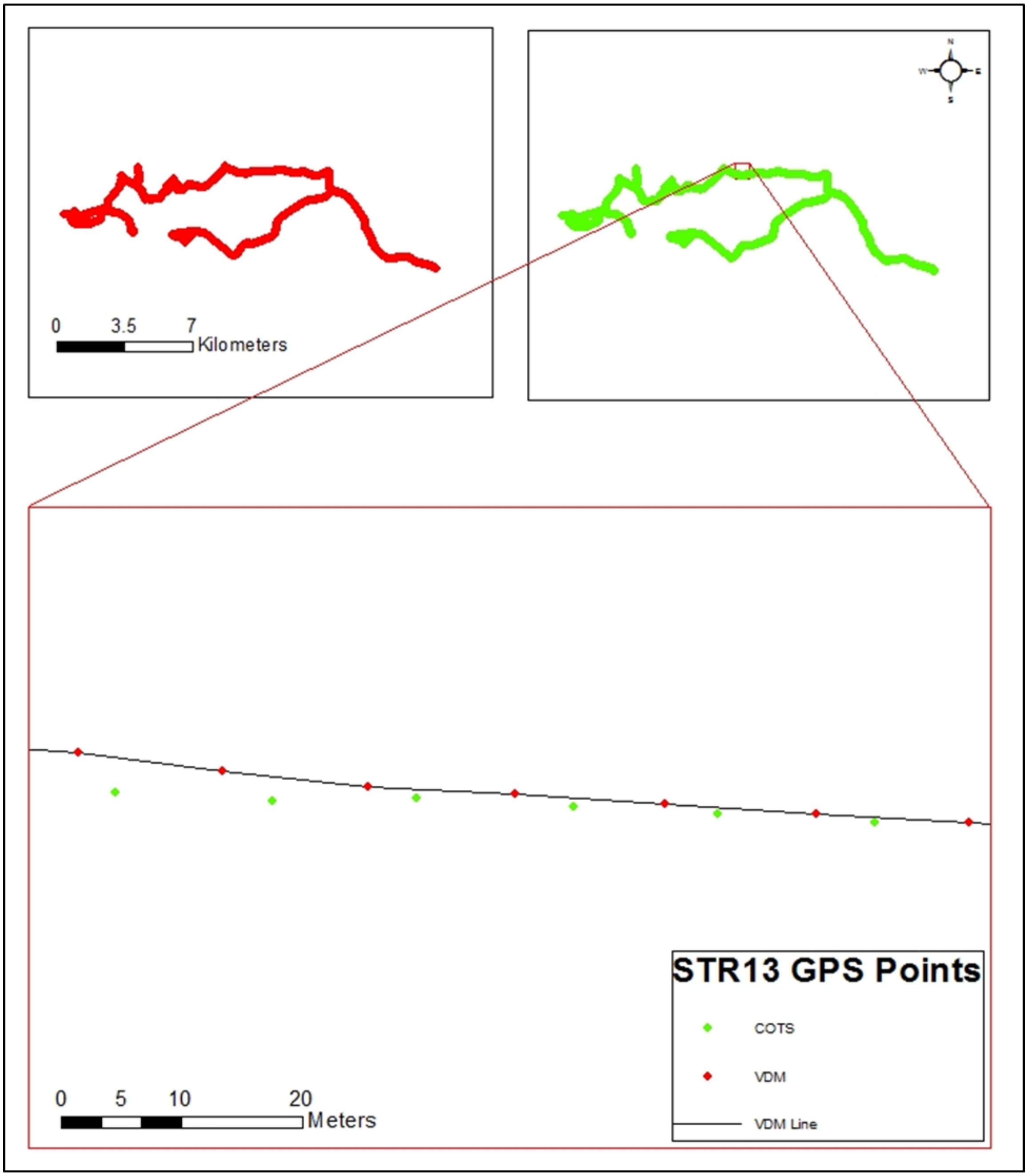
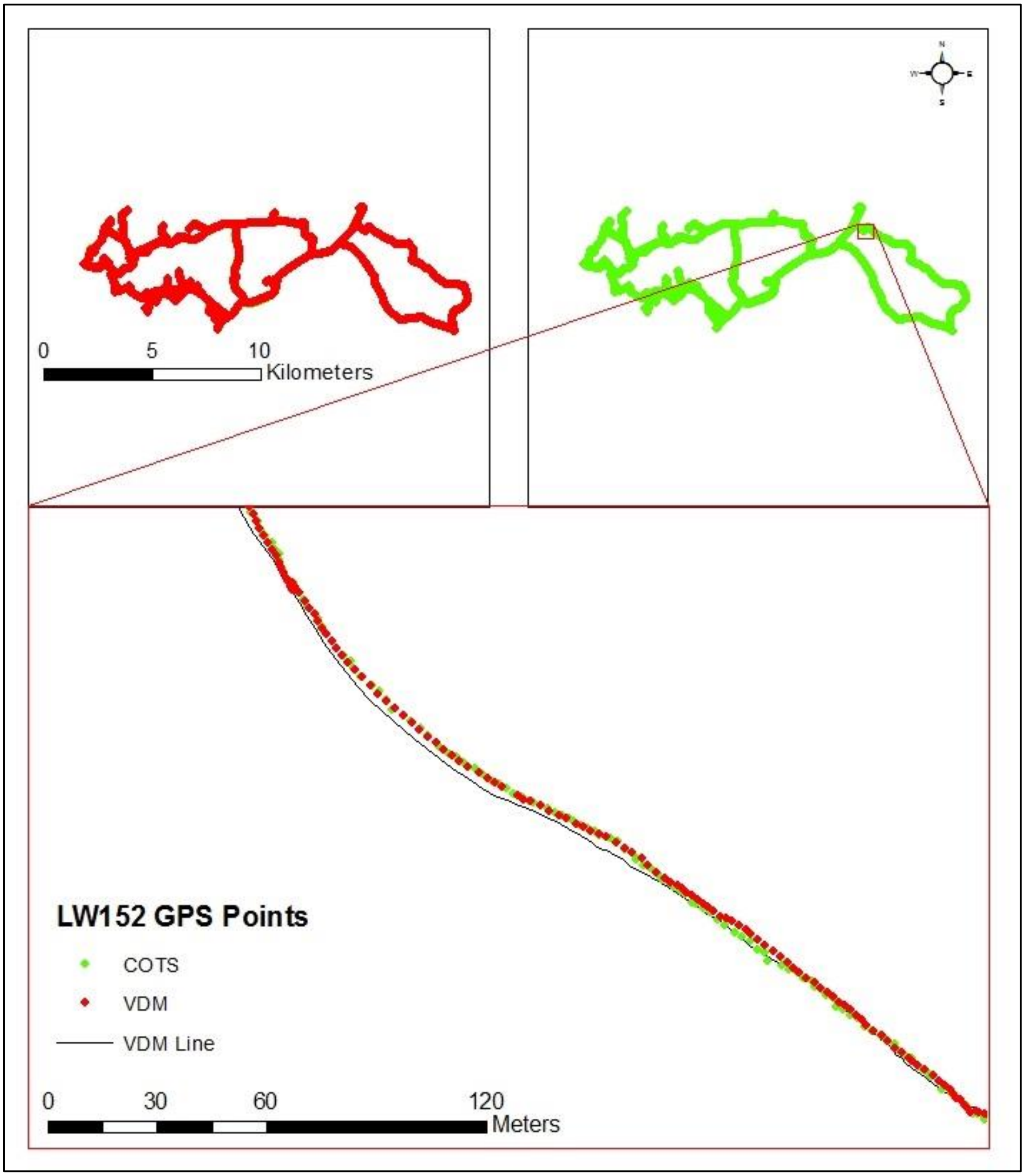


Figure 4-11 Comparison Data Sets for HMMWV LW152



Analysis of the resulting COTS/VDM/VTS data comparison is found in Table 4-5. Excluding the internally mounted device on vehicle LW202, the average distance of the COTS device from the line created by the VDM/VTS data is 2.073m. The COTS devices all had less battery life than the VDM/VTS devices only capturing 45.9% of the total GPS data of the coupled VDM/VTS device. The lone inside vehicle data set reviewed was the COTS device mounted internally on HMMWV LW202. This device recorded 45.8% of all data of the VDM device mounted on the same vehicle with an average distance from the COTS device to the VDM of 3.51m.

While with this test design, error of and individual device is not able to be precisely determined due to lack of a higher order GPS device, the range of error between the COTS device and the VDM/VTS devices is greater than the maximum errors found in the controlled accuracy test. The range of maximum error in the controlled accuracy test was the error associated with the VTS of 11.24m, whereas the difference between the VDM/VTS and the COTS device in the side by side field comparison had maximum differences exceeding 18 meters in all but one side by side comparison (LW154 8.75m). Table 4-4 displays the average distance, standard deviations of distance, and maximum distance of the COTS device from the line produced from the VDM/VTS GPS points for the same vehicle and tracking period.

Table 4-5 Comparative Analysis of COTS GPS Data During Simultaneous Field Collection with VDM/VTS GPS Devices

Comparison Vehicle: LW152	Total points	Total Distance (km)	Percentage of total VDM/VTS distance recored by COTS Device	Average Distance from VDM/VTS Line to COTS (m)	Std Dev of COTS distance from VDM/VTS line	Maximum distance from VDM/VTS line to COTS (m)
VDM LW152	41715	194.636				
COTS LW152	20522	128.092	65.8%	2.67	5.08	49.01
VTS LW154	42612	274.917				
COTS LW154	13940	86.883	31.6%	1.68	1.59	8.75
VDM LW202	44832	215.972				
COTS Outside LW202	16166	97.913	45.3%	1.61	1.31	18.6
COTS inside LW202	16276	98.976	45.8%	3.51	5.49	116.6
VDM STR13	41562	150.078				
COTS STR13	14737	70.973	47.3%	2.12	1.86	18.47

It should be noted that multiple vehicles had VDM/VTS devices functioning properly with COTS devices mounted inside of the vehicles that were not tested during this analysis. Simple mapping of that data set did indicate that some internally mounted COTS devices did not collect data while the vehicles were in motion (data collected from VDM/VTS) but did collect data after the COTS devices were recovered from the vehicles indicating a complete lack of signal during internal COTS mounting.

Discussion

Objective 1 of this research was to determine the ability of the selected COTS device to track military vehicles at a comparative accuracy level to that of the previously tested VDM and VTS devices. Analysis indicates that the COTS (2DRMS of 4.57 m to 4.68m) device may be marginally less accurate overall than the VDM (2DRMS 3.78m) or VTS (3.09m). While in the overall accuracy test indicate the accuracy may be slightly less than the VDM/VTS, the COTS devices produced accuracy levels nearly identical or exceeding those of the VDM and VTS at military operational speeds (off road training speed COTS accuracy. CERL determined accuracy requirements need for maneuver tracking GPS devices as having a positional accuracy within 5 m 95% of the time and turning radius accuracy within 10 m 95% of the time (Koch et al. 2012). The COTS devices tested met or exceeded the CERL accuracy requirements with overall accuracy just under 5 meters (4.57 to 4.68 meters during dynamic testing) and turning radius accuracy of 6.00m to 6.30m overall. When reduced to estimated military training speeds the accuracy results are further increased.

The COTS devices in direct field comparisons also indicate strong similarity to the previously tested and approved GPS devices. The COTS device when powered provides a similar data set to that of the previously tested device under similar conditions (vehicle types and speeds, terrain and canopy cover). On the limited analysis conducted with a COTS device placed inside an armored HMMWV the COTS device still was able to record data and provide a similar record of vehicle movement to that of the VDM/VTS although more analysis of inside mounting vs. exterior mounting needs to be conducted to provide significant evidence to the efficacy of the device when mounted inside a vehicle with theoretically reduced satellite signal.

The limiting factor for the COTS devices tested is the battery life. The VDM and VTS devices tested in side by side field comparisons collected data 34% to 65% longer than the COTS devices with the batteries used in the test. Results from the side by side test indicated an average battery life of 4.53 hours of moving time recorded by each device whereas the VDM and VTS average was 11.85 hours recorded over the same events. Subsequent tests conducted with the COTS using different batteries have shown a wide range of battery life based on battery type and brand. Even with battery types that are able to record more data on average the COTS devices lack the ability to expand recording life similar to VDM/VTS devices. Further tests to determine the best battery type to provide the longest operational battery life for the COTS device would need to be tested prior to wide ranging use for tracking longer training events. Other brands of civilian GPS devices may provide similar accuracy to the tested devices with longer battery life.

The tested COTS device provides comparable data to the VDM/VTS devices and could be used separately or in conjunction with the VDM/VTS to reliably track short duration military maneuver. For use in tracking longer duration events for more than a sample of training maneuver, the COTS would have to have battery replacement during the training or increased battery life.

Chapter 5 - Estimating Metrics of Maneuver Training Events Based on COTS Data through Case Studies

Introduction

Maneuver training lands provide some of the most diverse and least developed environments in parts of the U.S. Often they represent the only lands not converted to agriculture or urbanized in a particular environment. Subsequently they provide habitat to a disproportionately high number of threatened and endangered species. In addition to their natural value military lands provide a vital resource of significant strategic value as both training lands and force projection platforms. Overuse of training lands can limit their ability to be used for required training in the future (U.S. Army 2004). As such military training land managers must manage the resource not only to provide realistic training areas for current training requirements, but also in a sustainable fashion to be able to provide the needed resources for future training (U.S. Army 2004). The management of Army lands is directed under the Army Sustainable Range Program (SRP) under Army doctrine in Army Regulation 350-19 (U.S. Department of the Army 2005).

According to Army Regulation 350-19, the defined goal of the SRP is

> *"to maximize the capability, availability, and accessibility of ranges and training lands to support doctrinal requirements, mobilization, and deployments under normal and surge conditions. Within SRP—*
>
> *(1) Capability refers to the SRP core programs (the Range and Training Land Program (RTLP) and Integrated Training Area Management (ITAM)*

Program) and the continuing capacity of ranges to meet the demands dictated by the characteristics of its weapons systems and doctrinal requirements.

(2) Availability refers to the nonenvironmental facility management functions and the continuous availability of the infrastructure that is essential for safely operating the range complex.

(3) Accessibility refers to the environmental compliance and management functions and the continuous access to the land for realistic military training and testing."

Based on this goal, the task of managing the training lands is directed by the SRP to the RTLP and ITAM office at each installation. These land managers need to have the capability to determine what impacts military maneuver is having on the installation in order to make well informed management decisions. Without sound information on where, when and how military maneuvers are impacting the training lands, managers are unable to properly focus recovery efforts, understand what areas may need rested or what areas may be being underutilized.

There are some systems in place that can provide information to RTLP and ITAM about military maneuver training usage. These include range training schedules, the Range Facilities Management Support System (RFMSS), Army doctrine including: Combined Arms Training Strategies (CATS), Mission Training Plans (MTPs), and Army Training Circulars (TC). Army TC 25-1 issued as recently as 2004 provided the basic guidance on estimating the amount of training area required by unit size and type for several major training actives on an annual basis. This estimation is based on CATS and

MTPs and subject matter expert guidance. These estimates are broad area usage requirements, but do not specify provide information about specific spatial usage patterns. These estimation techniques provide some approximation of the required training area, but do not take into account specific wartime missions, training area availability, or the specific spatial relationships that may be present in training area requirements.

Beyond the basic training space requirement figures from TC 25-1 other estimations of training area usage can be figured based on RFMSS. RFMSS includes not only the range scheduling, but the unit type, a brief description of the training type and unit input on the vehicles to be used in the training. RFMSS provides a better understanding of the spatial relationships of maneuver training than the installation wide spatial scale estimate from TC 25-1, but is still limited to entire Maneuver Areas (MAs) which can be several square kilometers. RFMSS also relies on accuracy of input data by military units which can be suspect.

Simply knowing the amount of land or even the general MAs used by military units only provides limited information to military land managers. Due to the interactions of military vehicles on the landscape (often called disturbance) the difference between a highly degraded training area and an acceptable training area depends not only on the number of vehicles using the area, but the types of vehicles, the dynamic (moving) properties of the vehicles, and the natural conditions of the land at the time of disturbance (Althoff et al. 2007; Anderson et al. 2005a; Ayers 1994; Ayers et al. 2000b; Fehmi et al. 2001). More damage can occur from multiple vehicle passes than single vehicle passes (Althoff et al. 2010; Anderson et al. 2005a; Lindsey and Selim 2012; Prosser et al. 2000;

Rice 2006). The type of vehicle impacts maneuver disturbance (Anderson et al. 2005a; Anderson et al. 2005b; Goran et al. 1983; Haugen 2002; Li et al. 2007a; Liu et al. 2009; Sullivan and Anderson 2000). Heavier vehicles result in different amounts of disturbance. Maneuver disturbance varies by vehicle turning radius (Ayers 1994; Dickson et al. 2008; Liu et al. 2009). Environmental conditions such as soil type, soil moisture, and vegetative cover also affect the amount of disturbance (Althoff and Thien 2005; Althoff et al. 2010; Dickson et al. 2008).

The use of GPS devices to track military training maneuver has been successful in helping identify disturbance (Ayers et al. 2000a; Haugen 2002; Haugen et al. 2003a; Koch et al. 2012). The United States Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) in partnership with researchers at several universities have developed GPS data loggers for use in tracking maneuver training (Koch et al. 2012). These systems called the VTS and VDM (or VDMTS) have been implemented in several research studies to help further develop GPS tracking capabilities (Koch et al. 2012). The devices have also been used on small scale limited basis studies of military maneuver impacts. For example the VDM and VTS devices have been used to track military maneuver near the endangered red-cockaded woodpecker’s habitat on Fort Benning, GA. These devices have been reviewed for wider use as land management tools (Koch et al. 2012). These GPS devices have several limitations including complexity of use, size, and cost. A low cost Civilian Off The Shelf (COTS) device was selected and tested to determine if it could provide the same information with reduced costs and complexity.

In the previous chapter, the COTS device tested provided data that was similar to the VDM or VTS data in accuracy and composition. The device also was able to record data from military maneuvers at Fort Benning, GA. This research will use the previously tested COTS device in an attempt to quantify specific training by unit to training area disturbance. This research is designed to test under nearly ideal conditions (not laboratory conditions, but relatively similar conditions compared to the wide range of training conditions possible) what proportions of select training metrics can be determined by specific categories. In this research units were tracked while conducting a training exercise and the GPS data was partitioned into categories then analyzed to determine if there is a difference within specific recorded metrics. The categories the data was divided into were unit based (platoon/company/battalion) and vehicle type based (ex. M1A2 Abrams Tank, HMMWV etc.). The metrics compared were the total distance traveled, distance traveled off road, average speed, average speed off road, percent of total training time spent moving, percent of training time spent moving off road, and the percent of training time spent moving off road with a turning radius less than 30 meters.

U.S. Army Structure

In order to understand some of the important aspects of how this research was conducted a limited understanding of Army organizations and training regimes is required. The Army is a hierarchical structure going from large to small organizational element in the following order Army, Corps, Division, Brigade, Battalion, Company, Platoon, Squad, Team, Soldier. There are different types of units within this basic structure, examples include infantry brigades, armor brigades, and engineer brigades. The unit participating in this research, First Armored Brigade Combat Team, First Infantry Division (1ABCT/1ID) is a specific type of brigade, the Armored Brigade Combat Team (ABCT) with a modular formation similar in force structure to all other ABCTs in the Army. All ABCTs contain approximately 3,700 Soldiers split between one Armored Reconnaissance Squadron (also known as Cavalry), two Combined Arms Battalions (CAB), one Field Artillery (FA) Battalion, one Special Troops Battalion (STB), and one Brigade Support Battalion (BSB). Within the ABCT the two combined arms battalions and the reconnaissance squadron provide the vast majority of the units that conduct maneuver training while the other units primarily provide other auxiliary functions and therefore require less maneuver training (intelligence, communications, medical and mechanical support).

The force structure of the Brigade Combat Team (BCT) is designed to make it a deployable unit with internal capabilities sufficient to provide most of its own support and needed combat power. As all ABCTs are manned and equipped similarly they are supposed to be able to be conduct similar missions allowing them to rotate into combat areas and take over for other ABCTs with minimal force structure changes. This modular concept also applies to the Army's two other BCT formations the Infantry Brigade Combat Team (IBCT) and the Stryker Brigade Combat Team (SBCT), where any one IBCT is considered nearly equivalent in capability and structure to any other IBCT. There are significant differences in manning, equipment and capabilities between the ABCT, IBCT and SBCT. All of these formations are relatively new concepts having been implemented in their current forms over the past decade where they replaced a division centered Army. The current modular design allows the Army the flexibility to deploy an individual brigade instead of an entire division. Further revisions of the force structure within each BCT are currently being implemented, with the addition of a third CAB, a change to the structure of the FA battalion, and the change of the STB into an engineer focused organization the Brigade Engineer Battalion (BEB). These changes will impact the missions a BCT is capable of conducting. The numbers of BCTs in the Army is also changing due to the force structure changes within each BCT and due to budget considerations (available current estimates are for 12 ABCTs, 14 IBCTs, and 7 SBCTs).

Methods and Materials

Site Description: Fort Riley

Fort Riley is a U.S. Army military installation located in the north central to northeast portion of the state of Kansas, U.S.A. Fort Riley occupies a portion of three different counties, Clay, Geary and Riley Counties in Kansas with the majority in Riley County. It is bounded on the south by the Kansas River near the confluence of the Republican and Smokey Rivers. The cities of Junction City (population approx. 21,000), Ogden (population approx. 2000), Riley (population approx. 1,000), Milford (population approx. 900) and Keats (population approx. 400) are adjacent to the installation boundaries, with the city of Manhattan (population approx. 52,000) being approximately two miles to the east. The local climate is temperate continental with hot summers and cold dry winters. The installation area is approximately 100,775 acres, of which 70,000 acres is used for maneuver training. Fort Riley is an Army Forces Command (FORSCOM) installation with the mission of providing “trained and ready forces to meet Joint Force requirements.” The fort is the home to the Army’s First Infantry Division (1ID) also known as “The Big Red One” which includes three maneuver brigades (two armored brigades, one infantry brigade), along with one combat aviation brigade, and several separate battalions. Fort Riley's natural environment is part of the Flint Hills ecoregion and is dominated by gently rolling open topography covered primarily by tallgrass prairie (big bluestem, indiangrass and switchgrass). There is a woodland component to the installation primarily associated with stream drainages and ravines. The area surrounding the post is covered with agricultural row crops which provide a fire break for frequent grassland fires started on the installation. The installation elevation varies from 312 to 415 meters above sea level. (Fort Riley Directorate of Public Works 2010).

Military Vehicles

Within this research various vehicle types were fitted with COTS GPS devices. The vehicle types tracked in this research are the M1A2 Abrams main battle tank, the M2A3 Bradley Infantry Fighting Vehicle, the M3A3 Bradley Cavalry Fighting Vehicle, the M7 BFIST Bradley Fire Support Team Vehicle, the M113A3 Armored Personnel Carrier (APC), the High Mobility Multipurpose Wheeled Vehicle (HMMWV), and the Light Medium Tactical Vehicle (LMTV). Each vehicle type is designed for a specific purpose, having differing missions and capabilities. Different vehicles can be expected to operate differently in maneuver training due to their differing uses. A brief description of each vehicle follows.

M1A2

The M1A2 Abrams is the US Army's current main battle tank. The M1A2 is the third generation of the M1 Abrams vehicles which entered service in 1980. It is constructed by General Dynamics. The M1A2 is the primary vehicle weapon system of armor units in the Army. The M1A2 is a tracked vehicle operated by a crew of four, a driver, loader, gunner, and the vehicle commander. The M1A2 weights 69.54 tons (approximately 140,000 lbs), is 3.66 meters wide, 9.83 meters long and has a ground pressure of 106 kN/m^2. It is powered by a 1500 hp gas turbine engine. The M1A2 is armed with a 120mm smooth more cannon along with two 7.62mm M240 machine guns and one .50 caliber M2 machine gun (General Dynamics 2013).

Figure 5-1 M1A2 Abrams Tank

M2 Bradley Fighting Vehicle Family of Vehicles

There are numerous vehicles built on the M2 Bradley platform designed by BAE systems (formerly United Defense). This tracked vehicle platform entered service in the US Army in 1981 as the M2 Bradley Fighting Vehicle. Subsequent versions of the M2 have been designed to take advantage of technological advances. The US Army currently utilizes the M2A2 Infantry Fighting Vehicle (IFV), M3A2 Cavalry Fighting Vehicle (CFV), M2A2 ODS-E (an engineer variant), M2A3 upgraded IFV, M3A3 upgraded CFV and the M7 Bradley Fire Support Vehicle (BFIST) among others. All of these vehicles use the same vehicle hull with modifications to weapons systems, communications and other ancillary devices for specific military uses. The basic M2 platform weights approximately 34.5 tons (75,500 lbs), has a 600 hp diesel engine, is 6.5 meters in length, and 3.2 meters wide (AM General LLC 2013). The vehicle requires a three person crew (driver, gunner, vehicle commander), and can carry up to six dismount Soldiers in the back. The main gun on all M2 variants is the 25mm bushmaster chain gun, there is also a 7.62mm M240 machine gun, some variants also have additional missile systems. The M2A2 IFV and M2A3 IFV are the main weapon system for mechanized infantry companies. The M3A2 CFV and M3A3 CFV are the main weapon system for mechanized cavalry units. One M7 BFIST is found in nearly all mechanized maneuver units to provide fire support.

Figure 5-2 M2A2 ODS operating on Fort Riley, KS

M113 Armored Personnel Carrier (APC)

The M113 APC production started in 1960 with over 80,000 vehicles produced in various configurations for worldwide usage since. This tracked vehicle originally operated as a carrier for infantry Soldiers, it has been replaced in that role by the M2A2/M2A3 IFVs in the US. The M113A3 is the current variant used in the US Army. The M113A3's combat weight is 12.3 tons (approximately 27,180 lbs.) powered by a 275 hp diesel engine. It is 4.86 meters lone and 2.69 meters wide (BAE Systems Inc. 2013). The vehicle requires a minimum two person crew, but can carry up to 13 total including crew. The vehicle has been fitted with numerous different weapons systems, but is normally armed with a M2 .50 caliber machine gun. The vehicle is still used in numerous capacities in the US Army. Primary functions currently include medical evacuation vehicles, mortar weapon system carriers, and command post operations. Each infantry and armor company in has one or more of these vehicles usually within the company headquarters.

Figure 5-3 A variant of the M113A3 APC used for command and control purposes

High Mobility Multi-purpose Wheeled Vehicle (HMMWV)

The HMMWV is the most widely used wheeled vehicle in the US military arsenal. It first entered service in 1984 and replaced several other small wheeled vehicles including the jeep. It is a four wheel configuration with full time four wheel drive. There are over 15 different variants in use currently. The vehicle capacity can be from two to ten. The vehicle weights of the different variants can differ significantly but are usually between 2350 kgs to 5882 kgs. Dimensions are 4.84 meters long, 1.82 meters wide (AM General LLC 2013).

Figure 5-4 HMMWV M1152 Variant with Armor Kit (GVW 5882 kg)

Family of Medium Tactical Vehicles (FMTV)

The FMTV series of vehicles is primarily used for transport of personnel and equipment. This group of vehicles manufactured by the Oshkosh Corporation includes both four and six wheeled variants. Dimensions vary considerably between variants. The FMTV tracked in this research was a Light Medium Tactical Vehicle (LMTV). The LMTV is a four wheel vehicle with an unloaded weight of 10389 kg. The vehicle has a

2268 kg payload capacity and a 5443 kg towing capacity. Its overall length is 6.74 meters and its width is 2.44 meters (Oshkosh Corperation 2010).

Figure 5-5 Four and Six Wheeled Variants of FMTV (called LMTV and MTV respectively)

Case Studies

A series of case studies were conducted using the COTS GPS device to track military maneuvers and subsequently use the data to compare the maneuver events. The case studies consisted of tracking portions of three battalions as they conducted training related maneuvers on Fort Riley, Kansas. The three battalions tracked, 4th Squadron, 4th Cavalry (4-4CAV), 1st Battalion, 16th Infantry (1-16IN), and 2nd Battalion 34th Armor (2-34AR),were all subordinate units to 1ABCT/1ID. All three battalions were operating under the same command structure (same BCT), on the same installation (Fort Riley, KS), and with similar manning levels, maintenance, budget and time on the installation since their last overseas deployment. All three units had completed individual, team, and squad level training. All units had completed the same level of vehicle live fire gunnery (firing their vehicle mounted weapon systems) and were preparing for platoon level live fire maneuver training (Table XII gunnery). All three battalions were given the same mission of conducting the maneuver training required to complete a platoon Field

Training Exercise (FTX) concluding with a platoon maneuver live fire exercise. These similarities between units provided an opportunity to compare training maneuver within and between the units under a best case scenario to determine the similarities and differences within training. Below is a description of each battalion's structure along with the specific battalion training event design and execution.

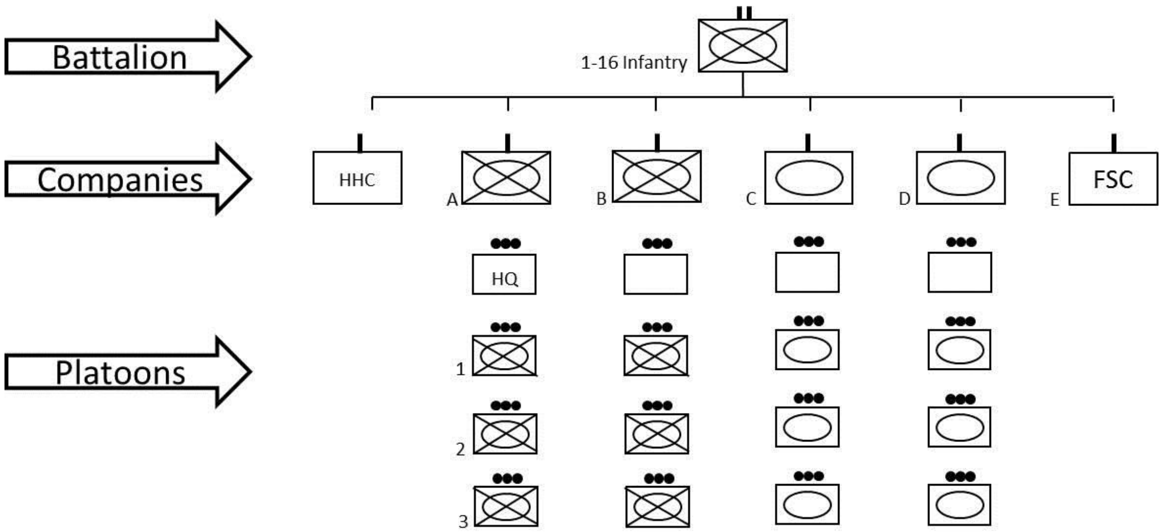
1-16 Infantry Battalion

One of the two CABs for 1ABCT/1ID is 1-16 Infantry Battalion. A CAB is the principle fighting force in the U.S. Army. All other functions in the BCT are designed to ensure the success of the two CABs. As a CAB, 1-16 Infantry has a wartime mission of providing full spectrum operations which includes closing with, maneuvering on, and destroying enemy formations.

Unit Task Organization

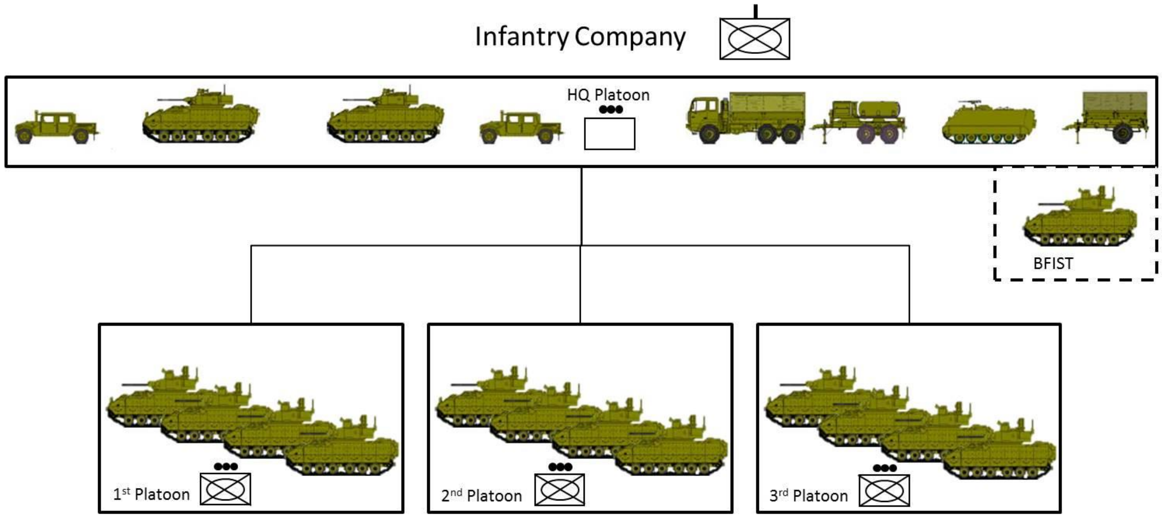
The standard design of a CAB in an ABCT consists of six companies. The Headquarters and Headquarters Company (HHC) provides command/staff functions, fires support, and intelligence to the maneuver (infantry and armor) companies. There are two infantry companies (normally designated as A company and B company) which have the direct fire capabilities of their M2A3 Bradley Infantry Fighting Vehicles, along with dismount infantry squads capable of engaging enemy targets. There are also two armor companies (normally designated as C company and D company) which have vehicles with greater lethality and survivability than the infantry companies, but do not have the capability to carry Soldiers that can dismount. The final company is a Field Support Company (FSC) which provides maintenance and logistical support to the maneuver companies. Figure 5-11 below shows the common structure of a CAB in a hierarchical fashion with the largest unit (battalion) on the top.

Figure 5-6 Simplified CAB Task Organization 1-16 Infantry Battalion



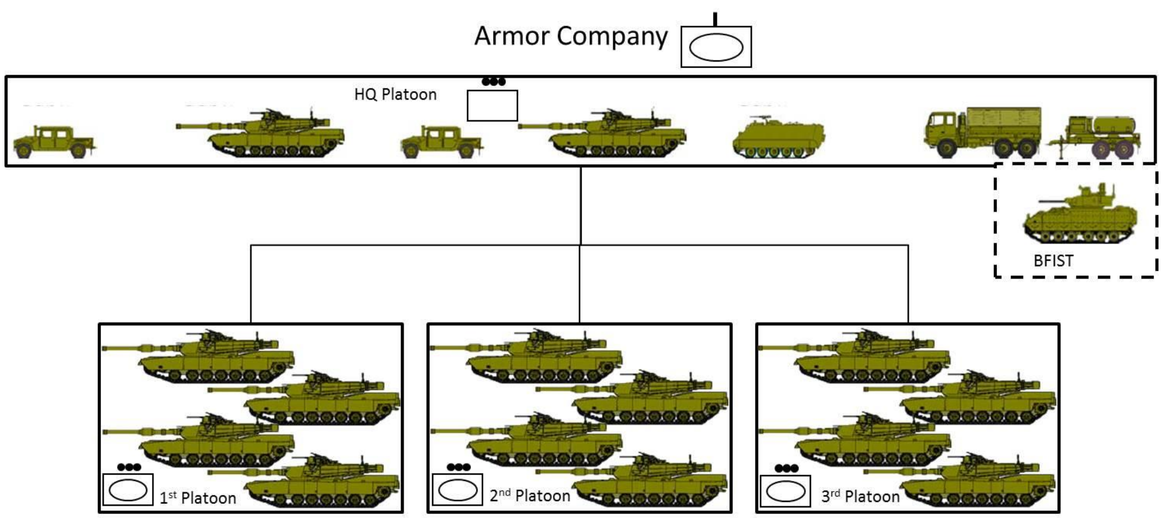
The breakdown of each maneuver company in a CAB is similar in that they have one headquarters platoon and three maneuver platoons each. The two infantry companies in each CAB have three infantry platoons, and the two armor companies have three armor platoons. Figures 5-12 provides a visual breakdown of the vehicle structure within the approximately 130 Soldier infantry company. The headquarters has two M2A3s and two HMMWVs for the company leadership, a M7 BFIST for fire support, a LMTV for company internal logistics, and a M113A3 (or variant of M113) that for command and control. Each of the three infantry platoon has four M2A3 vehicles.

Figure 5-7 Infantry Company Vehicle Organization



Figures 5-13 provides a visual breakdown of the vehicle structure within the approximately 60 Soldier armor company. The headquarters has two M1A2s and two HMMWVs for the company leadership, a M7 BFIST for fire support, a LMTV for company internal logistics, and a M113A3 (or variant of M113) that for command and control. Each of the three armor platoons has four M1A2 vehicles.

Figure 5-8 Armor Company Vehicle Organization



Training Event Design

1-16 Infantry Battalion's mission from 1ABCT/1ID was to conduct a platoon level FTX culminating in a platoon live fire exercise. The battalion scheduled the ranges and training land that the battalion staff determined would be required to conduct this training. Broad guidance from the battalion was given to the companies about the overall training goal of having platoons that were qualified on a platoon live fire exercise at completion of the training event. The battalion gave the companies the freedom to design the required platoon FTX training to ensure that the platoons would be successful on the live fire portion of the training which was ran by the battalion. The battalion established the overall schedule of when each company would be conducting dry fire (no ammo) and live fire exercises and which training areas were available to each company by day. Each company determined the individual needs of their subordinate platoons for training on the training days other than the dry and live fire. The battalion headquarters and FSC companies provided needed support in the field with stationary command posts established near the location of the live fire training.

Training Event Execution

On 06 August 2013 all units from 1-16 IN moved from Fort Riley garrison to the training area. The HHC, FSC and company HQ platoons for all four maneuver companies each established tactical operation centers in the training areas for the units to operate out of for the duration of the training. Each unit conducted its training plan for each day of training. Some units conducted dry fire and live fire towards the beginning of the training period (armor companies) while other units focused at the beginning on maneuver training and urban operations. Each company had approximately the same amount of time to conduct each type of training, but the companies did not follow similar internal training plans. One of the infantry companies, A company had several company established training lanes where they had platoons execute training against each other, in offensive and defensive operations both mounted in their vehicles and dismounted on foot. The same company had some training with no enemy forces, and other training where the enemy was a small section of their headquarters platoon. The other infantry company had more focus on urban operations training, made up some missed training by some of their platoons to prepare for the live fire, and had a lane where they used their BFIST crew operate as the enemy element. One of the armor companies, D company, started off with preparing the live fire range and conducting training focusing primarily on the live fire training along with some drivers training. All training was complete by 17 August 2013.

COTS GPS Device Installation and Recovery

COTS GPS devices were installed on 1-16 Infantry vehicles on 6 August 2013. The devices were installed on the same date as the training start date for the unit. COTS devices were only placed on vehicles from A company, B. company and D company. A & B companies are the battalions infantry companies. C&D companies are the battalion's armor companies (of which only D company participated in the research. In total 32 COTS devices were installed on the vehicles in 97 minutes by one installer. Of the 32 devices, 11 were installed on M1A2 Abrams tanks, 20 were installed on M2A3 Bradley fighting vehicles, and one was placed on a LMTV. The installation of each device consists of removing a battery override strip, checking for proper operation of device by inspecting power indication lights are on, securing of the device to the vehicle with two 20cm cable ties and tile tape for additional moisture protection. The installer also records the device COTS number, vehicle type, vehicle identification number, and unit name. Installation of the device and data recording averaged less than two minutes per vehicle. The devices were secured on the same location on each vehicle type as indicated in figures 5-14 thru 5-17 below. On the M1A2 the COTS device was placed inside of the right rear taillight cover. While this location could reduce signal to the device, the military unit recommended this mounting point as the only place on the hull of the vehicle that would not have direct impact from Soldiers stepping on the device or from vegetation striking the device during maneuver (Figure 5-14). On the M2A3 Bradley the device was placed on the right rear top portion of the hull on a cargo strap mount, this provided a secure location with a low likelihood of disturbance from or to the crew (Figure 5-15). On the LMTV the device was mounted on the right side of the vehicle on the side mirror mounting bracket (Figure 5-16). On the HMMWV the devices were mounted on the right side of the back deck lid on a cargo strap mount (Figure 5-17) this provided a clear skyview and should have been out of the way for the crews (in usage, the crews often placed ruck sacks over top of this mounting location). The devices were recovered with the battalion still conducting training on 12 August 2013. The de-installation took 1-2 minutes per vehicle including recording the power status of the device. If the device still had power at the time of recovery the batteries were removed immediately to ensure no further recording of data occurred. One COTS device was lost during training so no data was recovered.

Figure 5-9 COTS Device Mounting Location M1A2

Figure 5-10 COTS Device Mounted on M2A3, M3A3, M7 BFIST

Figure 5-11 COTS Device Mounting Location LMTV

Figure 5-12 COTS Device Mounting Location HMMWV

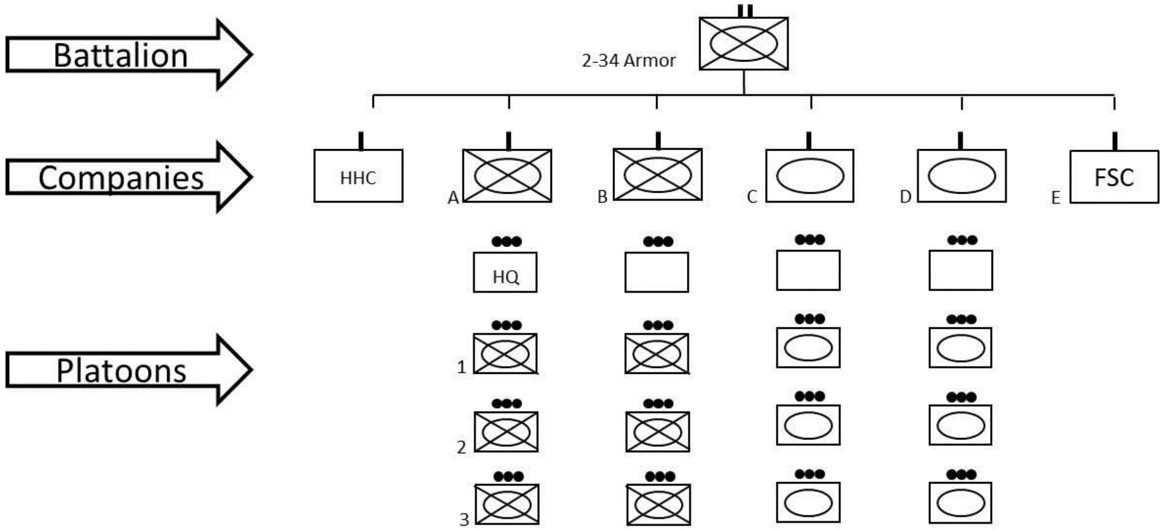
2-34 Armor Battalion

The other CAB in this research was 2-34 Armor Battalion. The battalion mission and description are the same as 1-16 Infantry.

Unit Task Organization

2-34 AR is designed nearly identical to 1-16 IN with the same number and types of companies and platoons. The battalion has the same capabilities and vehicle organization as 1-16IN (figure 5-18).

Figure 5-13 Simplified CAB Task Organization 2-34 Armor Battalion



Training Event Design

2-34 Armor Battalion's mission from 1ABCT/1ID was the same as that of 1-16 Infantry Battalion, the only differing guidance was the timeframe that the training would be conducted. While the mission to the battalion from the brigade was the same, the battalion leadership took a different approach to training the subordinate companies. Instead of conducting training of all companies in the battalion at the same time, 2-34AR staggered the training of the maneuver units. The battalion split the maneuver companies into two groups, with the infantry companies conducting their FTX training first then moving into their live fire training. Once the infantry companies had started their live fire exercise, the armor companies moved from garrison and started conducting their FTX while the infantry companies conducted their live fire. The companies were allowed to determine the training needed for each platoon during the FTX, and the battalion controlled the overall timeline and live fire.

Training Event Execution

2-34 Armor's HHC, FSC and both infantry companies (A company and B company) moved to the training areas on 16 August 2013 to start conducting platoon level FTXs. The units conducted various platoon lanes, and some maneuver training that included off road movements below the platoon level (squad level maneuver, and driver training). The infantry companies completed their FTX training and moved to live fire training on 20

The armor companies moved to the training area to start conducting their FTXs on 22 August 2013. They conducted similar maneuver training to the infantry platoons based on their companies training plans. The armor platoons completed FTX training on 27 August 2013 and then conducted live fire training.

COTS GPS Device Installation and Recovery

COTS GPS devices were installed on 2-34 Armor vehicles on two separate dates due to the battalion's divided training plan for the infantry and armor companies. On 15 August 2013 COTS devices were installed on the battalion's two infantry companies (A company and B company) prior to the vehicles moving to the training area. The units began training on 16 August 2013. A company had 15 COTS devices all of their maneuver vehicles (14 M2A3, 1 M7 BFIST), B company had 13 COTS devices placed (12 M2A3, 1 M7 BFIST). Two M2A3 for B company were not used in training. The COTS devices were recovered from A company and B company on 20 August 2013 while the units were starting their live fire gunnery. The data was downloaded and batteries were replaced. The COTS devices were installed on C company and D company vehicles on 21 August 2013. C company received 13 COTS devices, 12 on M1A2s, and one on an M7 BFIST. D company received 15 COTS devices, one on a

M113A3, one on a M7 BFIST, one on a HMMWV, and the remainder on M1A2s. The devices were left operating on C and D companies until 27 August 2013 when they were recovered. Battery status at the end of training was recorded for all devices.

4-4 Cavalry Squadron

The reconnaissance squadron for 1ABCT/1ID is the 4-4 Cavalry Squadron (the term squadron is a colloquialism that is nearly synonymous with the term battalion). 4-4 Cavalry has a wartime mission of providing full spectrum operations, but is and has operated in previous deployments similar to the other two battalions followed for this research. Based on Army doctrine the 4-4 Cavalry would have a mission of providing intelligence, surveillance and reconnaissance to the brigade. In that mission it would be out in front of the other battalions closest to the enemy trying to identify enemy forces and locations in order to give that information to the higher headquarters.

Unit Task Organization

Cavalry Squadrons in the ABCT are designed with a different personnel set and equipment that that of the CABs due to the nature of their mission. They normally consist of five troops (a troop in cavalry is synonymous with a company in an infantry or armor battalion). The Headquarters and Headquarter Troop (HHT) provides command/staff functions, fires support, and intelligence to the maneuver (cavalry) troops. There are three cavalry troops (normally listed as A troop, B troop, and C troop) which provide the combat power or fighting force for the squadron. There is also one Field Support Company (FSC) which provides maintenance and logistical support to the cavalry troops.

Figure 5-14 Simplified 4-4 Cavalry Squadron Task Organization

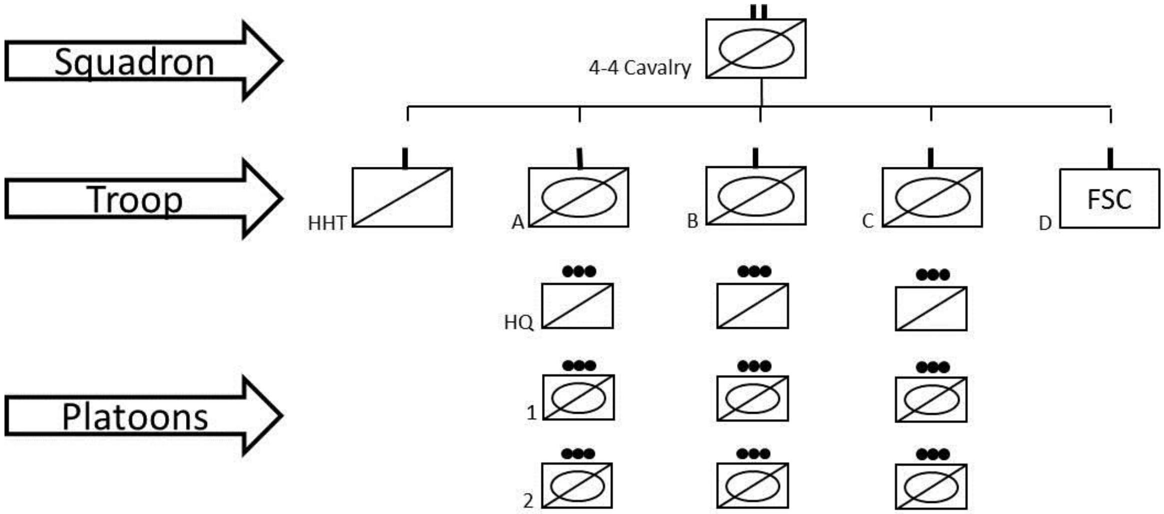
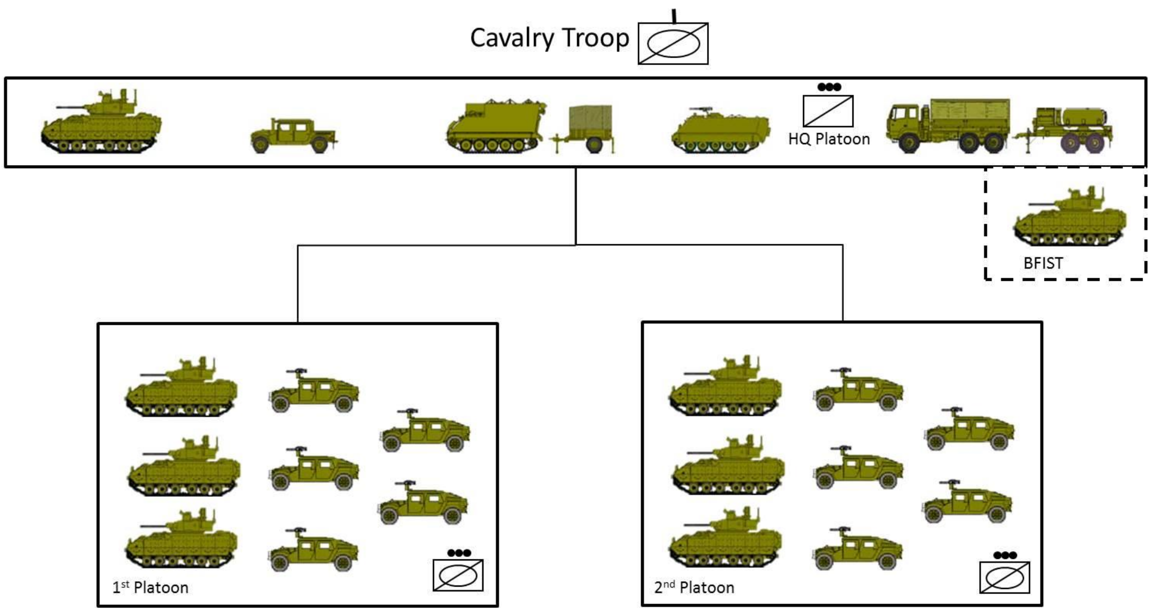


Figure 5-15 Cavalry Troop Vehicle Organization



Within each of the three Cavalry Troops there is one headquarters platoon, and two cavalry platoons (for a total of three headquarters platoons and six cavalry platoons in the squadron). The headquarters platoon is similar in function to that of the other headquarters platoons in that it provides command and control support to the maneuver platoons, it has one M3A3, one M113A3, one M7 BFIST, one LMTV, and two HMMWVs. The cavalry platoons each have four HMMWVs and three M3A3 Bradley Cavalry Fighting Vehicles.

Training Event Design

4-4 Cavalry Squadron had the same overall mission as 1-16IN and 2-34AR to conduct a platoon level FTX culminating in a platoon live fire exercise. The 4-4 Cavalry Squadron level leadership approached the training differently than the other two battalions. Instead of allowing each troop (company) to determine what training each platoon needed and to execute that training at the company level, 4-4CAV instead designed a training event that dictated the time, location and type of training each cavalry platoon would be conducting. They had six training lanes with specific missions for the platoons to execute. The training lanes included one mission each of: route reconnaissance, zone reconnaissance, area reconnaissance, area security, screen, and a gunnery table XII preparation. Some of these missions were conducted by one platoon executing by itself, other missions pitted one platoon versus another platoon. At the end of lane training the squadron would come back together and each unit would execute the live fire table XII gunnery.

Training Event Execution

4-4 CAVs FTX was conducted between 21 and 26 July 2013. The unit had reserved nearly all of Fort Riley's maneuver areas throughout the FTX portion of their training. The primary focus of the squadron's training event was on the cavalry platoons, but the squadron HHT provided a command post in the field and personnel to direct and give feedback to each platoon on their respective training lanes. The squadron's FSC provided food, fuel, mechanical and medical support to the squadron in the field during training.

On 21 July 2013 all the units moved from the Fort Riley garrison area into the maneuver training areas. The squadron headquarters, each troop headquarters, and the FSC moved into out and established command and control, and logistical networks in various maneuver areas, where they would remain throughout most of the following weeks training, with the exception of small support missions conducted from their respective sites. All six of the cavalry platoons moved from garrison and started their respective training lanes. Each lane was designed to start at approximately 2000 (8:00 pm) local time and conclude during the nighttime hours. As some platoons were conducting some platoon versus platoon training they were instructed to turn off the Blue Force Tracker ((BFT) is a GPS and GIS based system that allows military units to know where other friendly units are located). At the completion of each lane, the lane observers would conduct and After Action Review (AAR) of the training lane, and the platoons would be released from the lane and move to their respective troop headquarters location to rest and prepare for the next night's training mission. Each night the platoons would rotate in a predetermined manner so that over the course of the training each platoon would conduct each training lane one time.

During the daylight hours between missions, the platoons would rest and reset their equipment and conduct required preparation for the next mission. Much of this preparation for the next mission would occur with limited vehicle movement, but some preparation would have required additional on and off road vehicle movement. In particular, some crews were taking advantage of available training time to train additional

Soldiers on the operation of the vehicles including on and off road drivers training. After all training lanes had been executed the squadron relocated near the live fire range and prepared for the live fire exercises. No COTS GPS recording occurred during this live fire training portion for 4-4 Cavalry.

COTS GPS Device Installation and Recovery

COTS GPS devices were installed on 4-4 Cavalry vehicles on 16 and 17 July 2013. There were 32 COTS devices available. The devices were split between the three cavalry troops, (A troop, B troop, and C troop). A troop received eight COTS devices total, six were placed on M3A3 CFVs, two were placed on HMMWVs. B troop received 16 COTS devices, six were on M3A3 CFVs, 10 were on HMMWVs. C troop received eight COTS devices, three were on M3A3 CFVs, three were on HMMWVs, one was on a M7 BFIST, one was on a M113A3. All three troops from 4-4 CAV moved from garrison with the devices to start training on 21 July 2013. The units trained with the devices in place until they were recovered from the vehicles in the field on 27 July 2013. Battery status was recorded for all devices at the time of recovery.

Modeling COTS GPS Data

After recover of each COTS device the data was downloaded using the proprietary software provided with the device (Past-Track Version 9.2.0.0 from LandAirSea Systems Inc.). The Past-Track software downloads the COTS device and allows the data to be exported in a .txt file. The .txt file contains the date, Coordinated Universal Time (UTC), and coordinates in WGS 84 for each point (on a 1 second basis). This .txt file can be imported into ESRI ArcGIS for further processing. For this research the .txt file was processed using CERL tools and python scripting language to provide a shapefile output in the same format that CERL and other researchers have used with the VDM and VTS. This processing technique includes the calculation of distance traveled between points in meters, velocity, and turning radius. Using the CERL designed tools along with specific ESRI models created for this research the data was compiled into a single format for each event. The total data set contained over 2.2 million individual GPS points.

Some GPS points in the data set were removed as obvious errors in GPS data collection. These included points that exceeded 22 meters per second (49.2 mph), which exceeds the maximum speeds of all vehicles tested except for the HMMWV and LMTV, and exceeds the authorized speeds in the training area. This speed was also selected as it is greater than three standard deviations above the mean speeds recorded during all training tracked. The total number of points removed from the data set using this process was 2009 points or less than 0.1% of all points. A breakdown of points removed for each vehicle tracked can be found in appendix J.

GIS files containing information about Fort Riley (from Fort Riley ITAM) were used to further process the data. ITAM data files included installation boundaries, MAs, roads and tank trails. The roads and tank trails were merged into a single file then buffered by 30 meters (based on the ITAM roads GIS file accuracy level, and previous research indicating that a 30 meter buffer provided the best assessment for off road travel (Rice 2006). The 30 meter buffered file was used to remove the GPS points that were considered on road travel. The remaining points were considered off road maneuver training (although some on road points were likely included in the off road points and some off road maneuver would have been removed from the data set as on road movement). The total number of "off road training points" after processing was 427,614.

Research Questions

The GIS analyzed GPS data was next analyzed for eight research questions to determine if there is a statistical difference in seven possible maneuver related metrics (response variables). The seven metrics tested were:

1. Total distance traveled
2. Total distance traveled off road
3. Average total speed
4. Average off road speed
5. Percent of total training time spent moving
6. Percent of moving time spent in off road maneuver
7. Percent of off road maneuver conducted with a turning radius of less than 30 m (most damaging)

The eight research questions tested for the above metrics were:

- Question 1 (Q1): Is there a significant difference in the response variables when comparing **headquarters** platoons across all battalions?
- Question 2 (Q2): Is there a significant difference in the response variables when comparing **infantry** platoons across all battalions?
- Question 3 (Q3): Is there a significant difference in the response variables when comparing **armor** platoons across all battalions?
- Question 4 (Q4): Is there a significant difference in the response variables when comparing cavalry platoons?

- Question 5 (Q5): Is there a significant difference in the response variables when comparing the average of all **infantry** platoons in one CAB vs. the average of all **infantry** platoons in the other CAB?
- Question 6 (Q6): Is there a significant difference in the response variables when comparing the average of all **armor** platoons in one CAB vs. the average of all **armor** platoons in the other CAB?
- Question 7 (Q7): Is there a significant difference in the response variables when comparing **all** platoons across all battalions?
- Question 8 (Q8): Is there a significant difference in the response variables when comparing different **vehicle types** regardless of unit?

The hypothesis for each of these questions was that there would be no significant difference in the metrics based on the tested category. This hypothesis would equate to all unit/vehicles under the training events tested having behaved in a statistically similar manner. This hypothesis should hold true for each grouping except those in question 7 and question 8 if the assumption that unit training follows Army doctrine, and should realistically be able to be estimated based on doctrine.

Statistical Analysis

The statistical analysis for this chapter was conducted by the Kansas State University Department of Statistics. A description of the statistical tests used is provided below based on personal communication with Dr. Leigh Murray (2013):

> *"Two basic statistical analyses were performed. Both analyses had a one-way treatment structure (i.e., a single treatment factor) in a completely randomized design with subsampling (Kuehl 2000). For Q8, the treatment factor*

was Vehicle Type. For Q1-Q6, the Treatment factor was Platoon Type. For each treatment factor (Vehicle type or Platoon Type) contrasts and pairwise comparisons were conducted, depending on specific hypotheses of interest. Experimental Units were the various combinations of Vehicle Types and Platoon Types. Subsamples were individual vehicles being measured within each combination of Vehicle Types and Platoon Types. The Completely Randomized Design assumes that individual vehicles are uncorrelated with one another. This assumption is a limitation of the analyses performed.

Of the seven responses, three were based on percents (%time spent moving, %time spent moving off-road, and %time off-road with turning radius less than 30m) and four were based on absolute measurements (total distance, distance off-road, average total speed, and average speed off-road). Initial analyses for Q8 and for Q1-Q6 were performed assuming normally-distributed data, but evaluation of residuals showed that normality was not a good assumption. Therefore, percent responses were re-analyzed using the beta distribution, a common probability model used for percent data that is not based on counts (Stroup, 2012). In addition, because the responses based on absolute measurements tended to have positive skew (i.e., a long "tail" of observations on the upper end of the range of data), these responses were re-analyzed using the Gamma distribution with log-link function because the Gamma distribution is appropriate for positive measurements with an upward skew (Stroup, 2012). Analyses were performed in SAS version 9.3, using the MIXED procedure the normal distribution, and the GLIMMIX procedure for the beta and gamma *distributions. For all analyses, the following results were obtained: an overall Treatment F-test; contrasts and pairwise comparisons as appropriate for specific hypotheses; and means and standard errors An alpha level of 0.05 was used for the overall test of Treatment differences and a Bonferroni-adjusted alpha of 0.05 divided by the number of comparisons in each set of hypotheses was used for contrast and pairwise comparison tests, as appropriate"* (Murray 2013).

Results

A total of 121 vehicles were tracked during maneuver training across the three battalion sized formations. 116 vehicles had GPS tracking data after training (one device was lost during training, four vehicles with COTS devices attached never participated in training instead they were left in their unit's motorpools). A total of 35 M1A2 Abrams Tanks, 45 M2A3 Infantry Fighting Vehicles, 14 M3A3 Cavalry Fighting Vehicles, 5 M7 BFIST, 14 HMMWVs, 2 M113A3 Armored Personnel Carriers, and 1LMTV.

Event Summaries

Summaries of each event tracked are provided below. Tables 5-2 thru 5-4 below show values for the time related attributes associated with each GPS tracked vehicle broken down by the vehicle ID, vehicle type and platoon.

Table 5-1 Temporal Values of GPS Tracking 1-16 Infantry Battalion's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	VEHICLE TYPE	Hours of Recorded GPS Points	Total Days of Training Time Recorded	Percent of Training time spent moving (hours)	Hours moving per day
A11	1/A/1-16IN	M2A3	6.26	5.88	4.44%	1.07
A13	1/A/1-16IN	M2A3	4.24	4.76	3.71%	0.89
A14	1/A/1-16IN	M2A3	4.87	5.56	3.65%	0.88
A21	2/A/1-16IN	M2A3	8.09	5.77	5.84%	1.40
A22	2/A/1-16IN	M2A3	7.61	5.66	5.60%	1.34
A23	2/A/1-16IN	M2A3	8.12	6.02	5.62%	1.35
A24	2/A/1-16IN	M2A3	7.93	5.80	5.69%	1.37
A31	3/A/1-16IN	M2A3	5.89	5.96	4.11%	0.99
A34	3/A/1-16IN	M2A3	4.78	6.02	3.31%	0.79
B11	1/B/1-16IN	M2A3	6.79	5.32	5.31%	1.27
B12	1/B/1-16IN	M2A3	3.10	1.11	11.66%	2.80
B13	1/B/1-16IN	M2A3	8.43	5.94	5.91%	1.42
B14	1/B/1-16IN	M2A3	8.71	5.46	6.64%	1.59
B21	2/B/1-16IN	M2A3	7.35	5.74	5.34%	1.28
B22	2/B/1-16IN	M2A3	7.96	5.99	5.54%	1.33
B23	2/B/1-16IN	M2A3	8.15	5.73	5.92%	1.42
B24	2/B/1-16IN	M2A3	6.72	5.97	4.69%	1.13
B31	3/B/1-16IN	M2A3	2.19	5.16	1.77%	0.42
B34	3/B/1-16IN	M2A3	4.84	2.19	9.20%	2.21
D11	1/D/1-16IN	M1A2	6.41	4.05	6.60%	1.58
D12	1/D/1-16IN	M1A2	12.00	5.82	8.58%	2.06
D13	1/D/1-16IN	M1A2	4.00	2.93	5.68%	1.36
D14	1/D/1-16IN	M1A2	4.58	3.11	6.14%	1.47
D21	2/D/1-16IN	M1A2	16.25	2.93	23.14%	5.55
D22	2/D/1-16IN	M1A2	5.82	4.49	5.41%	1.30
D23	2/D/1-16IN	M1A2	4.41	4.34	4.23%	1.02
D24	2/D/1-16IN	M1A2	5.54	3.43	6.73%	1.62
D31	3/D/1-16IN	M1A2	6.97	3.59	8.09%	1.94
D40	HQ/D/1-16IN	LMTV	5.90	1.47	16.70%	4.01
D65	HQ/D/1-16IN	M1A2	3.72	4.14	3.74%	0.90
D66	HQ/D/1-16IN	M1A2	4.46	3.90	4.77%	1.14

Table 5-2 Temporal Values of GPS Tracking 2-34 Armor Battalion's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	VEHICLE TYPE	Hours of Recorded GPS Points	Total Days of Training Time Recorded	Percent of Training time spent moving	Hours moving per day
A11	1/A/2-34AR	M2A3	7.43	3.76	8.23%	1.98
A12	1/A/2-34AR	M2A3	5.67	3.77	6.28%	1.51
A13	1/A/2-34AR	M2A3	6.42	3.72	7.18%	1.72
A14	1/A/2-34AR	M2A3	6.07	3.72	6.79%	1.63
A21	2/A/2-34AR	M2A3	6.28	3.55	7.36%	1.77
A22	2/A/2-34AR	M2A3	6.02	3.55	7.06%	1.69
A23	2/A/2-34AR	M2A3	4.76	3.93	5.04%	1.21
A24	2/A/2-34AR	M2A3	4.61	3.56	5.39%	1.29
A30	HQ/A/2-34AR	M7 BFIST	4.32	4.20	4.29%	1.03
A31	3/A/2-34AR	M2A3	5.21	4.09	5.30%	1.27
A32	3/A/2-34AR	M2A3	4.45	4.09	4.53%	1.09
A33	3/A/2-34AR	M2A3	3.99	4.09	4.06%	0.98
A34	3/A/2-34AR	M2A3	3.79	4.09	3.86%	0.93
A65	HQ/A/2-34AR	M2A3	1.04	4.12	1.67%	0.25
A66	HQ/A/2-34AR	M2A3	6.10	4.17	6.09%	1.46
B11	1/B/2-34AR	M2A3	2.74	3.09	3.69%	0.89
B12	1/B/2-34AR	M2A3	2.85	3.33	3.56%	0.85
B13	1/B/2-34AR	M2A3	2.53	2.32	4.53%	1.09
B14	1/B/2-34AR	M2A3	1.73	1.07	6.72%	1.61
B21	2/B/2-34AR	M2A3	1.62	0.42	16.06%	3.85
B22	2/B/2-34AR	M2A3	7.04	3.76	7.79%	1.87
B23	2/B/2-34AR	M2A3	6.93	4.57	6.32%	1.52
B24	2/B/2-34AR	M2A3	6.86	3.76	7.60%	1.82
B30	HQ/B/2-34AR	M7 BFIST	3.28	4.07	3.36%	0.81
B31	3/B/2-34AR	M2A3	3.62	3.86	3.91%	0.94
B32	3/B/2-34AR	M2A3	4.11	3.92	4.36%	1.05
B33	3/B/2-34AR	M2A3	4.72	3.84	5.11%	1.23
B34	3/B/2-34AR	M2A3	2.56	2.25	4.74%	1.14
C11	1/C/2-34AR	M1A2	5.54	5.23	4.41%	1.06
C13	1/C/2-34AR	M1A2	4.46	2.75	6.77%	1.63
C14	1/C/2-34AR	M1A2	2.53	5.09	2.07%	0.50
C21	2/C/2-34AR	M1A2	4.79	2.75	7.27%	1.75
C22	2/C/2-34AR	M1A2	3.74	3.80	4.10%	0.98
C23	2/C/2-34AR	M1A2	4.52	3.08	6.12%	1.47
C24	2/C/2-34AR	M1A2	3.24	4.02	3.36%	0.81
C30	HQ/C/2-34AR	M7 BFIST	0.66	3.84	0.71%	0.17
C31	3/C/2-34AR	M1A2	5.75	3.45	6.95%	1.67
C32	3/C/2-34AR	M1A2	4.14	3.30	5.23%	1.26
C33	3/C/2-34AR	M1A2	4.02	3.50	4.78%	1.15
C34	3/C/2-34AR	M1A2	1.24	5.00	1.03%	0.25
C66	HQ/C/2-34AR	M1A2	4.37	3.41	5.35%	1.28
D11	1/D/2-34AR	M1A2	6.80	4.43	6.40%	1.54
D12	1/D/2-34AR	M1A2	5.32	4.99	4.44%	1.07
D14	1/D/2-34AR	M1A2	3.71	3.30	4.68%	1.12
D21	2/D/2-34AR	M1A2	3.59	3.10	4.83%	1.16
D22	2/D/2-34AR	M1A2	3.09	2.96	4.36%	1.05
D23	2/D/2-34AR	M1A2	4.80	3.08	6.49%	1.56
D24	2/D/2-34AR	M1A2	4.87	4.33	4.69%	1.13
D30	HQ/D/2-34AR	M7 BFIST	5.50	5.05	4.53%	1.09
D31	3/D/2-34AR	M1A2	4.96	3.32	6.21%	1.49
D32	3/D/2-34AR	M1A2	5.32	4.99	4.44%	1.07
D33	3/D/2-34AR	M1A2	4.62	5.31	3.63%	0.87
D34	3/D/2-34AR	M1A2	4.47	4.91	3.80%	0.91
D6	HQ/D/2-34AR	HMMWV	3.37	4.59	3.06%	0.73
D65	HQ/D/2-34AR	M1A2	3.54	3.14	4.70%	1.13
D77	HQ/D/2-34AR	M113	3.27	4.51	3.02%	0.72

Table 5-3 Temporal Values of GPS Tracking 4-4 Cavalry Squadron's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	VEHICLE TYPE	Hours of Recorded GPS Points	Total Days of Training Time Recorded	Percent of Training time spent moving (hours)	Hours moving per day
A11	1/A/4-4 CAV	M3A3	7.52	4.42	7.10%	1.70
A12	1/A/4-4 CAV	M3A3	8.85	3.66	10.07%	2.42
A14	1/A/4-4 CAV	HMMWV	6.92	5.30	5.44%	1.31
A15	1/A/4-4 CAV	M3A3	10.63	5.34	8.29%	1.99
A21	2/A/4-4 CAV	M3A3	8.85	2.70	13.65%	3.28
A22	2/A/4-4 CAV	M3A3	10.11	5.31	7.94%	1.91
A25	2/A/4-4 CAV	M3A3	10.41	4.72	9.19%	2.21
B11	1/B/4-4 CAV	M3A3	7.98	4.57	7.26%	1.74
B12	1/B/4-4 CAV	M3A3	8.33	4.50	7.70%	1.85
B13	1/B/4-4 CAV	HMMWV	2.17	1.39	6.51%	1.56
B14	1/B/4-4 CAV	HMMWV	3.64	2.43	6.25%	1.50
B16	1/B/4-4 CAV	HMMWV	5.36	3.42	6.53%	1.57
B17	1/B/4-4 CAV	HMMWV	5.33	3.30	6.72%	1.61
B21	2/B/4-4 CAV	M3A3	9.53	5.33	7.44%	1.79
B22	2/B/4-4 CAV	M3A3	10.06	4.73	8.85%	2.12
B23	2/B/4-4 CAV	HMMWV	8.51	4.34	8.17%	1.96
B24	2/B/4-4 CAV	HMMWV	5.82	2.62	9.26%	2.22
B25	2/B/4-4 CAV	M3A3	11.00	5.41	8.46%	2.03
B26	2/B/4-4 CAV	HMMWV	6.76	2.59	10.88%	2.61
B27	2/B/4-4 CAV	HMMWV	5.13	3.55	6.02%	1.44
B28	2/B/4-4 CAV	HMMWV	5.85	2.62	9.30%	2.23
C11	1/C/4-4 CAV	M3A3	4.21	2.57	6.82%	1.64
C14	1/C/4-4 CAV	HMMWV	5.53	2.88	8.00%	1.92
C21	2/C/4-4 CAV	M3A3	4.97	2.56	8.07%	1.94
C26	2/C/4-4 CAV	HMMWV	5.86	2.40	10.20%	2.45
C66	HQ/C/4-4 CAV	M3A3	1.38	0.06	0.91%	N/A
C7	HQ/C/4-4 CAV	HMMWV	1.98	0.08	1.30%	N/A
C77	HQ/C/4-4 CAV	M113	1.59	6.33	1.05%	0.25
C95	HQ/C/4-4 CAV	M7 BFIST	2.17	1.39	6.51%	1.56

Tables 5-5 thru 5-7 below provide the summary values used in statistical analysis of the GPS data from each of the three training events based on movement.

Table 5-4 Movement Based Values of GPS Tracking 1-16 Infantry's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	Total Distance (km)	Off Road Distance (km)	Averge Total Speed (m/sec)	Average Off Road Speed (m/s)	Percent of GPS Points Off Road	Percent of Off Road Points with a Turning Radius less than 30 m
A11	1/A/1-16IN	131.53	22.51	5.84	3.81	26.25%	52.73%
A13	1/A/1-16IN	86.61	14.90	5.68	3.10	31.51%	59.16%
A14	1/A/1-16IN	101.03	14.76	5.76	3.05	27.59%	58.12%
A21	2/A/1-16IN	182.44	12.07	6.27	3.11	13.33%	59.18%
A22	2/A/1-16IN	176.21	12.83	6.43	3.40	13.78%	58.88%
A23	2/A/1-16IN	185.04	12.15	6.33	3.24	12.84%	60.90%
A24	2/A/1-16IN	172.68	13.90	6.05	2.81	17.35%	64.79%
A31	3/A/1-16IN	136.49	9.81	6.44	3.88	11.95%	52.29%
A34	3/A/1-16IN	110.03	8.12	6.39	3.48	13.57%	58.96%
B11	1/B/1-16IN	162.89	13.12	6.67	3.13	17.16%	57.68%
B12	1/B/1-16IN	82.76	3.74	7.42	2.52	13.30%	65.50%
B13	1/B/1-16IN	207.08	21.09	6.82	3.76	18.50%	50.65%
B14	1/B/1-16IN	217.92	17.44	6.95	3.25	17.09%	56.29%
B21	2/B/1-16IN	184.22	17.29	6.96	3.05	21.42%	60.54%
B22	2/B/1-16IN	200.48	16.27	7.00	3.40	16.70%	56.81%
B23	2/B/1-16IN	207.84	16.82	7.09	3.56	16.08%	56.21%
B24	2/B/1-16IN	172.35	16.60	7.12	3.62	18.92%	53.24%
B31	3/B/1-16IN	60.66	1.75	7.70	2.73	8.14%	67.08%
B34	3/B/1-16IN	137.34	8.26	7.89	3.11	15.25%	61.68%
D11	1/D/1-16IN	130.44	13.80	5.66	4.18	14.31%	51.73%
D12	1/D/1-16IN	289.01	13.75	6.70	3.89	8.19%	54.57%
D13	1/D/1-16IN	81.56	11.55	5.67	4.02	19.99%	51.95%
D14	1/D/1-16IN	89.80	11.69	5.45	3.64	19.45%	55.95%
D21	2/D/1-16IN	376.32	21.07	6.44	3.80	9.50%	56.05%
D22	2/D/1-16IN	111.29	8.60	5.31	3.85	10.65%	55.31%
D23	2/D/1-16IN	99.27	6.67	6.25	3.35	12.55%	61.16%
D24	2/D/1-16IN	113.82	9.71	5.71	3.63	13.43%	58.59%
D31	3/D/1-16IN	174.50	8.36	6.97	3.44	9.71%	60.12%
D40	HQ/D/1-16IN	166.86	3.74	7.86	3.39	5.20%	55.67%
D65	HQ/D/1-16IN	77.83	6.50	5.82	3.63	13.40%	55.61%
D66	HQ/D/1-16IN	82.70	10.62	5.54	4.09	17.36%	54.90%

Table 5-5 Movement Based Values of GPS Tracking 2-34 Armor Battalion's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	Total Distance (km)	Off Road Distance (km)	Averge Total Speed (m/sec)	Average Off Road Speed (m/s)	Percent of GPS Points Off Road	Percent of Off Road Points with a Turning Radius less than 30 m
A11	1/A/2-34AR	131.48	15.45	4.92	2.70	21.37%	61.18%
A12	1/A/2-34AR	103.72	11.01	5.08	3.32	16.26%	57.95%
A13	1/A/2-34AR	113.11	12.26	4.90	2.87	18.52%	59.32%
A14	1/A/2-34AR	108.09	10.51	4.95	2.91	16.56%	58.74%
A21	2/A/2-34AR	126.54	23.24	5.60	2.99	34.43%	59.01%
A22	2/A/2-34AR	122.30	29.03	5.65	3.36	39.94%	53.82%
A23	2/A/2-34AR	96.23	20.16	5.62	3.33	35.40%	53.27%
A24	2/A/2-34AR	91.91	17.49	5.54	3.12	33.81%	60.14%
A30	HQ/A/2-34AR	90.58	4.32	5.83	2.95	9.42%	62.02%
A31	3/A/2-34AR	101.78	13.00	5.44	3.17	21.92%	62.72%
A32	3/A/2-34AR	82.78	11.29	5.17	2.83	24.92%	65.21%
A33	3/A/2-34AR	76.88	8.25	5.35	2.94	19.52%	64.30%
A34	3/A/2-34AR	73.87	7.45	5.42	3.23	16.91%	59.55%
A65	HQ/A/2-34AR	30.39	1.04	8.14	3.26	8.52%	64.47%
A66	HQ/A/2-34AR	120.81	10.62	5.50	3.53	13.69%	57.07%
B11	1/B/2-34AR	57.87	5.73	5.87	2.56	22.67%	66.74%
B12	1/B/2-34AR	71.87	8.41	7.01	3.72	22.09%	52.78%
B13	1/B/2-34AR	51.37	5.51	5.65	2.54	23.86%	65.27%
B14	1/B/2-34AR	43.14	3.02	6.94	2.96	16.39%	57.41%
B21	2/B/2-34AR	36.30	2.63	6.22	3.26	13.82%	53.90%
B22	2/B/2-34AR	133.61	7.90	5.28	3.50	8.92%	51.04%
B23	2/B/2-34AR	127.72	8.05	5.12	3.36	9.60%	53.76%
B24	2/B/2-34AR	125.18	7.19	5.07	3.32	8.77%	55.15%
B30	HQ/B/2-34AR	71.87	2.22	6.08	2.25	8.37%	66.16%
B31	3/B/2-34AR	74.87	6.83	5.74	2.61	20.10%	63.98%
B32	3/B/2-34AR	93.40	8.96	6.31	3.01	20.11%	59.35%
B33	3/B/2-34AR	109.32	9.62	6.44	3.13	18.10%	58.37%
B34	3/B/2-34AR	67.27	2.73	7.31	3.90	7.63%	44.16%
C11	1/C/2-34AR	96.82	13.86	4.87	3.10	22.49%	68.05%
C13	1/C/2-34AR	79.78	11.60	4.97	3.14	22.99%	64.81%
C14	1/C/2-34AR	46.64	3.46	5.13	2.73	13.95%	72.91%
C21	2/C/2-34AR	86.03	9.16	4.99	3.89	13.64%	56.29%
C22	2/C/2-34AR	85.77	14.87	6.37	5.41	20.39%	40.71%
C23	2/C/2-34AR	79.40	11.00	4.88	3.37	20.02%	59.77%
C24	2/C/2-34AR	70.81	13.01	6.08	4.65	24.02%	45.10%
C30	HQ/C/2-34AR	12.08	1.28	5.31	3.41	16.53%	62.50%
C31	3/C/2-34AR	94.02	9.78	4.54	3.03	15.58%	63.21%
C32	3/C/2-34AR	73.18	7.91	4.92	3.48	15.25%	58.04%
C33	3/C/2-34AR	73.00	4.96	5.05	3.17	10.80%	64.28%
C34	3/C/2-34AR	30.49	0.87	6.85	2.54	7.70%	69.39%
C66	HQ/C/2-34AR	76.68	2.74	4.87	2.71	6.44%	64.66%
D11	1/D/2-34AR	124.02	21.50	5.06	3.19	27.57%	61.66%
D12	1/D/2-34AR	104.91	18.42	5.48	3.38	28.47%	56.08%
D14	1/D/2-34AR	69.00	15.38	5.18	3.44	33.53%	54.03%
D21	2/D/2-34AR	82.80	3.09	6.43	3.73	6.44%	55.85%
D22	2/D/2-34AR	66.16	0.78	5.95	2.75	2.56%	68.77%
D23	2/D/2-34AR	110.17	1.35	6.38	2.24	3.49%	68.33%
D24	2/D/2-34AR	108.71	1.94	6.20	2.29	4.81%	72.04%
D30	HQ/D/2-34AR	116.24	13.56	5.87	4.11	16.66%	48.01%
D31	3/D/2-34AR	95.01	13.37	5.33	3.11	24.08%	62.34%
D32	3/D/2-34AR	104.91	18.42	5.48	3.38	28.47%	56.08%
D33	3/D/2-34AR	96.50	15.38	5.80	3.78	24.46%	55.94%
D34	3/D/2-34AR	93.03	13.74	5.80	3.61	23.71%	58.09%
D6	HQ/D/2-34AR	108.52	9.62	8.95	3.12	25.46%	57.42%
D65	HQ/D/2-34AR	69.13	14.07	5.42	3.64	30.34%	55.83%
D77	HQ/D/2-34AR	75.17	3.74	6.39	1.87	17.01%	63.87%

Table 5-6 Movement Based Values of GPS Tracking 4-4 Cavalry Squadron's Platoon Field Training Exercise

Vehicle ID	Platoon/ Troop/ Squadron	Total Distance (km)	Off Road Distance (km)	Averge Total Speed (m/sec)	Average Off Road Speed (m/s)	Percent of GPS Points Off Road	Percent of Off Road Points with a Turning Radius less than 30 m
A11	1/A/4-4 CAV	160.51	16.92	5.93	2.39	26.21%	64.89%
A12	1/A/4-4 CAV	234.65	16.24	7.37	2.61	19.53%	64.67%
A14	1/A/4-4 CAV	207.40	14.41	8.32	2.88	20.08%	64.76%
A15	1/A/4-4 CAV	250.75	32.69	6.55	2.92	29.23%	63.39%
A21	2/A/4-4 CAV	234.65	16.35	7.37	2.63	19.54%	64.64%
A22	2/A/4-4 CAV	230.63	28.42	6.34	2.59	30.11%	64.39%
A25	2/A/4-4 CAV	234.76	30.22	6.27	2.57	31.35%	63.88%
B11	1/B/4-4 CAV	208.27	7.27	7.26	2.38	10.65%	70.65%
B12	1/B/4-4 CAV	215.41	11.22	7.19	2.56	14.66%	68.14%
B13	1/B/4-4 CAV	67.99	1.63	8.69	2.95	7.06%	65.04%
B14	1/B/4-4 CAV	81.98	2.23	6.27	1.87	9.12%	73.60%
B16	1/B/4-4 CAV	130.71	5.35	6.78	2.09	13.27%	75.44%
B17	1/B/4-4 CAV	117.93	6.13	6.15	1.88	17.04%	73.86%
B21	2/B/4-4 CAV	221.21	19.02	6.45	2.50	22.20%	65.58%
B22	2/B/4-4 CAV	215.28	23.46	5.95	2.38	27.26%	69.67%
B23	2/B/4-4 CAV	194.92	15.91	6.37	2.27	22.84%	70.63%
B24	2/B/4-4 CAV	130.77	11.62	6.24	2.08	26.66%	74.23%
B25	2/B/4-4 CAV	234.58	19.52	5.93	2.18	22.68%	70.74%
B26	2/B/4-4 CAV	129.70	22.59	5.33	2.36	39.29%	69.67%
B27	2/B/4-4 CAV	132.85	9.65	7.24	2.83	18.61%	66.04%
B28	2/B/4-4 CAV	131.52	15.38	6.25	2.43	30.13%	70.28%
C11	1/C/4-4 CAV	110.08	5.35	7.26	2.38	14.87%	70.97%
C14	1/C/4-4 CAV	131.31	12.87	6.59	2.63	24.53%	66.65%
C21	2/C/4-4 CAV	121.42	8.41	6.79	2.51	18.75%	70.90%
C26	2/C/4-4 CAV	138.99	8.44	6.59	2.37	16.87%	66.73%
C66	HQ/C/4-4 CAV	41.24	1.73	8.29	2.52	13.86%	78.66%
C7	HQ/C/4-4 CAV	52.99	3.22	7.76	2.25	20.96%	77.30%
C77	HQ/C/4-4 CAV	42.94	3.46	7.49	2.30	26.28%	69.01%
C95	HQ/C/4-4 CAV	67.99	1.63	8.69	2.95	7.06%	65.04%

Case Study Research Question Statistical Analysis Summary

Using the data in the above tables (5-2-thru 5-7) the SAS based statistical testing was conducted. The platoon type tests (Q1-Q7) averaged the values of the data provided above for all vehicles within each platoon. Q8 averaged the values of the above data for all like vehicle types regardless of unit type (the LMTV and M113A3s were dropped from this test due to limited sampling numbers).

Table 5-7 Summarized Results of Case Study Statistical Analysis

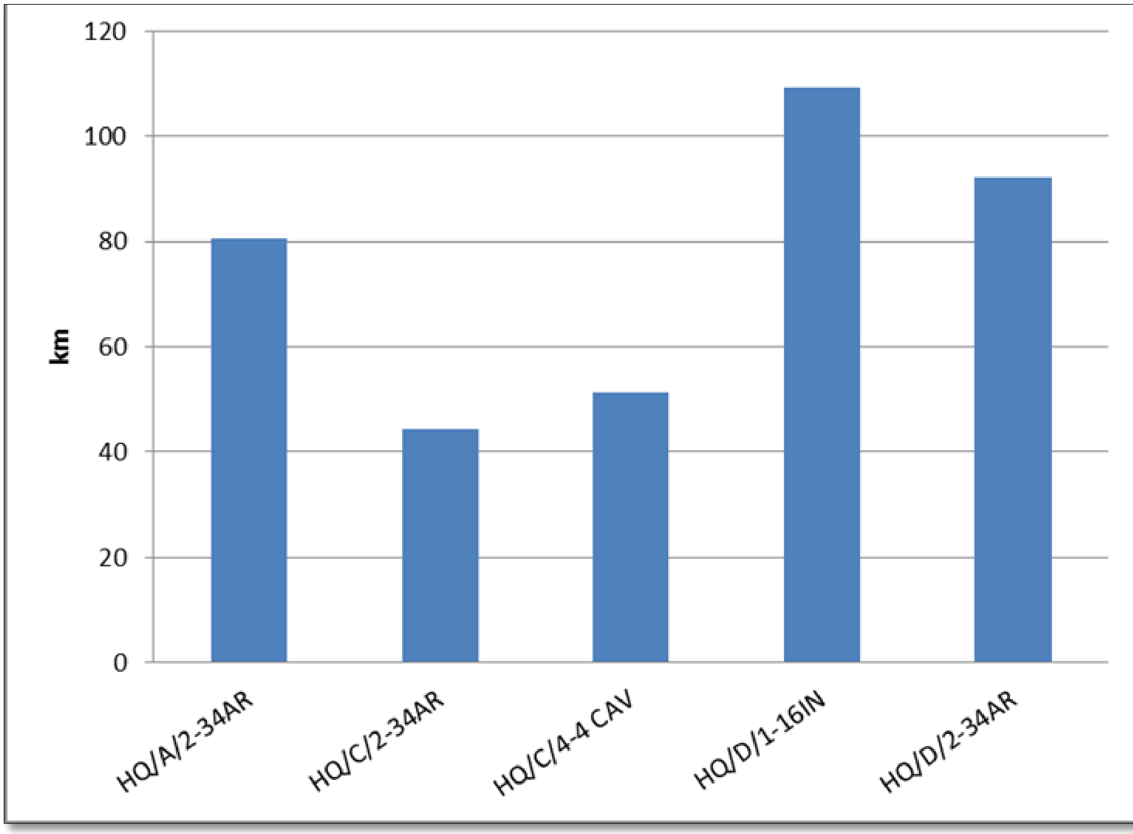
	Total Distance Traveled*	Distance Traveled Off-Road*	Average Total Speed*	Average Off Road Speed*	% of Training Time Moving	% of Training Time Spent Moving Off Road	% of Off Road Time with Turning Radius <30m
Question 1 Headquarters Platoon Comparison							
p-value<0.05		0.006	0.027				0.001
p-value<0.10	0.070					0.095	
Not Significant				0.134	0.109		
Distribution	No	No	No	No	OK	Ok	Ok
Question 1a Headquarters Unit Type Comparison (HQ Cavalry Company vs HQ AR Company)							
p-value<0.05		0.036	0.005	0.024			0.000
p-value<0.10							
Not Significant	0.266				0.123	0.471	
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 1b Headquarters Unit Type Comparison (HQ Infanrty Company vs HQ AR Company)							
p-value<0.05							
p-value<0.10							
Not Significant	0.654	0.885	0.602	0.904	0.737	0.360	0.391
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 2 Infantry Platoon Comparison							
p-value<0.05							
p-value<0.10		0.097				0.054	
Not Significant	0.618		0.278	0.574	0.1638		0.219
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 3 Armor Platoon Comparison							
p-value<0.05		0.008		0.008		0.010	0.004
p-value<0.10							
Not Significant	0.605		0.682		0.107		
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 4 Cavalry Platoon Comparison							
p-value<0.05		0.016					
p-value<0.10						0.065	
Not Significant	0.669		0.777	0.407	0.578		0.182
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 5 Infantry Battalion Comparison							
p-value<0.05			0.024				
p-value<0.10	0.075						
Not Significant		0.311		0.231	0.355	0.218	0.768
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 6 Armor Battalion Comparison							
p-value<0.05	0.038				0.009		
p-value<0.10				0.079			
Not Significant		0.344	0.139			0.143	0.103
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 7 All Platoon Comparison							
p-value<0.05		0.003		0.002		0.019	0.001
p-value<0.10					0.063		
Not Significant	0.211		0.170				
Distribution	No	No	No	Ok	Ok	Ok	Ok
Question 8 Vehicle Type Comparison							
p-value<0.05	0.013	0.046	0.001	<0.0001			<0.0001
p-value<0.10					0.083		
Not Significant						0.206	
Distribution	No	No	No	Ok	Ok	Ok	Ok

Case Study Research Question 1

There was only a marginally significant difference between the average total distances traveled by headquarters platoons (p-value 0.070). The distance traveled per headquarters platoon averaged 78.24 km, with a maximum of 109 km and a minimum of 51 km. Both the highest and lowest headquarters platoon averages of total distance traveled were the headquarters platoons of armored companies indicating the wide range of variation that can be seen within the same type of platoon even under the same type of training event. There was a significant difference in the distance traveled off road between headquarters platoons (p-value 0.006). When the same analysis was conducted comparing infantry company headquarters platoon distance traveled off road to armor company headquarters platoons there was not a significant difference.

The pairwise comparisons also indicate there is not a significant difference in the platoon average of off road movement between HQ/C/2-34AR, HQ/C/4-4CAV or HQ/A/2-34AR, nor was there a significant difference between HQ/A/2-34AR, HQ/D/1-16IN, or HQ/D/2-34AR but there is a significant difference between average distance traveled by HQ/C/2-34AR, HQ/C/4-4CAV,HQ/A/2-34AR and the average distance traveled by HQ/D/1-16IN and HQ/D/2-34AR. This again helps to demonstrate that while there are similarities in platoon movements, there is a huge amount of variation within even the same type of unit conducting the same training event under the same conditions.

Figure 5-16 Headquarters Platoon Average Distance Traveled Off Road



The average speed of headquarters platoons was statistically different (p-value=0.027). There were significant difference with HQ/C/4-4CAV and HQ/A/2-34AR (p-value=0.0497), HQ/C/2-34AR (p-value=0.0017), HQ/D/2-34AR (p-value=0.0499). When comparing the average speed of headquarters platoons in cavalry companies to the headquarters platoons in armor companies there is a significant difference (p-value=0.005). No significant difference was found when comparing infantry company headquarters to armor company headquarters.

There was no overall significant difference in average off road speed of headquarters platoons, but there were significant difference when comparing cavalry company headquarters to armor company headquarters (p-value=0.024). Again, there was no difference found between headquarters of infantry companies vs. headquarters of armor companies.

The statistical analysis of the averaged values within the headquarters platoons indicated that there was no significant difference between headquarters platoons for the metric of percent of training time spent moving. While there was a marginal difference between overall headquarters platoons based on percent of training time spent moving off road (p-value=0.095), there was a significant difference with HQ/D/2-34AR having spent significantly more time moving off road than HQ/D/1-16IN (p-value=0.0372) or HQ/A/2-34AR (p-value=0.0320).

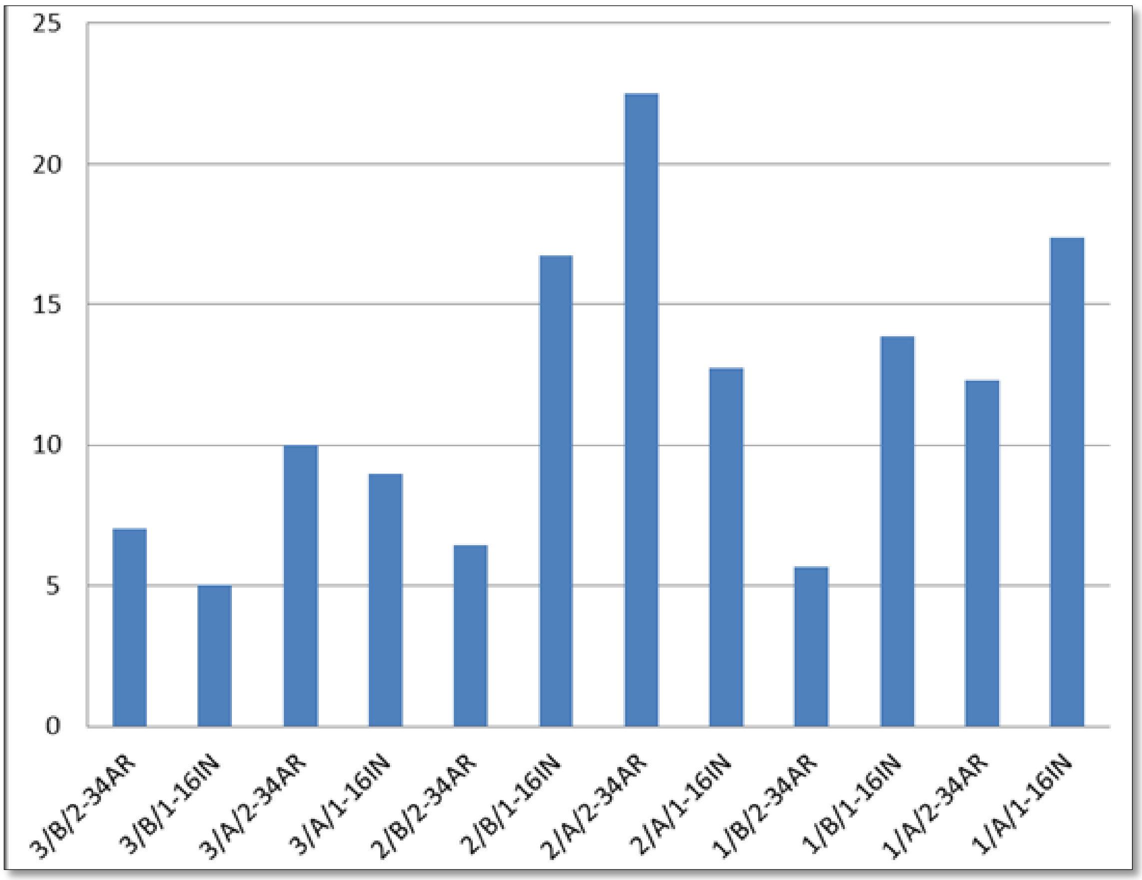
There was a significant difference within the headquarters platoon averages for the percent of time off road with a turning radius less than 30 m (p-value=0.001). Again, there was a significant difference (p-value=0.000) when comparing cavalry company headquarters to armor company headquarters, but not a significance when comparing infantry company headquarters to armor company headquarters.

The higher amount of variation found between the cavalry company headquarters when compared to the armor company headquarters than found when comparing the infantry company headquarters to the armor company headquarters for average total speed, average off road speed, and the percent of off road time with sharp turning radius may be explained by the fact that the infantry and armor company headquarters are collocated under the same battalion headquarters, operating under a more similar training plan than that of the cavalry headquarters platoon operating under only the cavalry battalion headquarters, or it could be due to the actual differences in the unit types.

Case Study Research Question 2

There were no significant overall differences between infantry platoons at the p level of 0.05. However there are two metrics when comparing averages across all infantry platoons that have a marginal significance; distance traveled off road (p-value 0.097), and percent of training time spent moving off road (p-value 0.054).

Figure 5-17 Average Distance Traveled Off Road by Infantry Platoons (km)

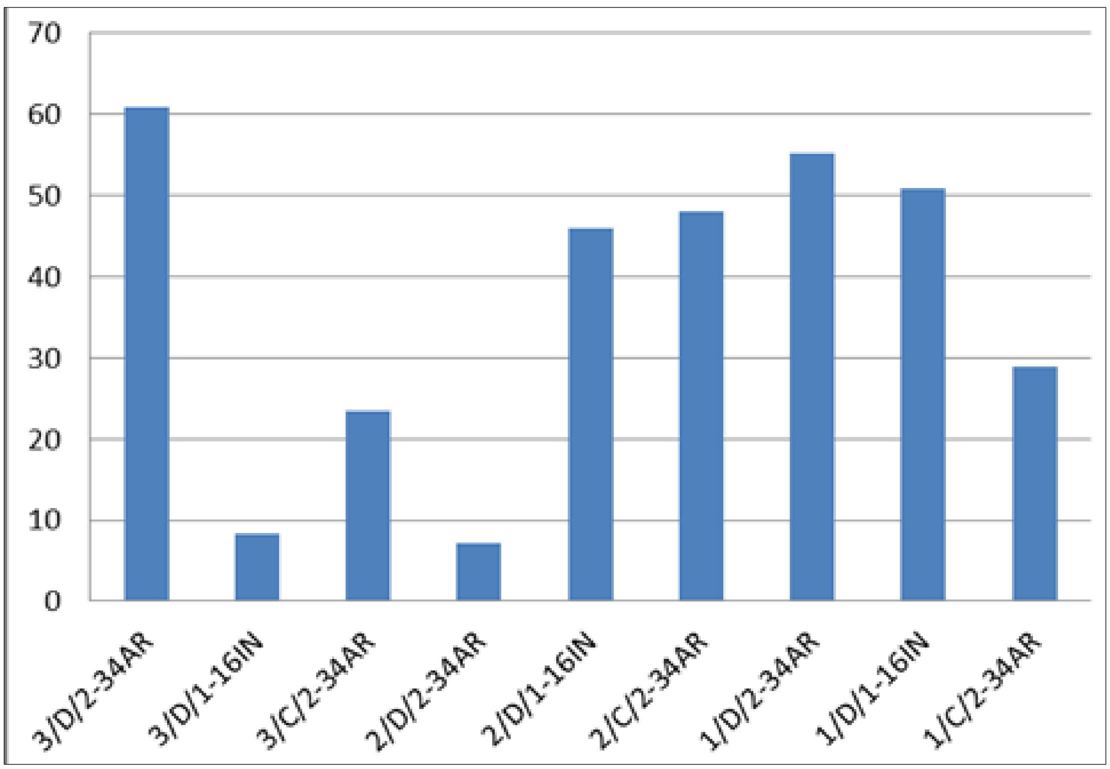


While there was only a marginally significant difference in the percent of time spent moving off road by infantry platoons, there were statistically significant groups in pairwise comparisons for example, 2/A/2-34 AR was statistically significantly different from 6 of the other 11 infantry platoons.

Case Study Research Question 3

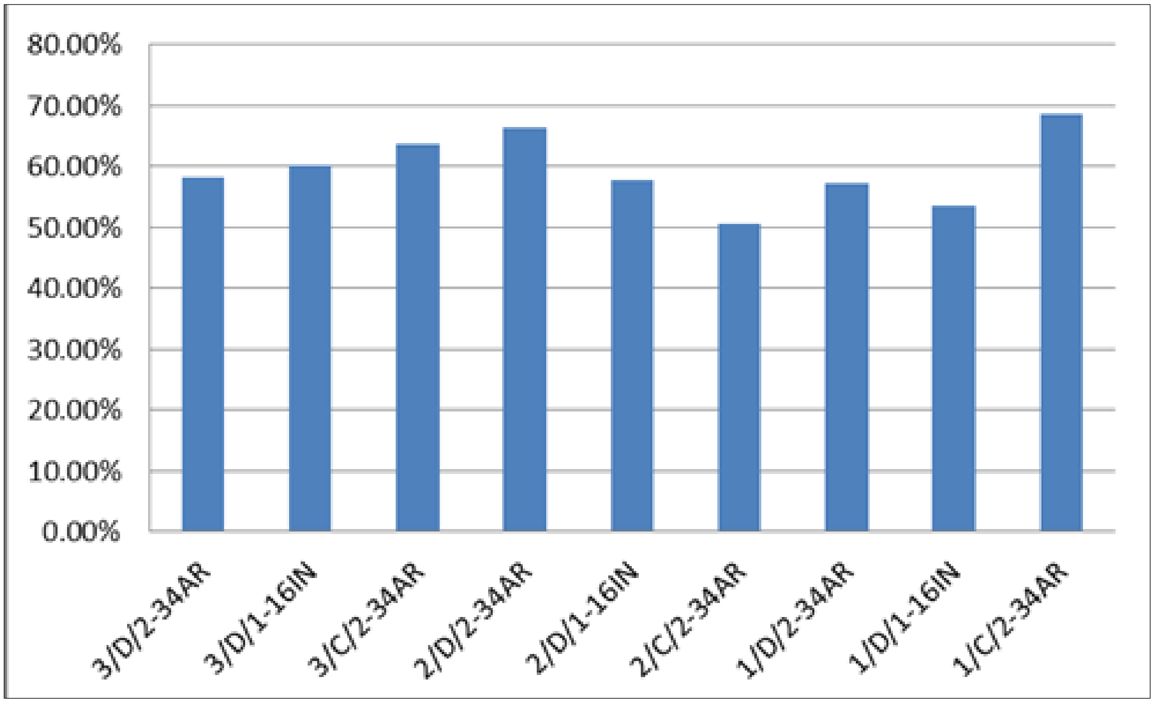
There was no statistical difference between armor platoon averages for total distance traveled, average total speed or percent of time spent moving. The average off road distance tracked for armor platoons was significantly different (p-value=0.008). The average off road distance traveled by armor platoons was 36.6km, but the high was nearly 61km, and the low was nearly 7km. Figure 5-23 provides a side by side comparison of the average off road distance for each of the armor platoons.

Figure 5-18 Average Off Road Distance Traveled for Armor Platoons (km)



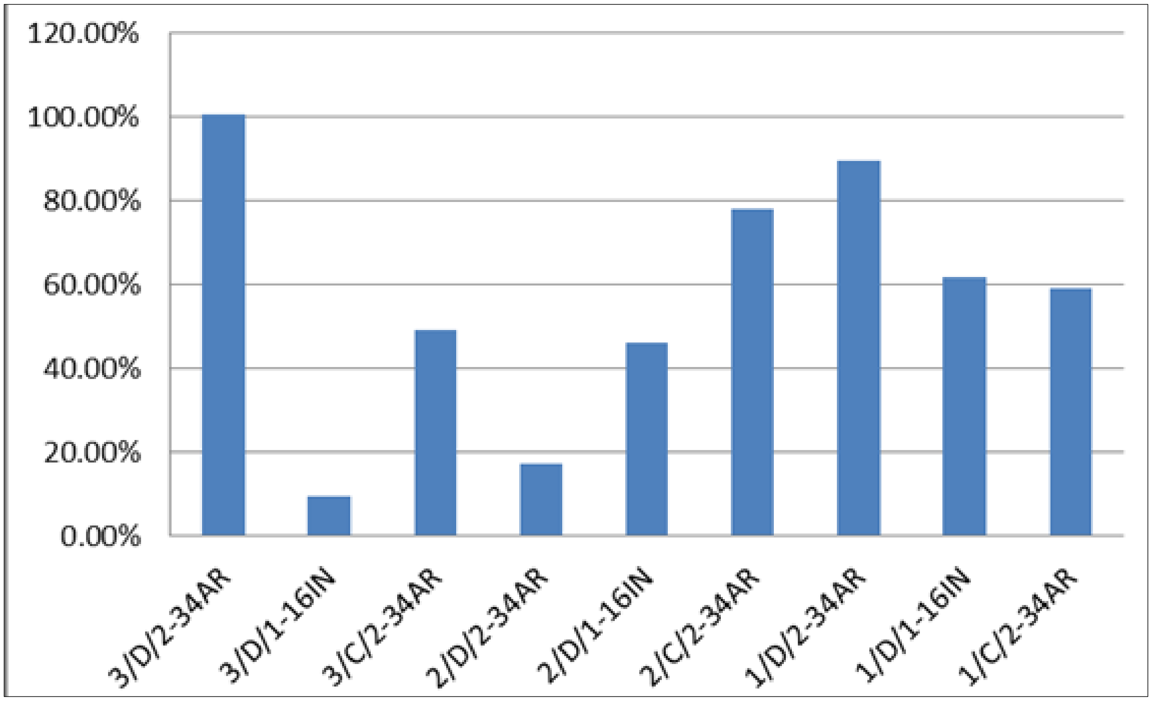
The average off road speed of armor platoons was significantly different from one another (p=0.008). The percent of time off road with a turning radius of less than 30m was also significantly different between armor platoons (p-value=0.004).

Figure 5-19 Armored Platoon Average Percent of Off Road Time with a Turning Radius <30m



There is a significant difference in the percent of time armored platoons spent moving off road (p-value=0.010). Within pairwise comparisons, significant differences could be found between the three armor platoons of D company 2-34AR. Two of the platoons from this company had statistically higher average percent of time spent moving off road than many of the other armor platoons, whereas one of the platoons from this company was statistically lower. This demonstrates the high variability that can be seen even within the same company. Figure 5-25 below shows the differences in off road movement by armored platoon.

Figure 5-20 Armored Platoon Percent of Moving Time Spent Off Road



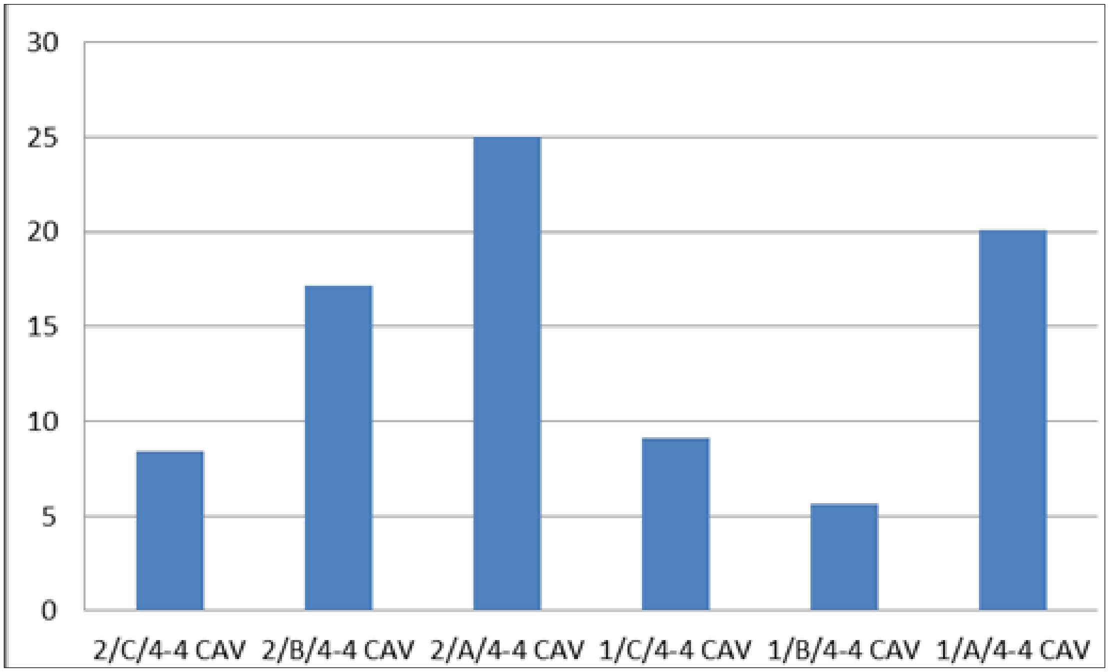
Case Study Research Question 4

All of the cavalry platoons within this research were within one squadron, conducting training at the same time. Statistical analysis found no overall significant difference between cavalry platoons for the percent of training time spent moving, total distance traveled, average total speed, average speed off road, and the percent of off road time with Turning radius less than 30m

A marginally significant (p-value 0.065) difference was detected in the percent of time spent moving off road between cavalry platoons with 1/B/4-4CAV being significantly lower than the highest three platoons (p-values of 0.024 (1/A/4-4CAV)), 0.014 (2/A/4-4CAV), 0.007 (2/B/4-4CAV)).

The distance traveled off road varied significantly between cavalry platoons (p-value=0.016). 1/B/4-4CAV has a significantly lower off road distance than 1/A/4-4CAV (p=0.005), 2/A/4-4CAV (p=0.003), and 2/B/4-4CAV (p=0.003).

Figure 5-21Cavalry Platoon Average Distance Traveled Off Road (km)

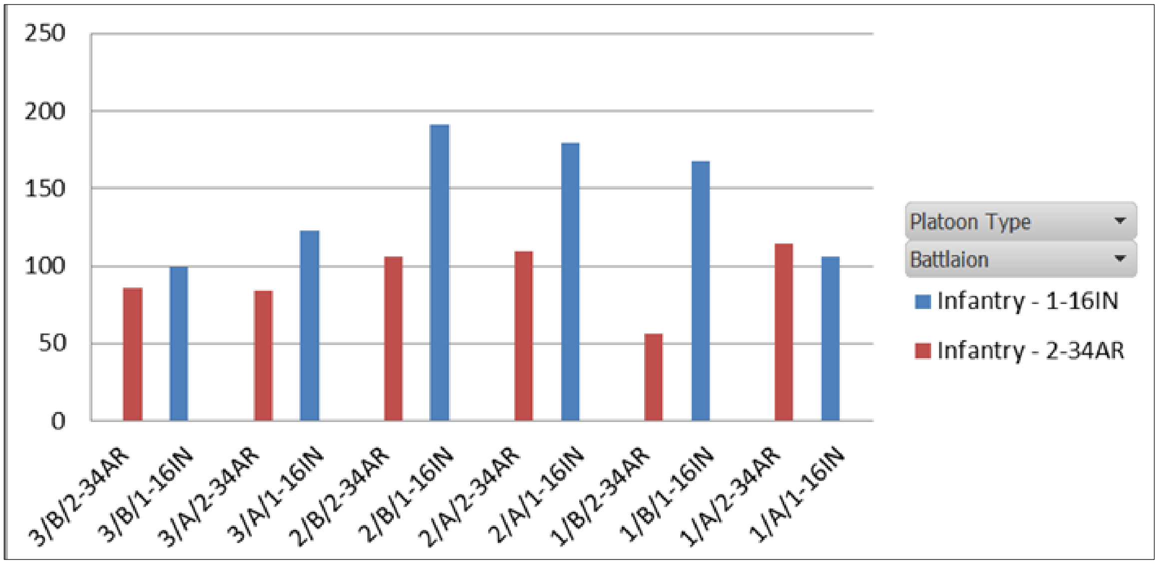


Case Study Research Question 5

Question 5 conducted pairwise comparisons that averaged the values of all infantry platoons within the 2-34 Armor, and compared them to the average values of all of the infantry platoons within 1-16 Infantry. Under these comparison conditions, there was not a significant difference in the percent of training time spent moving, percent of training time spent moving off road, total distance traveled, distance traveled off road, average speed off road, or percent of off road time with Turning radius less than 30m.

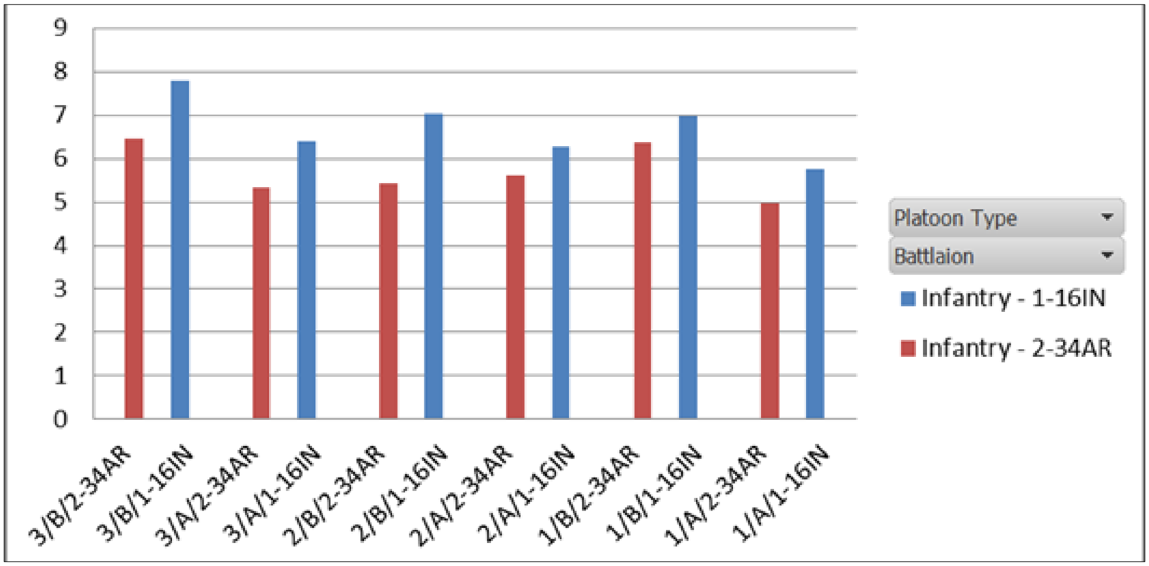
The total distance traveled by infantry platoons averaged at the battalion level demonstrated a marginal statistical difference (p-value=0.075).

Figure 5-22 Comparison of Infantry Platoons in 1-16 IN to Infantry Platoons in 2-34 AR: Total Distance Traveled (km)



When comparing the average of all infantry platoons of 1-16IN to the average of all infantry platoons of 2-34AR, there was a significant difference in the average total speed (p-value=0.024). While the total speed of 1-16IN's infantry platoons was higher than their counter parts in 2-34AR on average, the off road speed of infantry platoons between battalions was not significantly different.

Figure 5-23 Comparison of Infantry Platoons in 1-16 IN to Infantry Platoons in 2-34 AR: Average Total Speed (m/s)



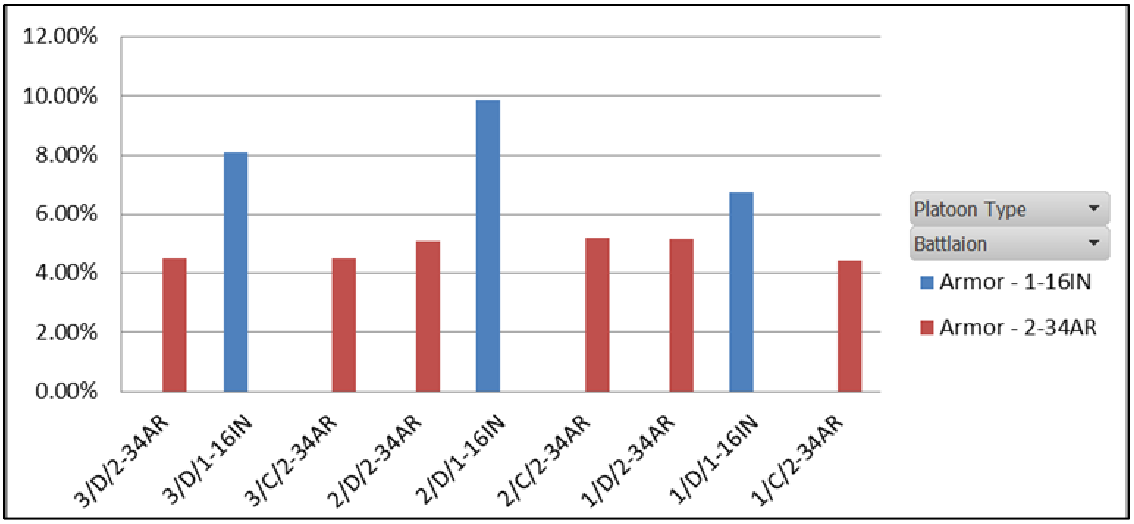
Case Study Research Question 6

Question 6 conducted pairwise comparisons that averaged the values of all armor platoons within the 2-34AR, and compared them to the average values of all of the armor platoons within 1-16IN. Under these comparison conditions, there was not a significant difference in the percent of training time spent moving off road, distance traveled off road, average total speed, or percent of off road time with turning radius less than 30m.

Average off road speed was marginally statistically significant (p-value=0.079), with armor platoons with 1-16IN recording and off road average speed of 3.76m/s, and armor platoons in 2-34AR recording and average off road speed of 3.34. Even though the battalion average was less, the single armor platoon with the highest average off road speed was within 2-34AR.

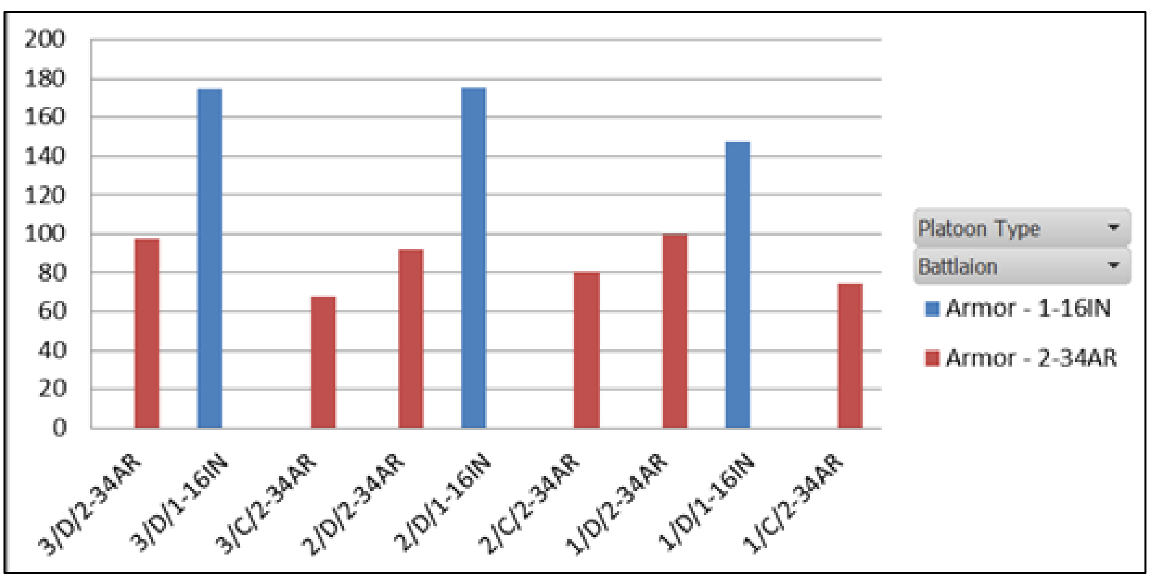
The percent of training time spent moving was statistically different when comparing armor platoons between 1-16IN and armor platoons in 2-34AR (p-value=0.009) with 1-16IN spending a larger portion of the training time moving.

Figure 5-24 Comparison of Armor Platoons in 1-16IN to Armor Platoons in 2-34AR: Percent of Training Time Spent Moving



There was a significant difference between armor platoons in 1-16IN and armor platoons in 2-34AR in the total distance moved (p-value 0.038). The average total distance traveled that was recorded for armor platoons within 1-16IN and 2-34AR was 163km and 85km respectively.

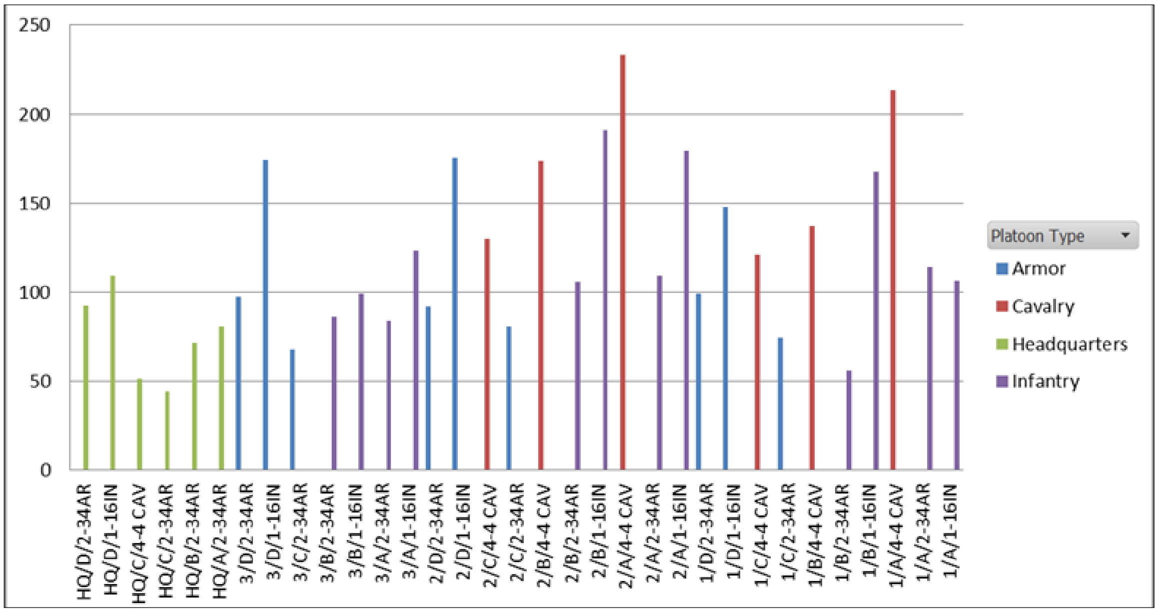
Figure 5-25Comparison of Armor Platoons in 1-16IN to Armor Platoons in 2-34AR: total Distance Moved (km)



Case Study Research Question 7

Question 7 compares the average values of all platoon types across all battalions regardless of type or unit. The total distance traveled by all 32 platoons was not found to be significantly different, nor was the average total speed (figure 5-31).

Figure 5-26 Average Total Distance Moved (km) all Platoons



The percent of training time spent moving by all platoons is only marginally significantly different (p-value=0.063).

When all 32 platoon movements were compared, there was a significant difference between platoons for the percent of training time off road with a sharp turning radius (p-value=0.019), the average distance traveled off road (p-value=0.003) figure 5-32, the average off road speed (p-value=0.002)figure 5-33, and the percent of training time off road with a sharp turning radius (p-value=0.001).

Figure 5-27 Average Off Road Distance Traveled (km) for All Platoons

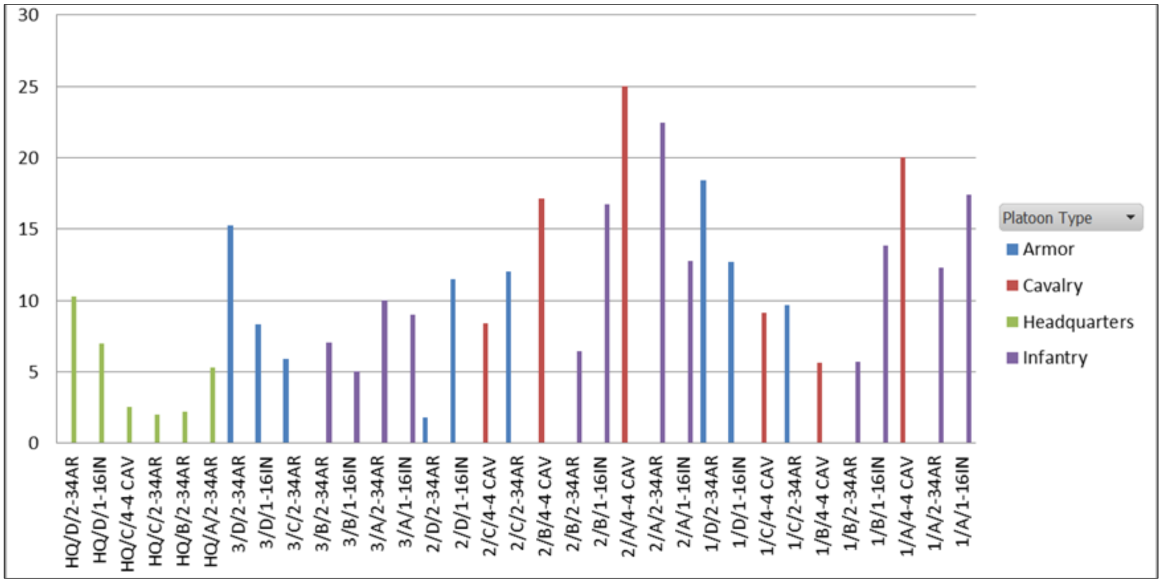
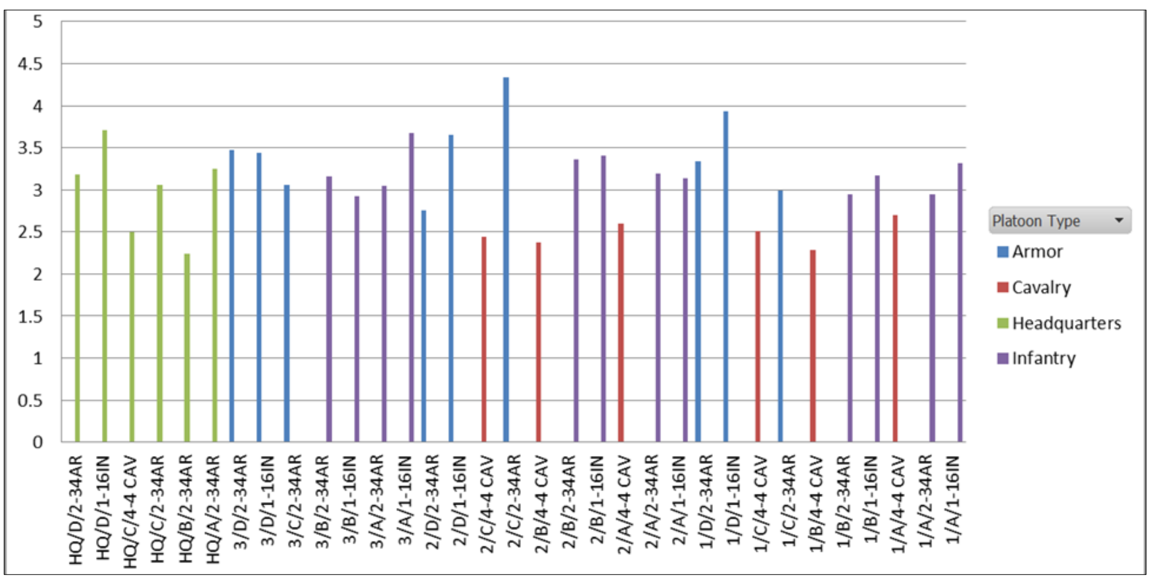


Figure 5-28Average Off Road Speed (m/s) for All Platoons



Case Study Research Question 8

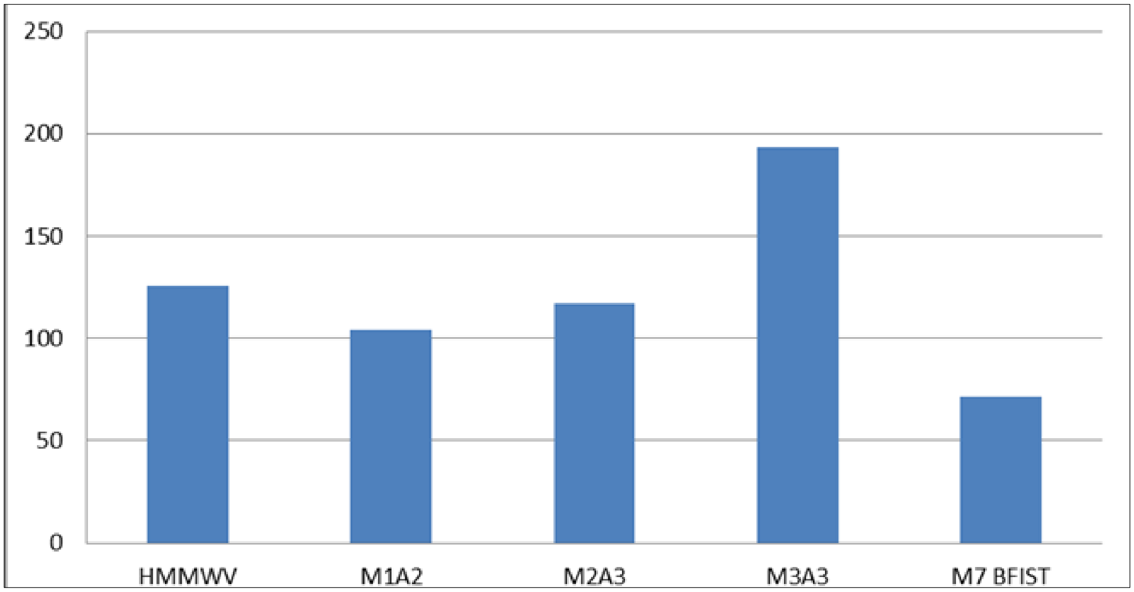
The final question, Q8, compared the average distance moved of vehicles by type. A total of 113 out of 116 total vehicles were used in the comparisons. The LMTV and M113A3s were removed due to small samples sizes. Comparison by vehicle type showed no significant differences between vehicle types only for the factor of percent of training times spent moving off road.

There was a marginally significant difference between all types of vehicles for the factor of percent of training time spent moving. The comparisons showed the M1A2, M7 BFIST, M2A3, HMMWV are all different than the M3A3 based on a marginally significant p=value of 0.083.

Total distance traveled was different between vehicle types with a p-value of 0.013. The average distance traveled by M7 B FIST vehicles was significantly less than the total distance of any other vehicle type tested except the M1A2. There was not a significant difference in the total distance traveled between M1A2s, M2A3s and HMMWVs. The M3A3 total distance traveled was significantly greater than all other vehicles (p-value=0.0186). Six of 113 vehicles were statistically significant outliers, with two M1A2 tanks (D21 and D12 1-16IN) and one M2A3 Bradley (A66 2-34AR) having much higher residuals, and two M2A3 Bradleys (B21 2-34AR, and A65 2-34AR) and one M1A2 (C34 2-34AR) having much lower residuals.

The higher than expected average total distance traveled by could be explained by vehicles that traveled extra distances due to drivers training exercises that were being conducted, or use in other training exercises separate from the platoon FTX. The lower than expected residuals could be from vehicles that had crew members injured/sick, or with other issues resulting in not complete crews for vehicle operation for a period of training, or from vehicles that broke during training and spent large amounts of time parked for repairs.

Figure 5-29 Comparison of Vehicle Types: Average Total Distance Traveled (km)

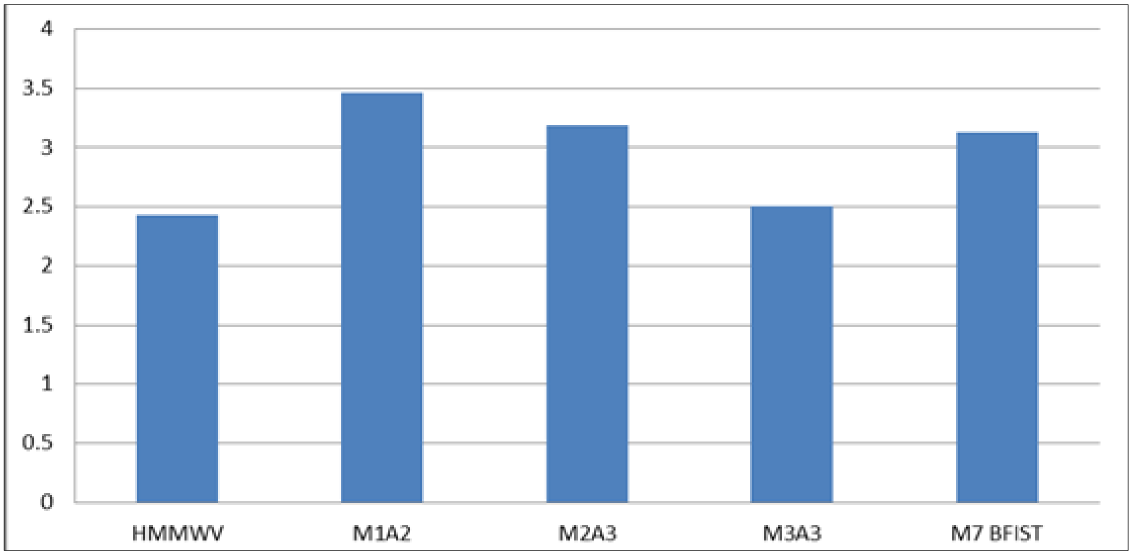


With a p-value of 0.046 there was a significant difference between distance traveled off road by type of vehicle. Again there were outliers with A66 2-34AR and D21 1-16IN showing significantly higher residuals, and C34 2-34AR and A65 2-34AR showing significantly lower residuals.

There were statistically significant differences between vehicle types in the average total speed ($p=0.001$). The M1A2 average total speed was significantly less than that of the M2A3, M3A3, and HMMWV (p-values 0.0442, 0.0009, and 0.0001 respectively). Three vehicles were significant outliers with higher than expected average speeds for their vehicle types (C34 2.34AR, B13 4-4CAV, and A65 2-34AR).

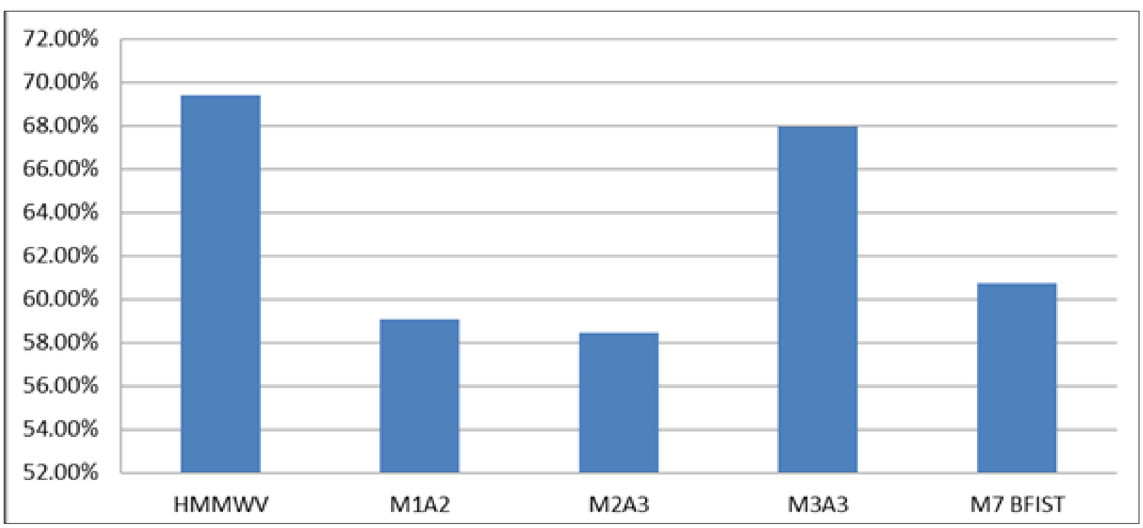
Average speed off road was significantly different between all vehicle types (p-value<0.0001). There was no statistical difference between M3A3s (2.96m/s) and HMMWV (2.97m/s), which both averaged slower off road speeds than the M2A3s (3.20m/s) and M7 BFISTs (3.23m/s), which had significantly slower average off road speed than M1A2s (3.26m/s)

Figure 5-30 Comparison of Vehicles Across All Unit Types: Average Off Road Speed (m/s)



The percent of off road time with turning radius less than 30m was statistically different (p-value <0.0001). There was no significant difference between M1A2s, M2A3s, and M7 BFISTs, but those three types had significantly less percent of time off road with tight turning radius than M3A3s or HMMWVs.

Figure 5-31 Comparison of Vehicles Across All Unit Types: Percent of Off Road Time with a Turning Radius <30m



A more in depth summary of the pairwise comparisons can be found in appendices D thru H showing which comparisons within each overall groups in each research question had significant differences. Appendix I (presented as an attachment) provides the analysis data from each pairwise comparison.

Discussion

This case study of GPS tracked vehicles attempts to compare the movements of military vehicles and units based on GPS tracking of training events using COTS GPS devices. There were some limitations of the devices during the tracking that may have limited the ability of the results to fully explain the unit's movements. First, not all vehicles within each unit were tracked. GPS tracking of 4-4 CAV, 1-16IN and 2-34AR maneuver company vehicles covered approximately 44%, 41%, and 74% of the total number of maneuver vehicles within each unit respectively. Second, the batteries died in many of the COTS GPS devices during training. 53% of all COTS devices had dead batteries at the time of device recovery indicating that some training was likely conducted after the batteries had died. While most of the devices that had batteries that died during training recorded greater than 80% of the total training time, the loss of power may still have affected the reliability of the results.

This research tracked two combined arms battalions with nearly identical personnel, equipment and mission design, and one cavalry squadron that should have been conducting a similar mission set. All three units were given the same general guidance from their higher headquarters and were to conduct a platoon FTX followed by live fire gunnery on the same military installation under similar environmental conditions. Overall there should be an expectation that the units tracked in this research should be significantly more similar in movement patterns than the movement patterns of other units and training types or even the same units at other installations.

The results of pairwise comparisons of platoons, vehicles and battalions provided no clear evidence that these units were very similar. While there were numerous treatments that were found to be not significantly different under some comparisons, there were no treatments that were not significantly different for all treatments. The one scenario tested that found no difference between treatments was that of the infantry company headquarters vs. armor company headquarters. Under this limited data set these two types of platoons could be assumed to have conducted very similar maneuvers, and therefore have had very similar disturbance patterns. Another treatment that showed little difference was that of infantry platoons with only off road movement and time off road showing marginally significant differences.

Most tested treatments showed statistically significant differences in one or more of the response variables. 34% of all response variables showed significant differences over the eight questions (including two sub-questions within the headquarters platoons). The treatment that showed the most significant difference between comparisons was Q8 which compared the average values of each vehicle type. This would be expected as vehicles are designed with particular parameters for the purpose of meeting specific mission needs. Their operations would be expected to differ significantly even within the same unit and training event.

The response variable that would likely have the most direct impact on the disturbance associated with a training event would be off road distance traveled. This response variable was significantly different in comparison tests between all platoons, headquarters platoons, armor platoons, cavalry platoons and vehicle types. This would seem to indicate that much care would be needed when assigning average off road distance values to training events for future estimates which is commonly done by researchers and land managers.

This research, under a nearly best case real world scenario, indicates that the variation between units and within the same unit is very wide on the factors tested. Further research would be recommended using the same tested factors on like units under similar tests at other military installations. The results of this study would indicate that it would be likely that units conducting similar training at other installations, under different environmental conditions, different command structures, and different FTX plans would exhibit more variation than observed in this research.

Chapter 6 - Development of a GIS Based Model for Depicting Maneuver Training Intensity Based on COTS GPS Data

Introduction

Military training maneuvers can have detrimental and lasting impacts on the landscape (Althoff et al. 2007; Althoff et al. 2010; Anderson et al. 2005a; Anderson et al. 2005b; Goran et al. 1983; Milchunas et al. 1999; Prosser et al. 2000). In order to better understand where military training maneuvers are occurring and how they are impacting the landscape, military land managers and researchers must have knowledge of when and where training maneuvers are occurring. Current methods of understanding the spatial distribution of military maneuver are limited at best, and can be deceptive at worst. These methods consist of two main types, physical land studies conducted by researchers and land managers, and data based systems that rely on the military to input data which is in turn used to determine the spatial distribution of training.

The first method of determining training related disturbance on the environment, physical land studies, involves repeated monitoring and inventory of the environmental conditions on the same plot or transects year after year. These studies have no direct record of what types of vehicles, how many vehicles, or date and time of impact, rather they must rely on evidence gathered on site (or from other systems) to relate environmental change to military impact.

The other means of comparing training maneuver to the environmental conditions utilizes military input of training data. In the Army the standard system of recording training use is the Range Facility Management Support System (RFMSS). This data set can be used separately or jointly with physical inventory data to estimate the training intensity of an area. This method has significant limitations in its ability to determine the actual spatial distribution of military maneuver impacts as the finest resolution level in this system is the Maneuver Area (MA), which can vary from several to tens of kilometers.

In order to provide a better understanding the spatial distribution of military maneuvers, GPS devices have been used to track military maneuver training (Ayers et al. 2000a; Haugen 2002; Haugen et al. 2003b; Koch et al. 2012; Li et al. 2007a; Rice 2006; Wu et al. 2007; Wu et al. 2008). These GPS data sets are limited in availability, with data only existing for several training events on several installations. The costs and usage of the VDM and VTS systems to collect data on a large scale may be prohibitive. Cost analysis plans for the Army use of GPS data to assess maneuver disturbance are currently limited to collection programs using these devices to track vehicles for several events (up to 10 events with 20 vehicles) at an installation per year (Koch et al., 2012). This data could then be fed back into ATTACC or other systems to provide more accurate estimates of military maneuver. Objective 2 of this research indicates that tracking a small number of events and applying the generated results across larger data sets should be done with extreme care.

The COTS device tested in this research (the LandAirSea Tracking Key 1505) or similar low cost civilian devices may be able to make tracking of large quantities of maneuver training not only less expensive than the VDM/VTS, they may be less expensive for the military than current manpower intensive methods of locating maneuver damage using personnel to drive around the maneuver areas and visually identify areas needing repair. The costs and ease of installation and data recovery of the

COTS device may allow for nearly complete collection of maneuver training on an installation. Complete maneuver data collection could provide military land managers and researchers with enough data to accurately estimate disturbance across an entire installation and also determine relatively fine spatial differences in disturbance. It may be possible to use this COTS GPS data, along with data collected from other GPS devices to map the maneuver of military vehicles thereby creating an intensity map of disturbance.

This chapter discusses a method of using COTS GPS data to map training intensity on an installation wide scale, compares the RFMSS training data to the GPS collected data at the installation wide scale, and then conducts a small area case study on one MA utilized by units during GPS tracking to demonstrate the spatial variation in training that is unable to be interpreted though RFMSS data but can be determine thought the use of GPS tracking.

Existing Methods

Range and Training Land Assessment (RTLA) Program

RTLA is a monitoring and inventorying program designed to provide information to help guide decision making under the Army's Sustainable Range Program (SRP). The RTLA mission is to "inform the process of military land management to maximizes the capability and sustainability of land to meet the Army training and testing mission" (U.S. Army Environmental Center 1999). The RTLA program varies by installation, but has historically conducted plot and transect studies at numerous installations. These plot and transect studies collect data on various conditions which can be impacted by military training. These studies along with some knowledge of training between data collection periods can provide indications of training intensity for an area.

Range Facility Management Support System (RFMSS)

RFMSS is a web based military system that allows military units and military training area range personnel the ability to manage training area usage. It is designed to help reduce scheduling conflicts, and allows area managers to prioritize land and airspace usage. The systems is designed to allow military units to request training areas, ranges and airspace, then allows the land mangers on each installations the ability to approve and schedule the area. The system provides a database for each installation this is able to be queried for various properties. RFMSS is used by all active Army, National Guard and Marine military installations. It was implemented Army wide in the late 1990s, with Fort Riley's RFMSS completely operational in 2007.

The use of RFMSS is a process. First the military unit decides the training it needs to conduct. Based on the type of training, the unit will determine what ranges or Maneuver Areas (MAs) will be needed to conduct the training. The military unit will inform the range scheduler in the unit of the desired training type, requirements, and dates of training. The unit's scheduler will query RFMSS to see if the requested training space is available. If available, the unit's range scheduler will request the areas needed in the online RFMSS system. The land managers at the installation will accept or reject the request based on the availability of the land. If the request is rejected the unit will reschedule the training for other dates or other training areas. Once the land is scheduled, no changes are made until the unit conducts training. When the unit conducts training the installations land managers will input more data about the training in the RFMSS system for record. This data will include when/if the unit used the requested training area and the number of personnel the unit reports being trained on the training area for the day. The RFMSS system can later be queried for units using each range or training area for a given time period, the number of personnel trained, and vehicles used on the training area.

Problems related to data inaccuracy or data interpretation can arise from the RFMSS system in several ways. First, units input data on the training type, vehicles and personnel when they are scheduling the range. This initial scheduling is done months in advance of the training in order to secure the range. Units will often not have a complete plan of who, what vehicles, or exactly how the training will be conducted at the time of scheduling, as those details are revised as training nears. While RFMSS has vehicle and personnel numbers in the system, they should be considered "ballpark" estimates. Units will often input all vehicles the unit owns, and a number of total personnel on hand, however numbers will likely be different when training. Other units may join with the scheduled unit to conduct the same training, so there may be more personnel and vehicles than scheduled, or other missions may conflict with the training and a significantly smaller element may conduct the training than was originally planned. Military units use RFMSS as a scheduling tool, and once the training area is scheduled they are unlikely to ensure validity of data as conditions change unless they need to adjust training areas due to the changes. The best updates to the data come from the training area personnel who update the system while the unit is conducting training. These personnel do make some updates (mostly to the time the unit occupied the range, and the number of personnel reportedly trained).

Army Training and Testing Area Carrying Capacity (ATTACC)

ATTACC was designed in and implemented in the late 1990s to provide a tool to ITAM for estimating the ability of the land to support training. The US Army Environmental Center defined it as:

> *"a methodology and integration decision support system for estimating the operations and support costs of using land at Army installations for training purposes. The ATTACC methodology includes specific processes and algorithms to predict land rehabilitation and maintenance (LRAM) requirements based on training load and environmental conditions." (US Army Environmental Center, 1999)*

ATTACC was designed to use inputs from RFMSS and Land Condition Trend Analysis databases to estimate the amount of training on an installation and the associated damage from the training load. The estimation of training load is derived from the RFMSS data set along with Army doctrine. The training load from the ATTACC program is defined by military impact miles (MIMs) which provide a value equal to the impact on soil erosion created by one M1A2 Abrams tank traveling a single pass for one mile during an Armor battalion Field Training Exercise (US Army Environmental Center, 1999). RFMSS provides the unit type, unit training type, vehicle counts (type and quantity) and number of days of training. Army doctrine provides estimates of the number of miles traveled by each vehicle type based on the unit type and unit training type. ATTACC uses the estimated training load and local conditions to apply a set of Training Impact Factors (TIFs) to estimate the total load from a specific training event.

The TIFs include the Vehicle Severity Factor (VSF), Vehicle Off Road Factor (VOF), Vehicle Conversion Factor (VCF), Event Severity Factor (ESF), and Local Condition Factor (LCF) (US Army Environmental Center 1999). VSF is a multiplier that compares the relative impact of the subject vehicle to the impact of an M1A2 Abrams. VOF is a multiplier that represents the proton of vehicle mileage typically operated off road compared to an M1A2 Abrams. VCF is a multiplier that represents the width of area impacted by a vehicle compared to an M1A2 Abrams. ESF is a multiplier that converts the standard training event (Armor battalion FTX) into the training event being compared. Lastly, the LCF is a multiplier that estimates the relative susceptibility of land on a given day compared to average conditions. All of these factors are relative to the M1A2 Abrams tank with the value of the M1A2 Abrams conducting an Armor battalion FTX on an average day (not wet or dry) given the value of 1.0. Any of the multipliers would be over 1.0 if they exceeded the impact of an M1A2 Abrams average for the same factor. (US Army Environmental Center, 1999).

GPS Vehicle Tracking

Researchers studying the impacts of military vehicles on training lands have proposed several methods of using the GPS tracking data to estimate disturbance (Ayers et al., 2000, 2005; Haugen et al., 2003; Haugen, 2002; Koch et al., 2012; Li et al., 2007; Rice, 2006; Wu et al., 2007, 2008). Most of these methods have been focused on further refining the process of using GPS data to model damage from individual vehicles.

Ayers et al., 2000 and Haugen et al 2003 used GPS devices (an early version of the VTS device) to track military vehicles at Yakima Training Center in Yakima, WA. Ayers et al. 2000 and Haugen et al. 2003 used an early version of the VTS (Vehicle

Tracking System) device to track vehicle maneuver. Ayers et al., 2000 and Haugen et al. (2003) used the GPS tracking to calculate vehicle dynamic properties (turning radius, speed, and velocity). Using the calculated dynamic properties they were able to estimate the loss of vegetation caused by the vehicle maneuver. This work was designed to support the use of the ATTACC model and provide further information to refine the parameters of the model.

Ayers et al. 2005 used GPS devices to analyze vehicle maneuver in order to identify the possible formation of roads caused by off road maneuver. This research used a 25 meter by 25 meter grid cell to count the number of vehicles crossing an area, and the pattern of use of those vehicles to determine where new trails were forming. They were able to find vehicles crossing following the same path in opposite directions and different days which helped indicate new trail formation.

Li et al. 2007 developed models to predict the severity of impact of military vehicles during maneuver. Their models used the static vehicle properties combined with the dynamic vehicle properties collected by GPS devices to estimate the amount of disturbed width and the impact severity of the military maneuver. These theoretical models defined relationships for different types of vehicles (tracked or wheeled) and dynamic properties. They found strong relationships between increased damage with reduced turning radius and higher speeds.

In his thesis, Matthew Rice (Rice, 2006), used GPS devices (the VTS) to track military maneuver at Fort Lewis (2005), Fort Riley (2005) and reused the data set collected at Yakima Training Center (2001) from Haugen et al 2003. The GPS data was used to estimate environmental impacts in the form of vegetative loss. Vegetation loss was estimated in square meters of removal using cumulative impact width relationships.

Methods

Site Description: Fort Riley

Fort Riley is a U.S. Army military installation located in the north central to northeast portion of the state of Kansas, U.S.A. Fort Riley occupies a portion of three different counties, Clay, Geary and Riley Counties in Kansas with the majority in Riley County. It is bounded on the south by the Kansas River near the confluence of the Republican and Smokey Rivers. The cities of Junction City (population approx. 21,000), Ogden (population approx. 2000), Riley (population approx. 1,000), Milford (population approx. 900) and Keats (population approx. 400) are adjacent to the installation boundaries, with the city of Manhattan (population approx 52,000) being approximately two miles to the east. The local climate is temperate continental with hot summers and cold dry winters. The installation area is approximately 100,775 acres, of which 70,000 acres is used for maneuver training. Fort Riley is an Army Forces Command (FORSCOM) installation with the mission of providing “trained and ready forces to meet Joint Force requirements.” The fort is the home to the Army’s First Infantry Division (1ID) also known as “The Big Red One” which includes three maneuver brigades (two armored brigades, one infantry brigade), along with one combat aviation brigade, and several separate battalions. Fort Riley’s natural environment is part of the Flint Hills ecoregion and is dominated by gently rolling open topography covered primarily by tallgrass prairie (big bluestem, indiangrass and switchgrass). There is a woodland component to the installation primarily associated with stream drainages and ravines.

The area surrounding the post is covered with agricultural row crops which provide a fire break for frequent grassland fires started on the installation. The installation elevation varies from 312 to 415 meters above sea level. (Fort Riley INRMP, 2010).

GPS Tracking of Maneuver Training

Three separate maneuver training events were tracked with GPS devices on Fort Riley, Kansas from 21 July 2013 thru 27 August 2013. These three events consisted of three separate maneuver battalions conducting platoon level FTX and live fire platoon gunnery. The three units were 4-4 Cavalry Squadron (4-4 CAV), 1-16 Infantry Battalion (1-16 IN), and 2-34 Armor Battalion (2-34 AR). All three battalions conducted training under the same brigade level command (1st Brigade, 1st Infantry Division). A total of 120 vehicles were equipped with COTS GPS tracking devices, of which 116 devices provided data (one device lost, three device did not participate in training). 4-4 CAV had 29 vehicles with data recovered; 1-16 IN had 31 vehicles with data recovered; 2-34 AR had 56 vehicles with data recovered. Only a portion of each battalion's vehicles were tracked while training due to limited quantities of COTS devices. Devices were primarily placed on maneuver vehicles (those vehicles primarily used for off road training, as opposed to logistics and support vehicles). The battery life of the COTS devices was not adequate to capture all of the training on a single set of batteries which resulted in differing total amounts of data collection per vehicle. The complete data set from all three maneuver battalions consisted of over 2.2 million individual GPS points. Chapter 5 contains more description of the GPS tracking events, and Appendix A provides greater detail on the GPS data collected.

GIS Modeling of Training Intensity

The GPS data was downloaded from each device and converted to a .txt file by the proprietary software issued with the COTS device. The device records GPS data in the standard 0183 NMEA code, but the device manufacturer has programmed the device to only be able to be downloaded with their proprietary software. This may be limiting some data about satellite availability and dilution of precision. The .txt file as downloaded contained the date, Coordinated Universal Time (UTC), coordinates in decimal degree (WGS 84 coordinate system), speed (MPH), and elevation (ft). The US Army Corps of Engineers Construction Engineering Research Laboratory (CERL) produced python scripting, which used in ESRI ArcGIS models, converted the .txt into a ESRI shapefile with calculated values for distance, velocity, turning radius and local northing and easting. This shapefile format is the same format CERL uses for other GPS processing applications. Once in the shapefile format the data was further processed to include unit and vehicle specific information (vehicle bumper number, vehicle platform type (tracked versus wheeled), vehicle type (M1A2, M2A3, HMMWV etc.), and specific unit identifiers for platoon, company/troop and battalion/squadron.

All the GPS data for one training event were merged together into one ESRI feature class within an ESRI file geodatabase. As off road travel is of most concern to land managers the GPS points were separated into two categories, on road and off road. In order to separate the two categories, the ITAM GIS road layer was buffered by 30 meters (same buffer distance used by Rice, 2006). The 30 meter road buffer was used to select all points falling within a road or tank trail. Those points at a minimum of 30 meters from the road were considered off road travel.

Once each event had a completed off-road dataset, further processing was conducted to include non-GPS tracking data into the dataset.   Soil data was mapped using the US Department of Agriculture Soil Survey Geographic Database (SSURGO). The soil data was spatially joined to each GPS data point based on the USCS (Unified Soil Classification System) engineering properties. Daily soil moisture was also incorporated into the GPS dataset for each field based on soil moisture data collected at Konza Prairie Biological Station (KPBS) for the National Science Foundation (NSF) funded Long Term Ecological Research (LTER) program rainfall manipulation plot study (RaMPS) (Fay et al. 2000). The RaMPS project has been collecting daily soil moisture at KBPS for over 13 consecutive years. The RaMPS project at KPBS is approximately 16 kilometers southeast of the center of Fort Riley, and has historically similar topography, vegetation types, and soils. The data used for soil moisture was collected using time domain reflectometry (TDR) at a depth of 15 cm from a continuously operating TDR. The TDR data was collected from four control plots on KPBS (Fay et al. 2000). The daily soil moisture of the control plots was averaged and then applied to each GPS point of the same date in the maneuver tracking dataset.

Using the estimated soil moisture data and the USCS soil engineering properties a rating cone index (RCI) was calculated for each GPS point within the GIS framework. Jones et al. 2005 defined the RCI as “a measure of the penetration resistance of a 30º right circular cone with a 3.23-cm^2 base area times the ‘remold index.’” The remold index “is a factor that relates to the apparent soil strength loss ascribable to application of work or traffic on the soil.” The formulas used for estimating the RCI of various soils were provided in Sullivan and Anderson 2000. The two equations from Sullivan and Anderson 2000 used for Fort Riley soil types are below in equations 6-1 and 6-2

Equation 6-1 Rating Cone Index for USCS Soil Type CL

$$RCI_{CL} = exp^{[15.506 - 3.530 \ln(\% soil\ moisture)]}$$

Equation 6-2 Rating Cone Index for USCS Soil Type CH

$$RCI_{CH} = exp^{[13.686 - 2.705 \ln(\% soil\ moisture)]}$$

Once each GPS point had a RCI value based on the local soil conditions at the time of the maneuver, a calculation of the sinkage of each vehicle could be calculated for the point. Sinkage according to Sullivan and Anderson 2000 "is defined as the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding caused by vehicle traffic." Sinkage has a long history of study on military vehicles beginning in the 1940s and continuing through the 1990s with incorporation in the NATO Reference Mobility Model (NRMM) (Priddy, 1999). Sinkage was selected by Sullivan and Anderson, 2000 as the measure of site damage caused by vehicle to use in estimating ATTACC VSF. The same sinkage equations from Sullivan and Anderson 2000 were used in this research and have been reproduced below in equation 6-3 for tracked vehicles and in equation 6-4 for wheeled vehicles. These equations have not been adjusted into metric equivalents.

Equation 6-3 Tracked Vehicle Sinkage Equation (Sullivan and Anderson 2000)

$$Sinkage = TrackLenght * 0.00443 * e^{\left[\frac{5.887*\left[\frac{VehicleWeight/NumTracks}{TrackLength*TrackWidth}\right]}{RCI}\right]}$$

Where:

Sinkage	=track sinkage or rut depth (in)
TrackLength	=Length of the track in contact with the ground (in)
RCI	= Rating Cone Index of soil (unitless)
VehicleWeight	= Total Vehicle Weight (lb)
NumTracks	=Number of tracks (unitless)
TrackWidth	=Single Track Width (in)

Equation 6-4 Wheeled Vehicle Sinkage Equation (Sullivan an Anderson 2000)

$$Sinkage = \frac{5 * TireDiameter}{\left[\frac{RCI}{\left[\left[\frac{VehicleWeight/NumberWheels}{TireDiameter * TireWidth}\right] * \left[1 - \left[\frac{TireDeflection}{TireSectionHeight}\right]\right]^{3/2}\right] * 0.7247797}\right]^{5/3}}$$

Where:

Sinkage	=wheel sinkage or rut depth (in)
TireDiameter	=Tire Diameter (in)
RCI	= Rating Cone Index of soil (unitless)
VehicleWeight	= Total Vehicle Weight (lb)
NumberWheels	=Total Number of Wheels (unitless)
TireWidth	=Single Tire Width (in)
TireDeflection	=Tire Deflection (in)
TireSectionHeight	=Tire Section Height (in)

Jones et al. 2005 developed separate equations based on the above equations to provide a separate value for sandy soils versus clay soils for each wheeled and tracked vehicles. The Jones et al. 2005 rewrites may be more explanatory of sinkage rates in major soil categories, but the level of increased precision was determined to not offset the increased computational requirement in this modeling exercise therefor the Sullivan and Anderson 2000 equations were used.

Equations 6-3 and 6-4 were simplified for each vehicle type tested and an ESRI model was constructed to calculate the sinkage at each GPS point based on the vehicle static properties and the RCI.

Once the sinkage was calculated for each GPS point based on the equation above, a reference sinkage was calculated for each point based on the M1A2 at the same point. Next the ATTACC method Vehicle Severity Factor (VSF) was calculated for each GPS point. The VSF is a ratio of the sinkage of the vehicle at the select point to the sinkage of a reference vehicle (M1A2) at the same point (equation 6-5) (Sullivan and Anderson 2000).

Equation 6-5 Vehicle Severity Factor Equation (Sullivan and Anderson 2000)

$$VSF_v = \frac{Sinkage_v}{Sinkage_{reference}}$$

Where:

VSF_v	=the vehicle severity factor for vehicle v
$Sinkage_v$	=the single-pass rut depth for vehicle v using the same soil type and soil moisture at the reference vehicle
$Sinkage_{reference}$	=the single-pass rut depth for the reference vehicle v using a reference soil type and soil moisture

The Local Condition Factor (LCF) based on the ATTACC model was then calculated for each GPS point. The LCF is typically a standard value of 1 for relatively dry and trafficable conditions (Sullivan and Anderson, 2000). The LCF for each GPS point is a ratio of the soil type and soil moisture at the time of trafficking to a standardized soil moisture for the same type soil Equation 6-6.

Equation 6-6 Local Condition Factor Equation (Sullivan and Anderson 2000)

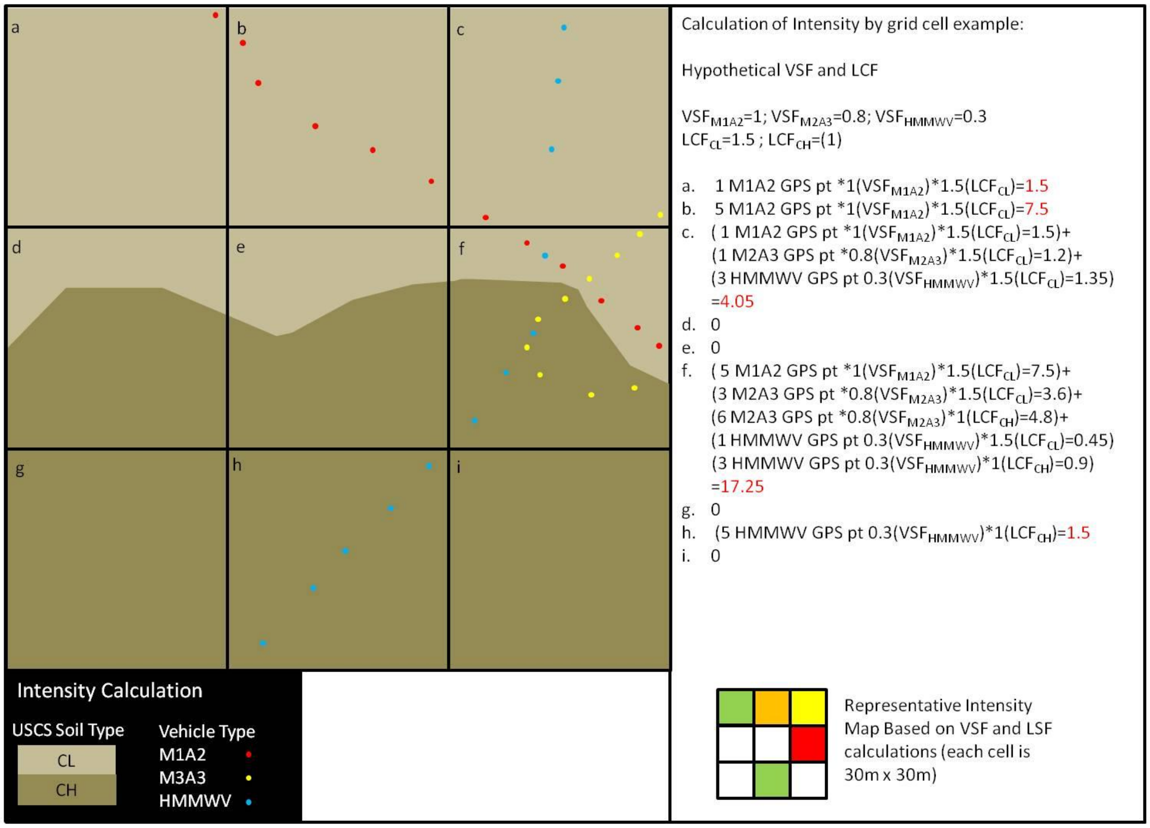
$$LCF_m = \frac{Sinkage_m}{Sinkage_{reference}}$$

Where:

LCF_m	=the local condition factor for soil moisture value m
$Sinkage_m$	=the single-pass rut depth for soil moisture value m for the same soil type and vehicle used in $Sinkage_{reference}$
$Sinkage_{reference}$	=the single-pass rut depth for the reference soil moisture value, soil type, and vehicle type used to calculate VSF

Next a 30 by 30 meter grid was created to cover Fort Riley. The grid was used to get a summation of all GPS points within each grid square based on the relative disturbance of each GPS point. The LCF and VSF for each point were multiplied for each GPS point to produce a relative disturbance at the coordinate and time. Figure 6-2 is a simplified illustration of mapping techniques providing an example of VSF and LCF calculations.

Figure 6-1 Intensity Mapping Using VSF and LCF



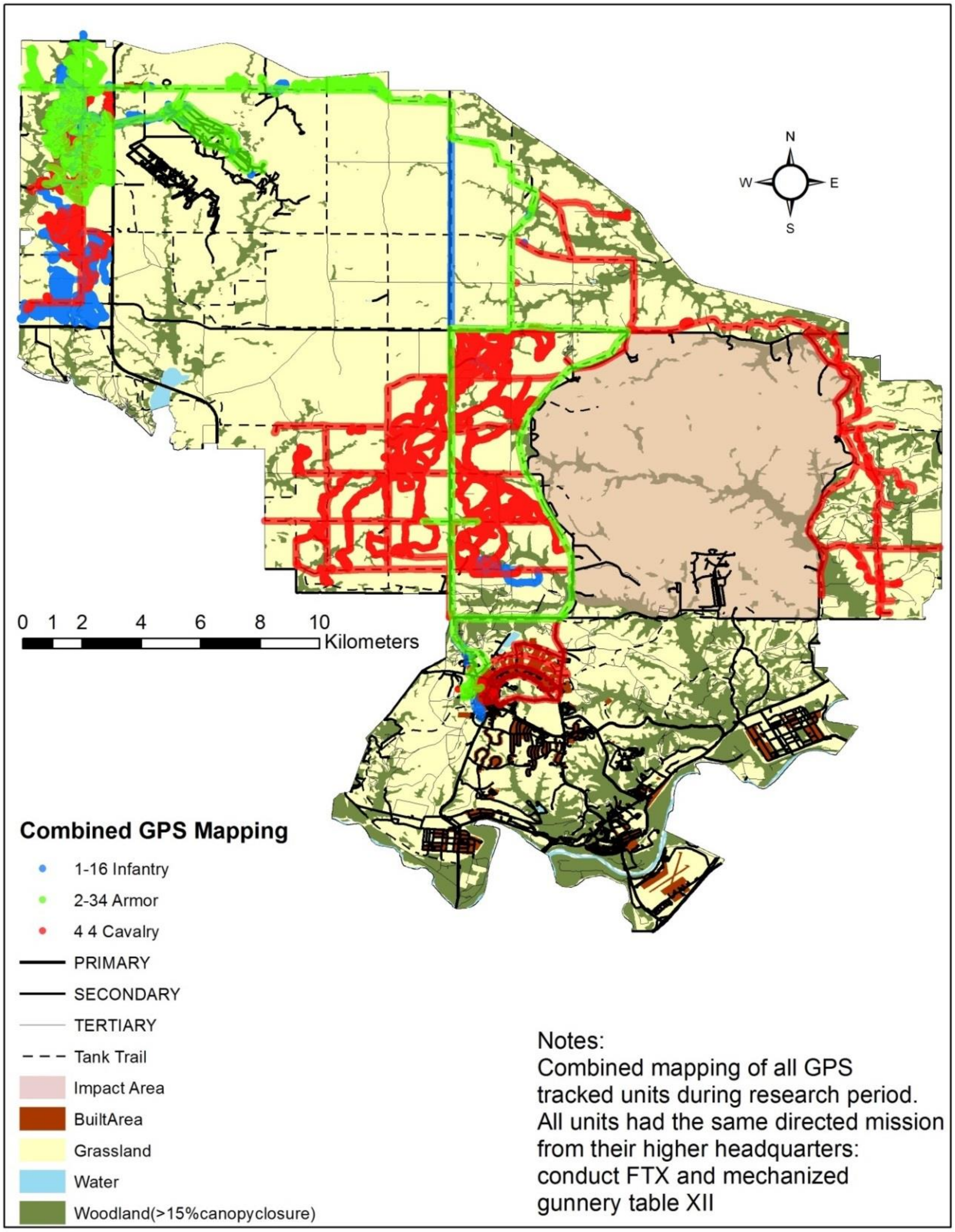
The final aspect of the intensity mapping approach outlined above was to compare an intensity map based on GPS data and one based on RFMSS data. As RFMSS data is the primary source of data input by military units with vehicular estimates and updated by installation range mangers as training occurs, it provides the best available digital record of maneuver training. The current ATTACC model uses RFMSS as a source for maneuver training. Several other studies and objective 2 of this research provide data that could be used in coordination with RFMSS to estimate maneuver training. In order to compare the intensity mapping approach provided here to RFMSS, data from each training event that was tracked with COTS GPS devices was downloaded from the RFMSS database. The data was collected four weeks after the training was complete so all adjustments to the data set by range managers should have been completed. The data collected included the training areas reserved for the GPS tracked training by the unit, the vehicles by training area input by the units, and the duration of training on each area recorded by range managers. All three battalions scheduled their ranges as “FTX” or “Field Training” when scheduling the training areas. The estimates of vehicles by training area were used to estimate a percent of training spent in each training area by unit. This estimated percent was compared to the GPS recorded percentages.

One area (Maneuver Area N) was used by all three units during the training. A comparison of training on this maneuver area was conducting comparing the spatial distribution of training by all three units. Also a distribution of training across the area was conducted to determine the distribution of training from the edge of the installation, from roads/tank trails, and from wooded vegetation (determined from ITAM GIS land cover). A series of simplistic spatial relationship comparison techniques were conducted using GIS geoprocessing. First, the GPS points were plotted within the maneuver area. A cluster analysis was conducted to determine if the GPS points within the training area could be determined to be random or clustered (for RFMSS data to be spatially accurate at the MA level the GPS points within the MA would need to be evenly distributed). A distance was calculated for each point to the nearest edge of Fort Riley, the closest tank trail or road, and nearest woodland features. A random distribution of the same number of points (146,932) was constructed within MA N and the same distance calculations were completed. Summary statistics were determined for all distance calculations and comparisons between the GPS collected points and the random points.

Results

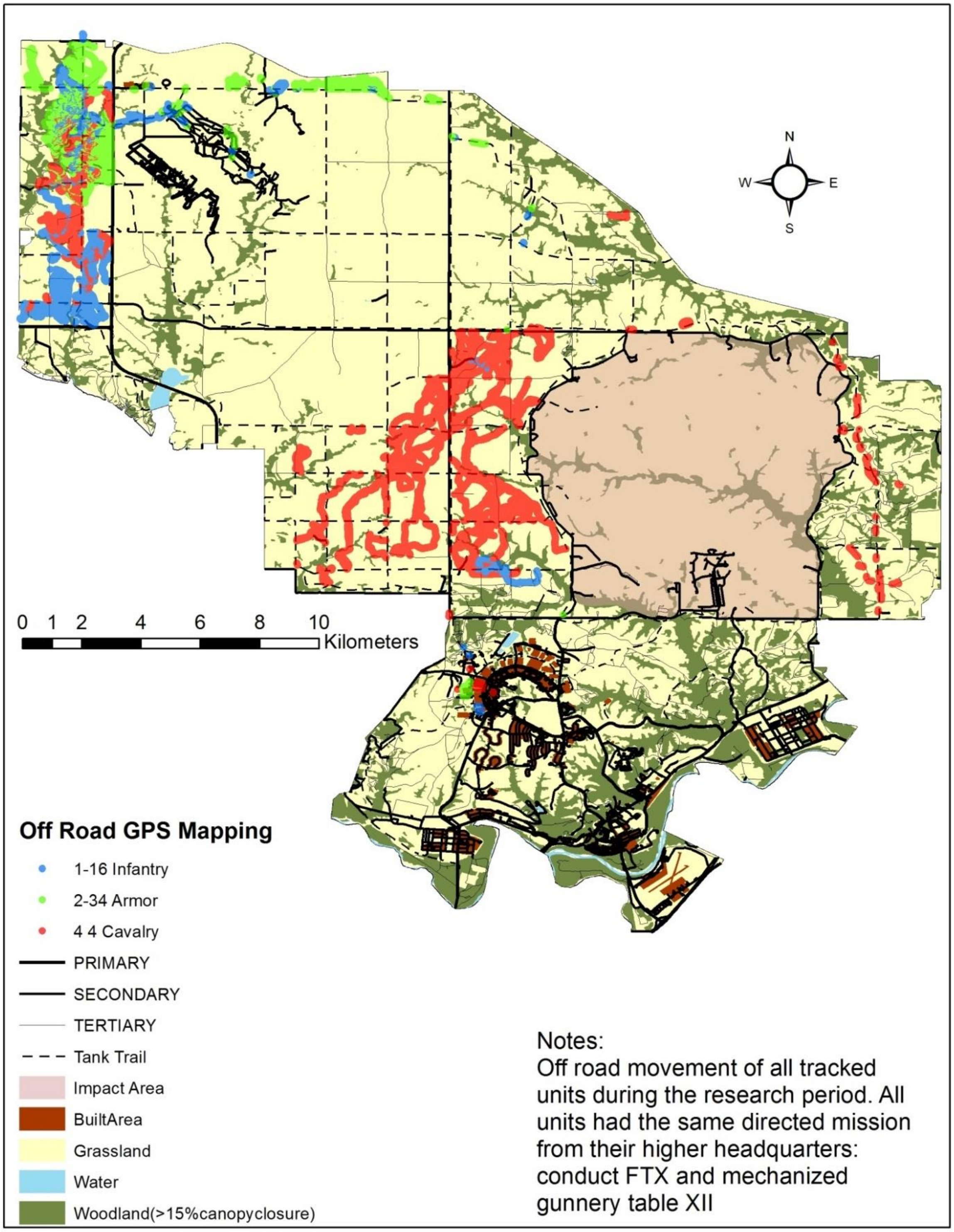
The COTS data for all three tracked training exercises is shown below in Figure 6-3 as a map of GPS points followed by a map of the off road points (those 30 meters off roads and tank trails) Figure 6-4. A total of 2,274,481 GPS data points were analyzed for the three events. Of these data points, 727,532 GPS points were collected from 1-16 IN, 874,634 GPS points from 2-34 AR, and 672,315 GPS points from 4-4 CAV.

Figure 6-2 Combined Mapping of GPS Points for All Three Training Events



Of the over 2.2 million points, 427,614 GPS points were in the off road data set (18.8%). The off road percent by battalion was 15.1%, 19.1% and 22.4% for 1-16 IN, 2-34 AR, and 4-4 CAV respectively (figure 6-4 below).

Figure 6-3 Mapping of Off Road GPS Points for All Three Training Events

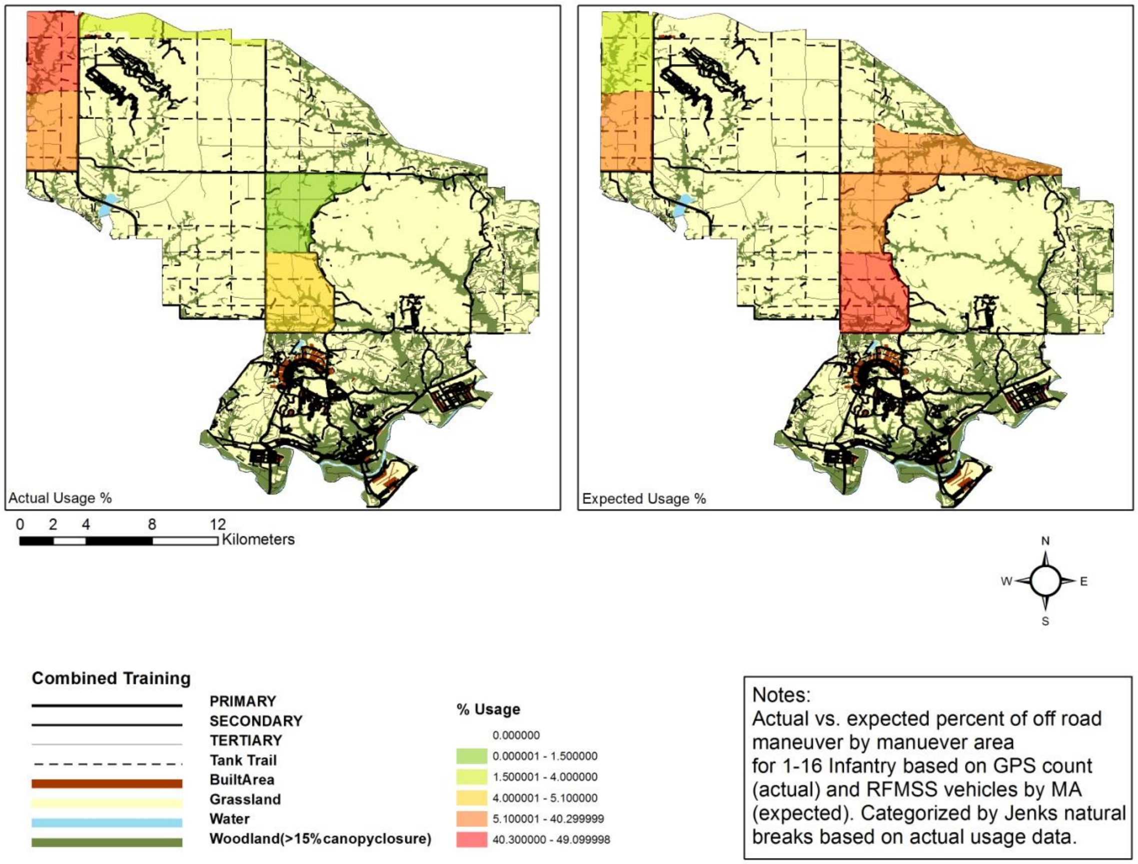


The first comparison of existing intensity mapping techniques is a comparison of expected versus actual training use. RFMSS provides at best MA wide intensity estimates. While other GPS data collection has provided much information on off road vehicle use, a major goal of that GPS tracking is to provide support or refinement to the doctrinal and subject matter expert estimates used in RFMSS for future mapping of intensity. The following series of maps show the expected training intensity based on RFMSS data input by the Army units tracked, and the actual intensity. For these maps GPS intensity was on a purely GPS count scale with one GPS point equivalent to all other GPS points regardless of vehicle type or environmental conditions.

1-16 Infantry Expected vs. Actual

1-16 Infantry RFMSS data analysis is shown in the map on the right in figure 6-5 below. The estimated usage from user input in RFMSS would indicate a significant portion of training occurring in the southern training areas on Fort Riley, with limited training occurring in the north east. Mapping of the actual GPS tracking of training indicates that a relatively larger amount of training occurred in the areas expected to and reported to have received the least amount of training in RFMSS (figure 6-5).

Figure 6-4 Expected versus Actual Maneuver Area Usage of 1-16 Infantry



The actual percentage of training estimated in each maneuver area compared to the RFMSS recorded training is shown below in table 6-3. Comparing the RFMSS data to the GPS recording of actual usage indicates a nearly inverse relationship in recorded training intensity from GPS devices to the training intensity recorded in RFMSS with four of six maneuver areas recording differences in expected versus actual usage of in excess of 30%.

Table 6-1 1-16 Infantry Battalion Expected versus Actual Usage

Unit	Maneuver Area	Expected%	Actual use%	% Difference
1-16 IN	B	40.6%	5.1%	35.53%
1-16 IN	E	37.5%	1.5%	36.00%
1-16 IN	J	10.2%	40.3%	-30.14%
1-16 IN	M	9.4%	0.0%	9.38%
1-16 IN	N	2.3%	49.1%	-46.76%
1-16 IN	Q	0%	4%	-4.00%
Std Dev		16%	20%	31%

2-34 Armor Expected vs. Actual

Mapping of 2-34 Armor Battalion shows a similar pattern to that of 1-16 IN with RFMSS expected and reported training data not reflected in the actual recording of data by GPS devices. Figure 6-6 and table 6-3 provide expected versus actual usage for 2-34 Armor Battalion. Expected use for MA Q as recorded by the unit in RFMSS was only 1.9% of total training time, the GPS data indicates that 2-34 Armor Battalion conducted 53.1% of all GPS recorded training within MA Q.

Figure 6-5 Expected versus Actual Maneuver Area Usage of 2-34 Armor

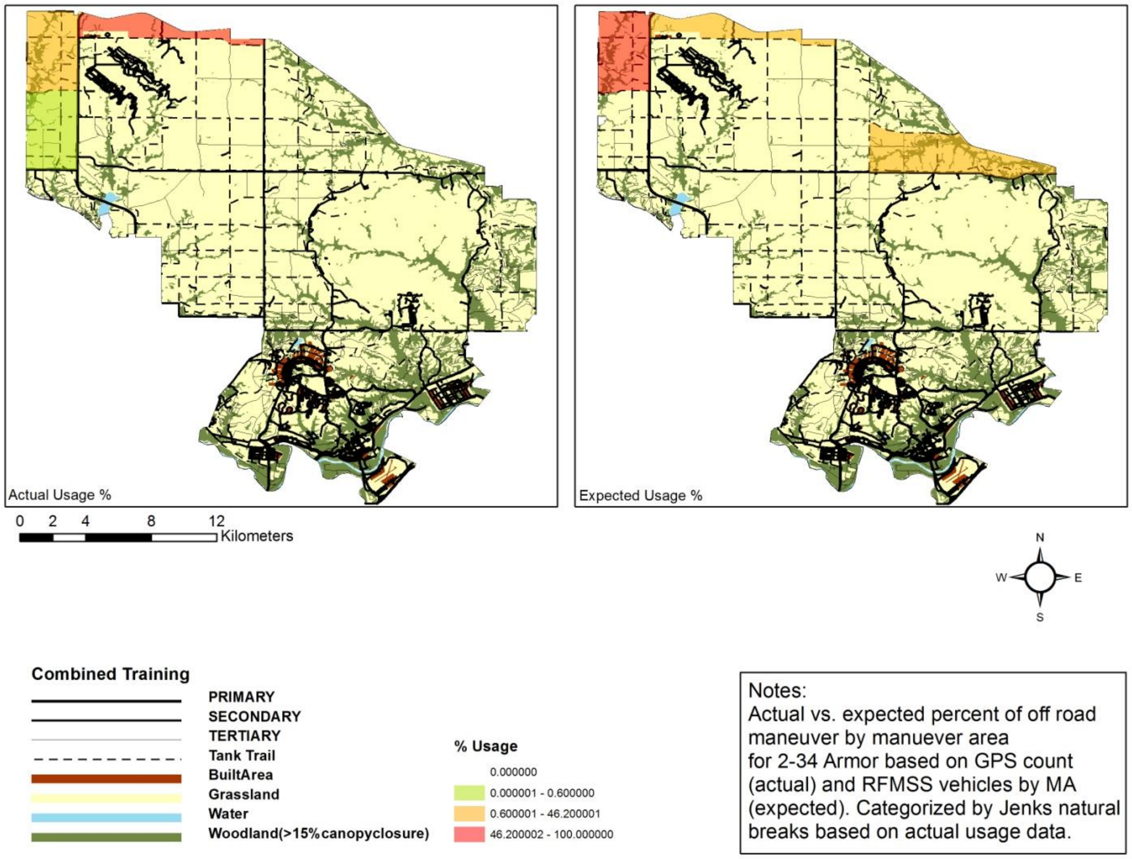


Table 6-2 2-34 Armor Battalion Expected versus Actual Usage

Unit	Maneuver Area	Expected%	Actual use%	% Difference
2-34 AR	J	0.0%	0.6%	-0.6%
2-34 AR	M	27.4%	0.0%	27.4%
2-34 AR	N	70.7%	46.2%	24.5%
2-34 AR	Q	1.9%	53.1%	-51.2%
Std Dev		28.5%	24.8%	31.5%

4-4 Cavalry Expected vs. Actual

The distribution of 4-4 CAV training by maneuver area estimated using unit input from the RFMSS system and can be seen in on the right in figure 6-7 below. The map on the left below shows the distribution of training as recorded by COTS GPS devices. The unit input of training usage was nearly uniform for all training areas reserved for their FTX. GPS data points indicate a departure from the expected usage. Estimated usage based on RFMSS vehicle data indicates the expected use of MA P to be the most utilized MA at 13.6% of total use. GPS data collected on MA P indicate usage to be 0.4%, nearly the least utilized training area. Likewise, the most heavily used area based on GPS data was MA D receiving 25.9% of all use. MA D unit estimates provided by RFMSS data equate to 8.6%.

Figure 6-6 Expected versus Actual Maneuver Area Usage of 4-4 Cavalry

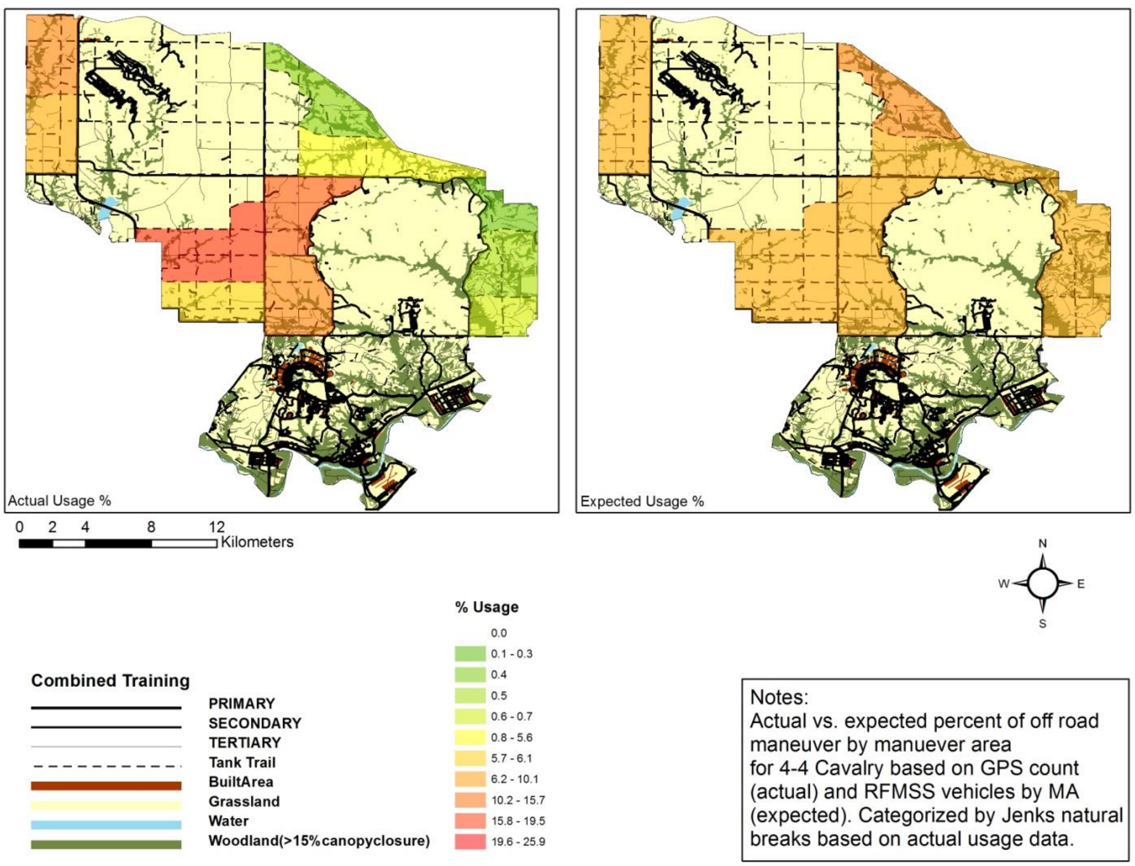


Table 6-4 below shows the change from the RFMSS expected spatial distribution of training entered by the unit and the recorded distribution of training from GPS data collection.

Table 6-3 4-4 Cavalry Squadron Expected versus Actual Usage

Unit	Maneuver Area	Expected%	Actual use%	% Difference
4-4 CAV	A	9.0%	6.1%	3%
4-4 CAV	B	8.6%	15.2%	-7%
4-4 CAV	C	8.6%	0.7%	8%
4-4 CAV	D	8.6%	25.9%	-17%
4-4 CAV	E	8.6%	19.5%	-11%
4-4 CAV	F	8.6%	0.5%	8%
4-4 CAV	I	8.6%	0.3%	8%
4-4 CAV	J	8.5%	10.1%	-2%
4-4 CAV	M	8.6%	5.6%	3%
4-4 CAV	N	8.9%	15.7%	-7%
4-4 CAV	P	13.6%	0.4%	13%
Std Dev		1.4%	8.5%	9.0%

A Chi-square test was performed for all RFMSS expected versus GPS actual usage of maneuver areas. The test indicated a significant difference between the expected use versus the actual used with a chi-square p=0.0023 (alpha level 0.05).

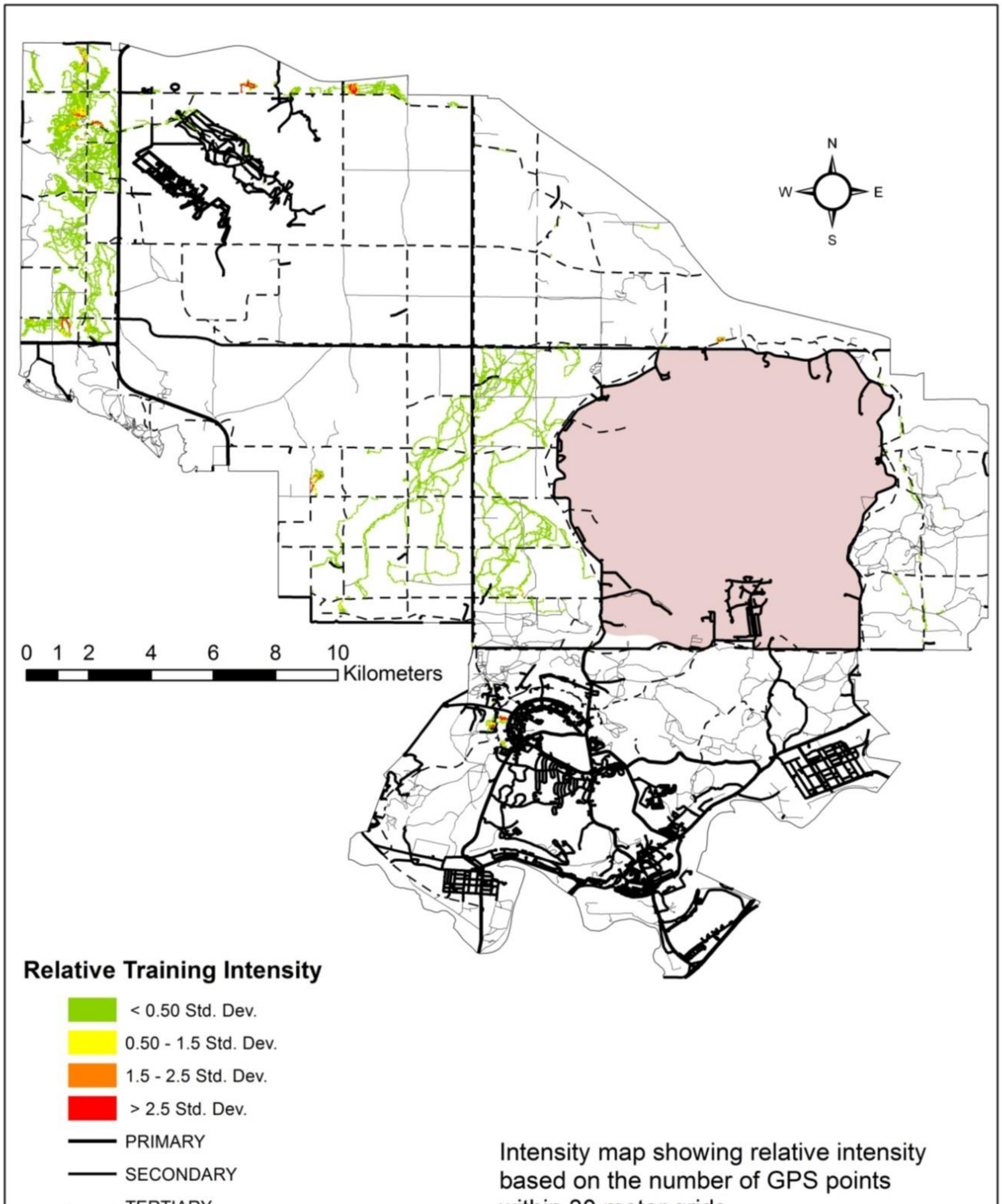
Intensity Mapping

To demonstrate the intensity mapping method described in this research, three different approaches were taken. First, mapping of GPS data was completed using a simple count of GPS coordinates falling within 30m x 30m grid squares created over Fort Riley. Secondly, using the same grid squares, mapping of the points was conducted using a calculated LCF and generic VSF values provided in Sullivan and Anderson 2000. Lastly, intensity mapping was completed using the same grid squares and a calculated LCF and calculated VSF for each point. The sum of the count is provided as the value of grid squares.

30m by 30m grid squares were selected for a multitude if reasons, first they coincide with readily available digital elevation data sets for most installations, second, the landsat program provides 30m resolution remotely sensed imagery data which could provide valuable to long term monitoring programs, the ITAM roads and tank trails data sets have a reported accuracy of 30 meters so the off road data reduced by the roads and trails data could be less accurate than the GPS device accuracy near these features, lastly, previous researchers have used grid squares in their studies (Ayers et al., 2005) which were recorded with a slightly higher accuracy GPS device. The spatial resolution provided by 30 by 30 meter accuracy should provide considerable detail for land managers and researchers, and the GPS point data can still be retained for more thorough inspection at a finer scale if needed.

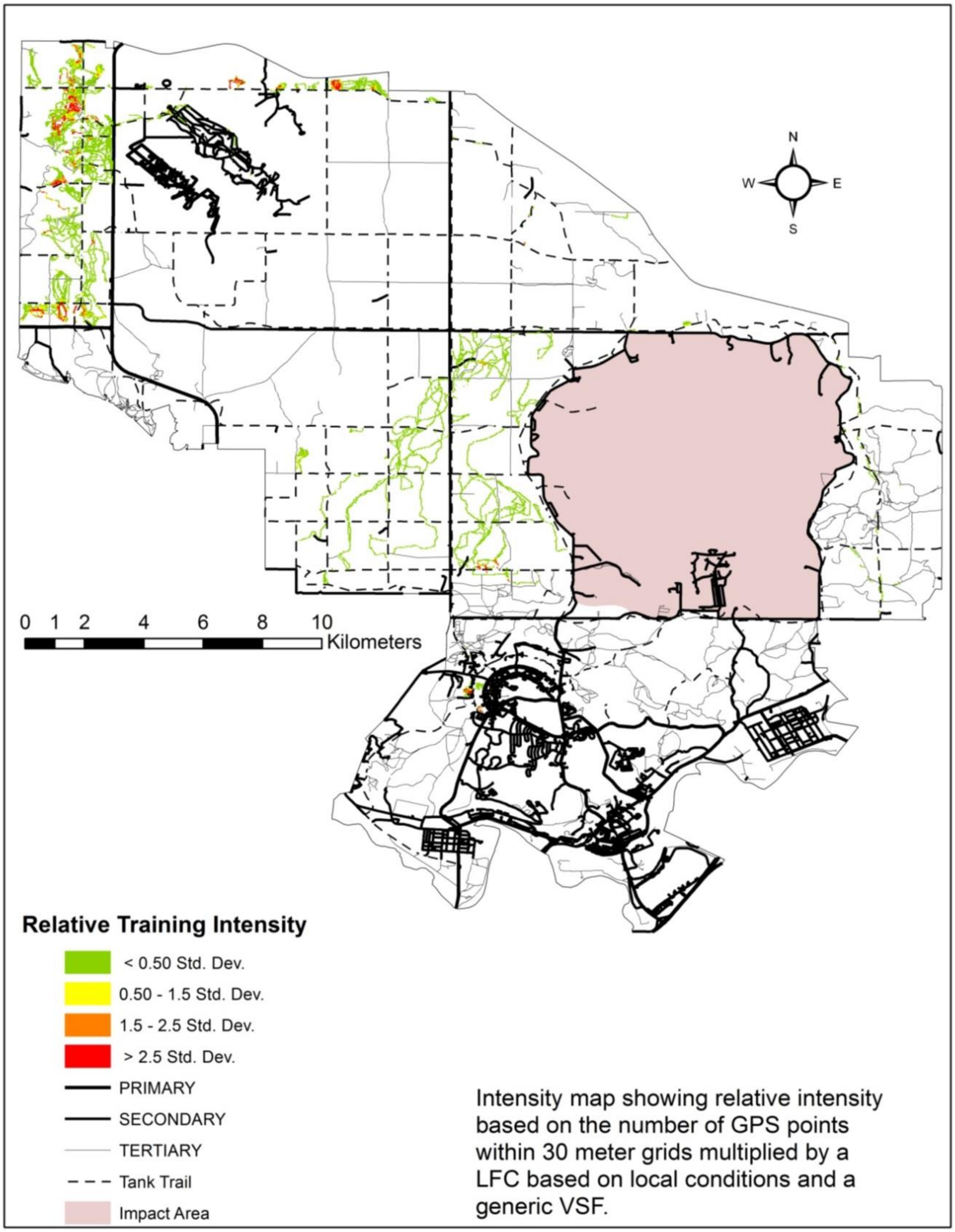
The following three maps display the relative intensity of maneuver training on Fort Riley, Kansas from the three training events conducted by 1-16 IN, 2-34 AR, and 4-4 CAV from 21 July 2013 to 27 August 2013. All on road points have been filtered out in order to show the intensity off road where the most maneuver disturbance is expected to occur. Figure 6-8 is an intensity map solely based on the count of GPS points within a 30 m by 30 m grid. As can be seen from this simplistic map the majority of training tracked from the three units was located in the northwest corner of the installation. The intensity map is a relative map, with red indicating higher training intensity and green being low level intensity. Areas with no color had no recorded training during the data collection period.

Figure 6-7 Intensity Mapping of Training Based on GPS Coordinates Only



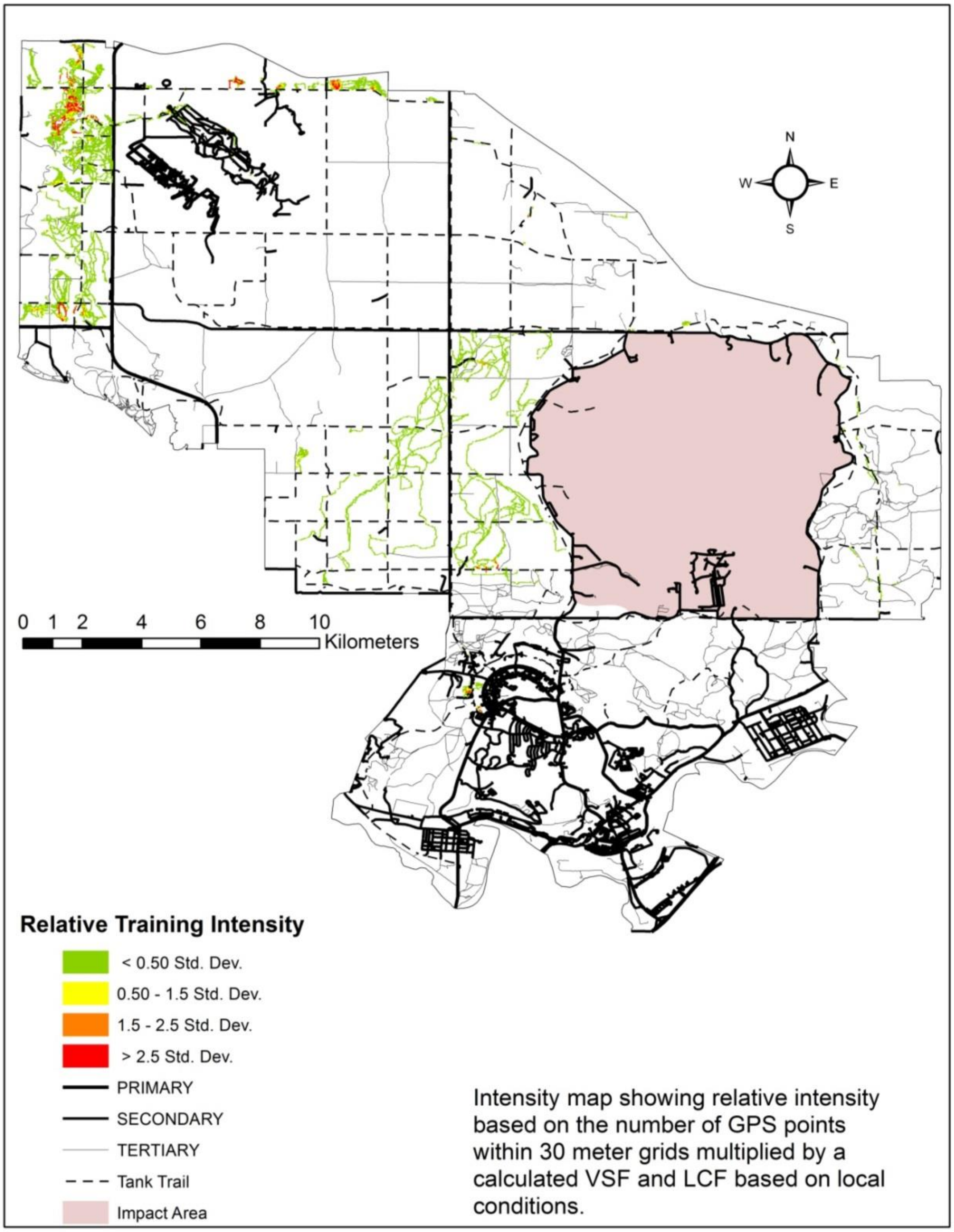
Intensity mapping of training can also be conducted using a calculated LCF based on the soil type and soil moisture where the training occurred and a VSF based on a generic VSF factor provided by Sullivan and Anderson 2000. Mapping using this method provides more detail information about the training disturbance that could be expected within an area as vehicle properties and environmental factors (soil type and moisture) are included in the mapping. Relative disturbance based on generic VSF and the LCF can be seen below in figure 6-9.

Figure 6-8 Intensity Mapping of Maneuver Training using Calculated LCF and Generic VSF for Vehicle Types



The final intensity map produced of the training events can be seen below as figure 6-10. This map incorporated both a calculated LCF and calculated VSF specific to the vehicle type and conditions at the time of training.

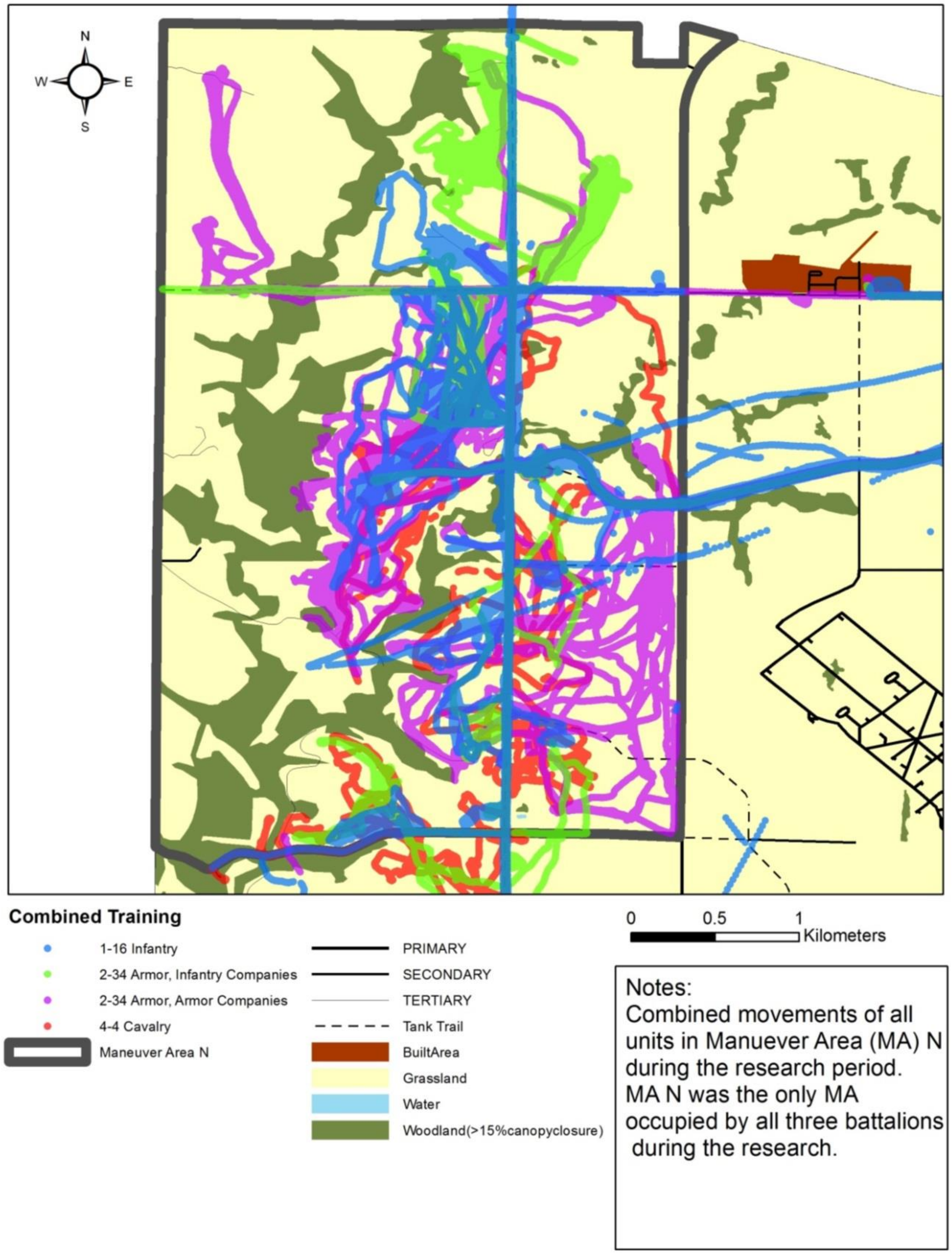
Figure 6-9 Intensity Mapping of Maneuver Training using Calculated LCF and Calculated VSF



Maneuver Area N Comparative Analysis

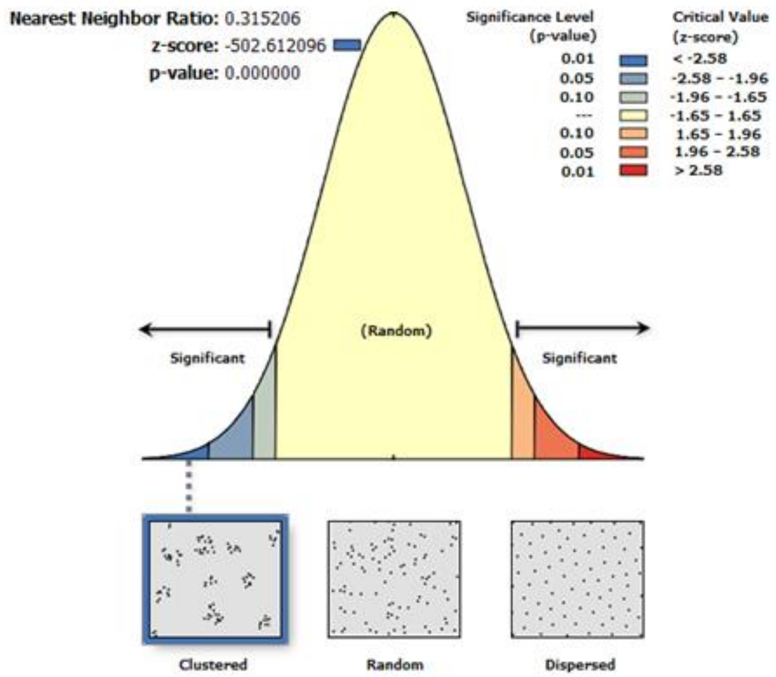
Using an installation wide intensity map of only three events it is difficult to determine the spatial variation in training intensity. In order to better illustrate the spatial variation observed in training as tracked by COTS GPS devices, a comparison of the one training area utilized by all three tracked units was conducted. Maneuver Area N was used by 4-4 Cavalry from 21 July 2013 to 27 July 2013, 1-16 Infantry from 06 August 2013 to 12 August 2013 and 2-34 Armor from 16 August 2013 to 27 August 2013. No other units were recorded in RFMSS as having signed for or conducted training in this maneuver area during this timeframe. Figure 6-11 below shows all of the GPS points recorded by all units training in MA N.

Figure 6-10 Movement of all Units in Maneuver Area N



One of the key assumptions of RFMSS would be uniform spatial distribution of maneuver training within a training area. The ESRI ArcGIS "average nearest neighbor" tool was used to determine if the distribution of GPS points within MA N could be considered random. The GPS points within MA N were found to be highly clustered (figure 6-12).

Figure 6-11 Average Nearest Neighbor Summary

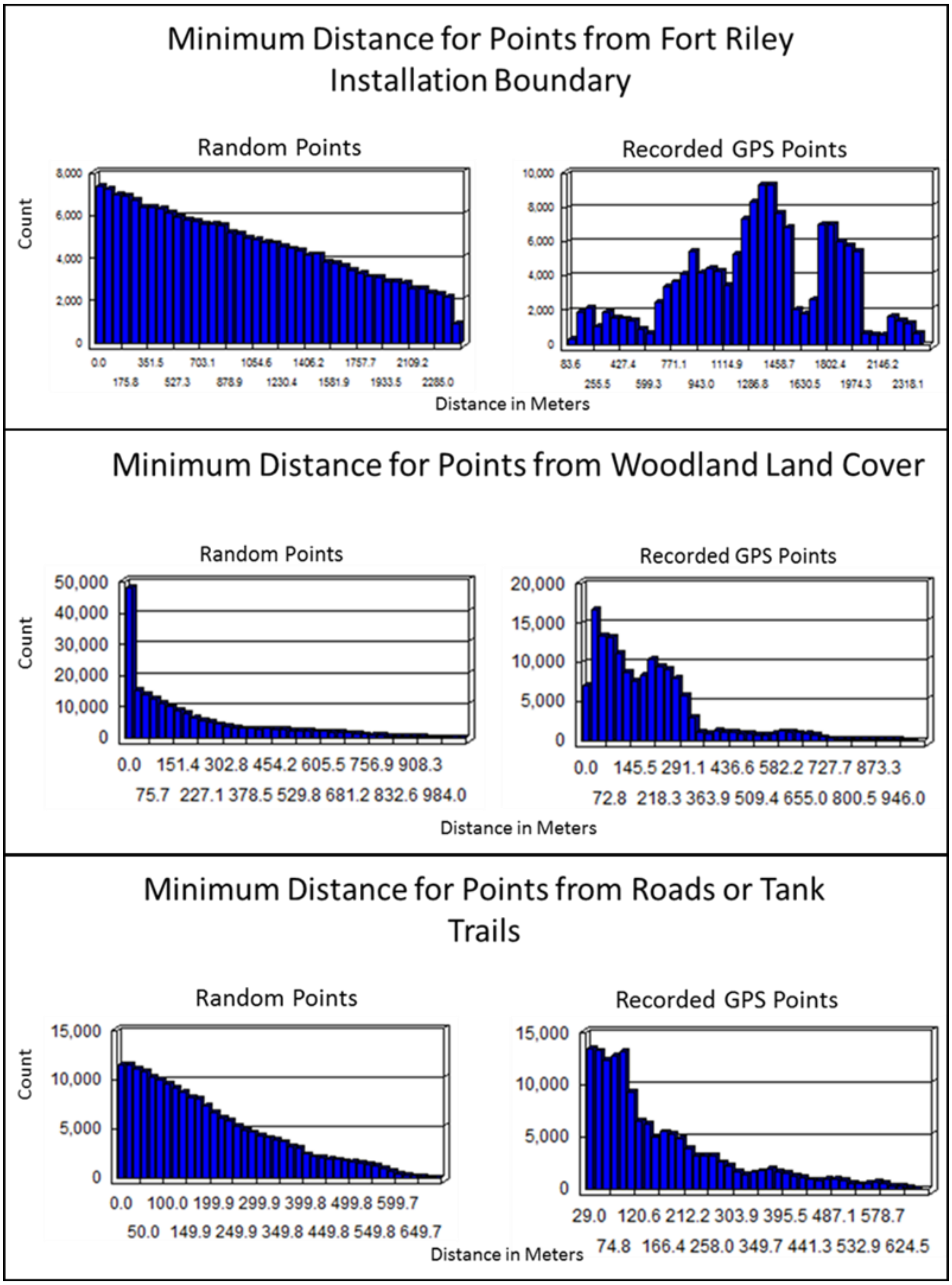


Given the z-score of -502.61, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary	
Observed Mean Distance:	1.304906
Expected Mean Distance:	4.139852

In addition to the clustering analysis above, the spatial distribution of training may be impacted by several landscape variables. Simply looking at the map of GPS points above seems to indicate that there is spatial variation in the distribution of points with relation to the installation boundary, wooded vegetation and possibly the roads/trails. There seems to be less training near the installation boundary and within wooded areas, and there may be more training near roads than away from roads. If these three variables dictate spatial distribution of training, then the assumption of uniform distribution within MA N would be invalid also. To determine if these variables dictated spatial distribution a simple check of distribution was conducted by comparing the average distance of GPS points to three selected variables (installation boundary, road/tank trails, and wooded vegetation) and the average distance of randomly plotted points to the same three variables. GIS was used to randomly plot an identical number of points within the MA boundaries as the number of GPS points located within the boundaries (147,192 points) and then average distances from the points to the nearest installation boundary, wooded area and roads were calculated.

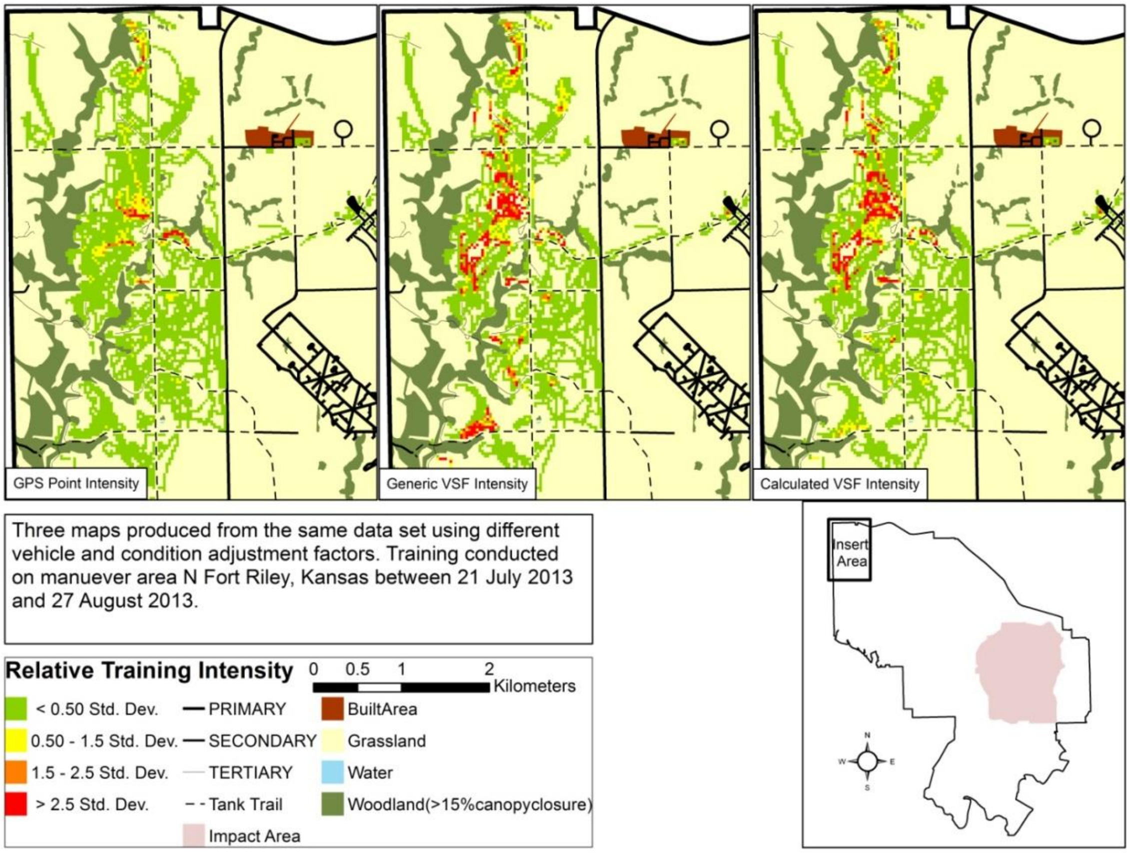
Figure 6-12 Frequency Distribution Distance of Random Points (left) and GPS Recorded Points (right) to Three Possible Explaining Variables for Spatial Distribution



The spatial distribution of the recorded training points to the randomly placed equivalent number of points for this one case study shows a tendency to train further from the installation boundary (average distance 1336.6 meters from the boundary for tracked points compared to an average of 980.8 meters for a random distribution). Also the spatial distribution of random to tracked points varies near woodland features. Based on a random distribution of points, nearly 50,000 points should have been recorded within the woodland features, whereas closer to 7,000 points where within the woodland features. Lastly, the distance of random points from a road or tank trail is a smooth where the distribution of the tracked points to the roads shows a strong shift in favor of shorter distances from points to road/trails.

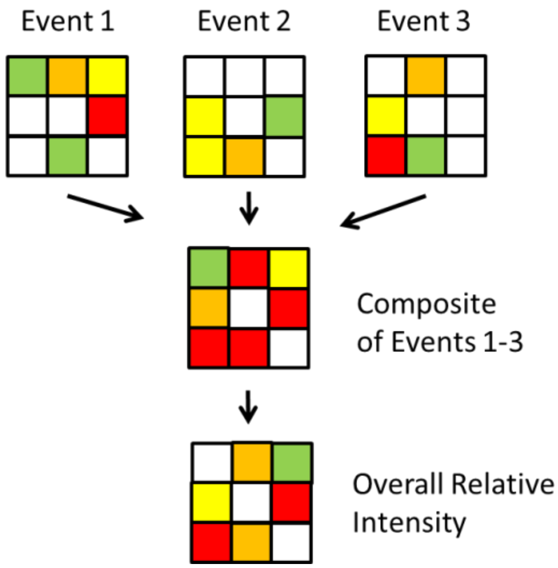
All three of the above average distance comparisons along with the cluster analysis demonstrated how the assumption of uniform spatial training distribution based on RFMSS data or doctrinal estimates would be broken. In order to map the spatial distribution more effectively the method outlined in this chapter has been provided for MA N below in figure 6-14. From left to right in figure 6-14 training is mapped using the same 30m x 30m grids using GPS point count, point count multiplied by LCF and a generic VSF, and point count multiplied by LCF and calculated VSF. Theoretically these three images should progress from least representative from left to right also. These three maps provide an example of a simple long term mapping and monitoring program that could be completed on an installation.

Figure 6-13 Intensity Mapping of Maneuver Area N, Fort Riley, Kansas, Based on COTS GPS Data using Three Intensity Estimation Methods



This mapping technique also allows for an additive approach, where the relative intensity from one training event can be added to the next training event. As the grids used in the calculation of intensity are reused overlapping grids from separate training events can be added together in a GIS providing a map over time that provides a great amount of detail of the long term training intensity on an installation. Figure 6-15 provides a line drawing of additive mapping using the gridded approach.

Figure 6-14 Additive Relative Mapping Combining Three GPS Tracked Events into Composite and Relative Maps



The same methods used in this mapping approach could be used with more complex and more accurate representations of intensity by including more parameters in the point calculation of disturbance. Vehicle dynamic factors could be included that would help explain disturbance based on turning radius and velocity at the point. Environment factors could be included describing the existing soil compaction at the site and the vegetative type and conditions. The same data set can also be used with recovery estimates, the intensity of each pixel could be multiplied by a recovery rate allowing managers to model future impacts from training and resting of training areas.

Discussion

Summary

Three maneuver training events were tracked on Fort Riley, Kansas using COTS GPS devices. The GPS points were separated into on and off road data sets. The off road data sets were used to calculate Vehicle Severity Factors and Local Condition Factors which were used to modify the GPS point data to estimate a relative intensity for the point. A 30m by 30m grid was used to calculate a summation of the relative disturbance and then mapped to display the relative training intensity recorded during the three events on Fort Riley. Three intensity maps were produced showing changes to patterns of intensity as more variables are included in intensity calculations.

Comparisons were made of the expected training intensity based on RFMSS derived data, and the data actually recorded using GPS tracking. RFMSS data was inaccurate at determining the spatial distribution of training at the installation level with a significant difference seen between expected and actual usage of maneuver areas based on chi-square testing ($p=0.0023$ with alpha 0.05).

Recommendations

GPS technology now allows for relatively accurate maneuver tracking. Researchers are providing increasingly better tools to use GPS tracked data to better understand the direct disturbance from military training maneuvers. There is desire to use this data collected from GPS devices by applying it to the military's recorded scheduling data and military doctrine to estimate where, when and how maneuver training is impacting ecologic systems. Until a better understanding of how units spatially utilize training areas there must be a high level of uncertainty in any estimates of disturbance.

Using RFMSS as a tool to estimate training intensity is a crude tool at best. While RFMSS may be the most readily available tool and provide the best scheduling data available, extreme care must be used when attempting to use RFMSS unit input data to make assumptions of training intensity. An understanding of the process used by the military to schedule training in RFMSS helps to illustrate why the data captured within the system should be considered suspect for mapping training intensity and maneuver disturbance regimes. RFMSS scheduling is conducted by individuals at the military unit who are uninformed of the eventual distribution of training (due to scheduling of ranges being completed prior to finalization of training plans), and therefore provides data that is highly likely to be inaccurate for final training distribution. While the RFMSS system does provide a tool that may accurately designate the unit types, dates and training areas signed for, it could over or under represent the amount of disturbance from the training.

A better means of determining military maneuver training disturbance may the mapping of tracked maneuvers over a period of time and developing a better understandings of the spatial relationships of training and the environment. An approach to intensity mapping that includes spatial distribution is likely to provide a vastly different picture of training area use than those based on current methods. Not only does the intensity mapping methods discussed here provide details on the spatial relationship of maneuver training, the dataset used to create this mapping still provides the necessary positional accuracy to incorporate many of the disturbance pattern analysis and measurement techniques that others in the field have been developing to further understand training landscape interactions.

While the method of mapping used in this research my prove useful for showing where vehicles have been and their relationships to other features, it does not include any data about the amount of disturbance that would be reasonable to expect based on the vehicle type, soil type, or soil moisture. In order to have a more complete understanding of maneuver disturbance, a long term GPS augmented monitoring program could be conducted at an installation. A long term GPS monitoring program that also included field data collection of vegetation changes, soil compaction, and recovery could be used to quantify the damage provided from the relative mapping approach to actual disturbance over time.

Chapter 7 - Conclusions

Summary

The relationship between military off road maneuver and environmental disturbance has been well documented. The ability to accurately map the spatial distribution of off road maneuver has been limited and costly. GPS tracking of military maneuver has proven effective at tracking off road training. This research demonstrated that low cost civilian off the shelf (COTS) GPS devices can effectively track military vehicles with similar accuracy levels to those demonstrated by devices designed and previously studied for tracking military maneuver.

The tracking of military training using GPS devices could provide data that could be used to estimate the future disturbance caused by off road training. Chapter 5 of this research indicates that using estimates of training intensity based on unit type and training type is likely to have a large amount of variance even under ideal conditions. Based on data from the pairwise comparisons extreme care needs to be taken when applying data from previously tracked maneuver training events to other training events. While there were significant differences between units tracked, with enough data a range of training by unit and event type could be developed that may be able to be developed to estimate how much future training would impact the landscape. Tracking of training events to date have not been frequent enough to develop ranges of metrics for future events. The three battalions tracked in this research may or may not have been representative of platoon level FTXs, other events will need to be tracked to see if the amount of variation found in these three battalion level events are representative.

Lastly, a method of maneuver intensity mapping was developed that incorporates many variables known to contribute to disturbance during training. This method included vehicle static properties (weight, drive type, tire/track dimensions, etc.), and environmental conditions (soil type and soil moisture) to better estimate localized disturbance. A mapping method similar to this one could be used as a basis for a long term monitoring program of military maneuver training on military installations.

Validity of COTS GPS

The COTS device tested (LandAirSea Inc. Tracking Key 1505) was tested during dynamic accuracy testing to have an average CEP of 1.93m and a 2DRMS of 4.63m. The COTS devices tested were marginally less accurate in overall accuracy than the VTS/VDMTS devices currently used by researchers and land managers, but within the accuracy requirements defined for this study as reported by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (Koch et al. 2012).

In side by side comparison tests with the VTS/VDMTS at Fort Benning, GA, the COTS devices tracked the same four military vehicles (HMMWV and Strykers) during maneuvers for over 482.8 kilometers. The average distance recorded between the COTS device and the collocated VTS/VDMTS device was 2.23 meters.

In maneuver tracking tests on Fort Riley, Kansas, the COTS device was installed on three maneuver battalions as they conducted field manevers. The COTS device recoreded 116 vehicles as they conducted platoon level field training exersizes. A total of over 2.2 million seconds of movement were recorded during this training. The number of points removed from data as obvious recording error was only 2833 (0.184% of total points removed). The total distance tracked was 14,050 kilometers of which 1,295 kilometers was determined to be off road maneuver (based on 30 buffering of roads and tank trails).

A significant liability of the COTS device tested was the battey life. 63 of the vehilces tracked at Fort Riley, Kansas had the batteries die during tracking, the remaining GPS devices tracked thru the duration of training. Of the devices that experienced battery failure the average amount of maneuver that was tracked was approximately 5.5 hours of movement over an average of 3.4 days of training. There were zero devices that experienced a recorded failure of the GPS device to record, although it is possible that some device may have stopped recording with loose batteries as the research did not provide an alternate method to verify that the device recorded for the entirety of the exersize. Battery failure also occurred on all devices that recorded training at Fort Benning, GA.

Intensity Mapping

Comparison of the existing mapping techniques with the mapping of COTS data using the methods outlined in this research indicate that the proposed method provided a more accurate representation of actual training distribution. Current methods rely on military input of training area usage which can be unreliable. Results from a comparison of data recorded by the military in RFMSS, and that from the recording of the actual training using COTS GPS devices reveled the average difference between expected maneuver area usage (as recorded by units) and the actual usage (as recorded by the GPS devices) was a 23% difference producing a significance based on Chi square testing (p-value =0.0023). This result is at a maneuver area wide scale (several square kilometers). Other methods of estimating maneuver disturbance at a smaller spatial scale rely on physical observations of the landscape without the vehicle present which compounds the difficulty of determining the disturbance from individual training events which may be important for forecasting disturbance for future events.

A demonstration of the ability of the intensity mapping method provided here on a single maneuver area (MA N) showed that the assumption of uniform distribution of training within a maneuver area is invalid. A review of expected versus observed spatial patterns of training was conducted on an individual maneuver area on Fort Riley, Kansas (MA N). Spatial distribution of training at the maneuver area level was not random as is assumed when using RFMSS to map training intensity. Moreover, an average nearest neighbor analysis indicated a high level of clustering associated with the GPS points (p-value <0.0000). A simple analysis comparing the distribution of GPS points within MA N showed that the distribution of points was different from a random set of points when distance to three possible variables were introduced (installation boundary, wooded vegetation and roads/tank trails). This proposed method of mapping could allow for a much higher level of spatial accuracy when estimating the training intensity on an installation over existing methods.

Problems of Previous Military Maneuver Impact Studies

There is a common thread thru much of the research into military maneuver impacts. The standard logic used by most of the researchers in the field seems to indicate if an impact can be attributed to a specific set of vehicles for a given maneuver event then that impact would have a strong relationship to events labeled the same in the future. There is considerable error in this line of logic as it relates to military training. Personal experience in Army training by the author has shown training to be primarily designed by the unit commander and his/her staff, there is not a set script that is followed for each type of training event even though there is basic doctrine that can be followed. Army doctrine is more of an example of a way the training could be conducted rather than a recipe or formula for how to conduct the training. As such, even training events labeled the same and trained by the same unit at two different times could vary substantially. While there are broad training guidelines written in military doctrine that outline many of the various training events, those guidelines leave large amounts of flexibility to unit commanders to ensure they are able to meet their mission requirements.

One common training event in the Army is known as a FTX (field training exercise). The term FTX may be affixed to numerous different types of training events at levels from platoon to brigade and for many different types of military units. As an example the term FTX could refer to an infantry company conducting dismounted operations focusing on urban terrain within a training area, or to the same infantry company conducting mounted vehicle maneuvers off-road in the same training area. Each of these events could vary dramatically in the impact on the environment. The Army system of record for tracking training area use (RFMSS) would not necessarily differentiate between the first two completely different events and their vastly different impacts on the landscape. Both events could entail the same unit, the same number of personnel and vehicles, but in one training scenario the vehicles may sit staged in one location while the soldiers spend most of their time separate from the vehicles on foot, whereas the other scenario the soldiers spend most of their time operating the vehicles.

Unit training for military units is a constantly evolving and changing phenomenon. As missions change the types of training are changed. The maneuver requirements for units training for cold war era warfare were quite different than the training conducted by units deploying in support of the global war on terror. Future conflicts will undoubtedly necessitate different training requirements. Not only does the geopolitical climate affect training types, natural climate causes training events to be altered. With a single training event factors such as weather, resource availability, and personnel limitations can impact how much or little off road maneuver is conducted. Lastly, the terrain itself dictates changes to training plans. Off road maneuvers by tanks and infantry fighting vehicles are extremely limited on installations with large quantities of woody vegetation, but relatively free to maneuver on installations dominated with grasses. An armored brigade conducting operations in preparation for a deployment at the national training center in Fort Polk, LA will have substantially less off road maneuver than the same unit at the national training center at Fort Irwin, CA. Same unit same mission, different impacts.

Herl et al. (2005) stated a phrase heard often throughout US Army officer ranks and attributed to a German general officer in WWII ‘‘The reason that the American Army does so well in wartime is that war is chaos and the American Army practices chaos on a daily basis.’’ This demonstrates that even though there may be written doctrine to follow, military maneuver rarely follows its own doctrine. Researchers and land managers would do well to find means of determining disturbance that removes military doctrine from the determination process to a large extent.

Ecological Disturbance Management

This research provided little in the form of quantifiable measures of disturbance at a local level. Many other researchers have used GPS devices to measure disturbance directly resulting from vehicle traffic. This research conversely provides a relative intensity at a site that would need to be quantified using one of several other approaches. The intensity at a site could be quantified using GPS as done by Haugen et al. (2003) or Rice (2006), it could also be estimated by remote sensing data, or through field measurements along with a program like LCTA.

Disturbance Site Identification/Restoration

What the mapping techniques proposed in chapter 6 lack in quantifiable disturbance measurements may be overcome by the quick identification of sites that require restoration, rest, or rehabilitation. With a continuous GPS monitoring program, high intensity usage areas can be identified at a relatively small spatial scale allowing land managers to focus their efforts and increase efficiency.

Understanding Usage Trends

A program of continuous GPS tracking of maneuver training could also provide substantial data that would allow for better understanding of spatial trends in maneuver training. Knowing where different types of units are likely to train within a maneuver area could allow land managers to make determinations of the best maneuver areas to use for particular unit training. This could benefit the landscape by allowing hard hit areas time to rest, but also support better training opportunities for military units as land managers could help ensure continued sustainability of training lands.

Military Use

One seemingly overlooked area of military land management is 'how can military units benefit from training data collected for sustainability purposes?' Several researchers have commented about a desire to use the current GPS devices in use by military units and repurpose the data for land management, but this may face insurmountable obstacles as discussed early in this research in the discussion of the BFT/JCR. However, there may be benefits to military units from a device used to track training that could allow for adoption of a GPS tracking program that is mutually beneficial. While land managers need the data to help provide sustainable training lands, military users could have at least four other direct benefits of a continuous military maneuver training GPS tracking program. Military units could use the GPS device data for After Action Reviews (AARs), safety investigations and to support the development of training simulations. Military leaders at strategic levels could also use the data to help develop future doctrine, simulations and to provide strategic data for installation needs and budgeting.

Feasibility for AAR

GPS data has been used to support After Action Reviews of training at the combined training centers for many years. This data is collected from the Army's BFTs and is then used to build video clips that demonstrate where the units operated. This helps lead discussions at squad thru brigade level on how to better maneuver for future missions. During the collection of data for this research, AAR clips were developed and delivered to each of the three battalion size elements for use to help facilitate battalion level AARs of the training events. The most useful AARs are those that happen on a short time scale after training has completed. The closer to the completion of the event the better as the training is fresh in the minds of the soldiers. The data from the COTS devices was not able to be processed and delivered to the units in a rapid manner reducing its effectiveness as a training tool. Better data processing tools could allow for

AAR products to be delivered to the units on a much shorter time scale. Some COTS GPS devices currently available have blue tooth connectivity that could allow for device download in the field and near real time AAR use with proper programming developed to process the data. Active GPS devices could also be used to track military maneuver training which could not only provide near real-time AARs.

Pattern Analysis and Strategic Investigations

Having a dataset that provides precise locations of training could allow higher echelon military leaders and planners to better utilize military lands. Currently there is no way to truly map training intensity. With a solid understanding of training intensity and spatial usage patterns, leaders could relocate units to different installations that could provide better training for the unit while minimizing impacts to sustainability. Also, reduction in the size of military forces has caused a nearly continuous base closure and realignment process over the last 30 years. Further base closures are being discussed at the time of this report coinciding with a reduction in total Army personnel and brigade combat team reductions and reorganizations over the next 10 years. Knowledge of spatial training use could help determine the most responsible drawdown of installations while still providing necessary land for continued training by larger future brigades.

Simulations

The DoD has increased focus on simulation training environments to reduce costs, injuries to soldiers, damage to equipment, and the environment. The tracking of real maneuver could help develop rules for future maneuver training simulations. An understanding of where and when units operate on the landscape could support more realistic simulations. Also, simulations used to estimate the maneuver of future maneuvers could be developed based on knowledge gained from tracking current training.

Safety Investigations

Probably the most significant reason for a future GPS tracking program would be in support of safety investigations that could save the lives of soldiers during training along with saving large sums of money from damage to equipment. Soldiers are injured every year in maneuver training. During the tracking of the three training events in this research, two incidents resulted in injuries to three soldiers, two of which were removed from training and taken to the Fort Riley, hospital for treatment. One incident involved two M2A3s conducting a rehearsal of a live fire training lane. One vehicle was following the other when the lead vehicle stopped and the trail vehicle ran into the back of the lead M2A3. The GPS devices on both vehicles provided a second by second review of the speeds of the vehicles along with the distance between the two vehicles up to the time of the incident. The second incident involved a vehicle that ran into a gulley on Fort Riley injuring the back of the vehicle's commander. The second incident involved a vehicle with a GPS with dead batteries resulting in no data collected but had the device been active at the time of the incident it could have provided data about the speed of the vehicle and location when it ran into the gully. All incidents involving soldier injury or damage to high dollar equipment is investigated as part of standard operating procedure. Data gained by investigators in these events could lead to safer operations due to lessons learned along with repairs to dangerous areas within the training lands.

Limitations of COTS Device

The device tested in this research has several limitations. The first limitation is the ability of the device to detect signal when covered. The efficacy of the device to track was severely limited in trials using the device inside armored vehicles (HMMWVs) at Fort Benning. While some devices still acquired signal and tracked locations when mounted inside of vehicles the accuracy may have been reduced, and some devices did not record any data even though the devices were moving (as tracked by externally mounted VDMTS/VDM devices). Secondly, the battery life of the COTS device was not adequate to track full length of battalion training events on a single battery set. While the average battery life of 3.4 days of training observed in this research may be adequate for shorter company level operations, a better battery must be used, replacement of batteries during training, or a device with better battery life would be recommended for long term studies.

Chapter 8 - Recommendations

Recommendations for the COTS Device Use

The COTS device tested in this research is capable of maneuver tracking for limited duration training events. The device should be tested with other battery types or another battery configuration to see if the device can be adjusted to record for a minimum of 7 days (long enough to track most battalion level training events). The device should also be accuracy tested with a higher order GPS device under heavy canopy cover to determine the validity of the device for multiple operating environments.

Recommendations for Maneuver Mapping

Mapping of maneuver training using the current methods based on doctrine and unit input data should be considered to have limited reliability at spatial scales below the installation level. Mapping of intensity using the techniques within chapter 6 would allow land managers to have a much better understanding of the spatial distribution of training at a usable level. While researchers should continue to further develop equations and techniques that better estimate training related disturbance levels, a simplified maneuver intensity mapping program could provide data that would benefit many other areas of research on military land sustainability.

Recommendations for Future Studies

Further studies that track training using the same or similar GPS devices on other installations could be conducted then compared to the results of this study. This could help confirm the results of chapter 5 of this research. Confirmation of the existence of a wide variation in maneuver training disturbance by similar unit types and training types would help steer future intensity mapping.

Many different types of training are conducted by military units at different levels of hierarchy. GPS tracking of off road drivers training, vehicles used within dismount training operations, land use near bivouac sites in addition to more maneuver tracking is needed to better understand how training impacts training lands. GPS tracking of units as they undergo transformations may help better understand how future units will impact the landscape. As Army brigades add an extra CAB to the formation over the next few years will the level of training disturbance of the brigade increase by a proportional amount, or will the training disturbance change non-proportionally due to some other factors?

Intensity mapping using GPS would also allow for many future studies. After mapping all maneuver training for an area for a period of time, comparisons could be made to remotely sensed data to determine what levels of disturbance remote sensing platforms are capable of detecting. Also plot level studies on different grids described as high, medium and low levels of disturbance by a continuous monitoring program could be field verified for compaction, plant species composition, and recovery rates.

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Appendix A - GPS Point Maps for Each Event

Figure A-1 All Points 2-34 Armor Battalion

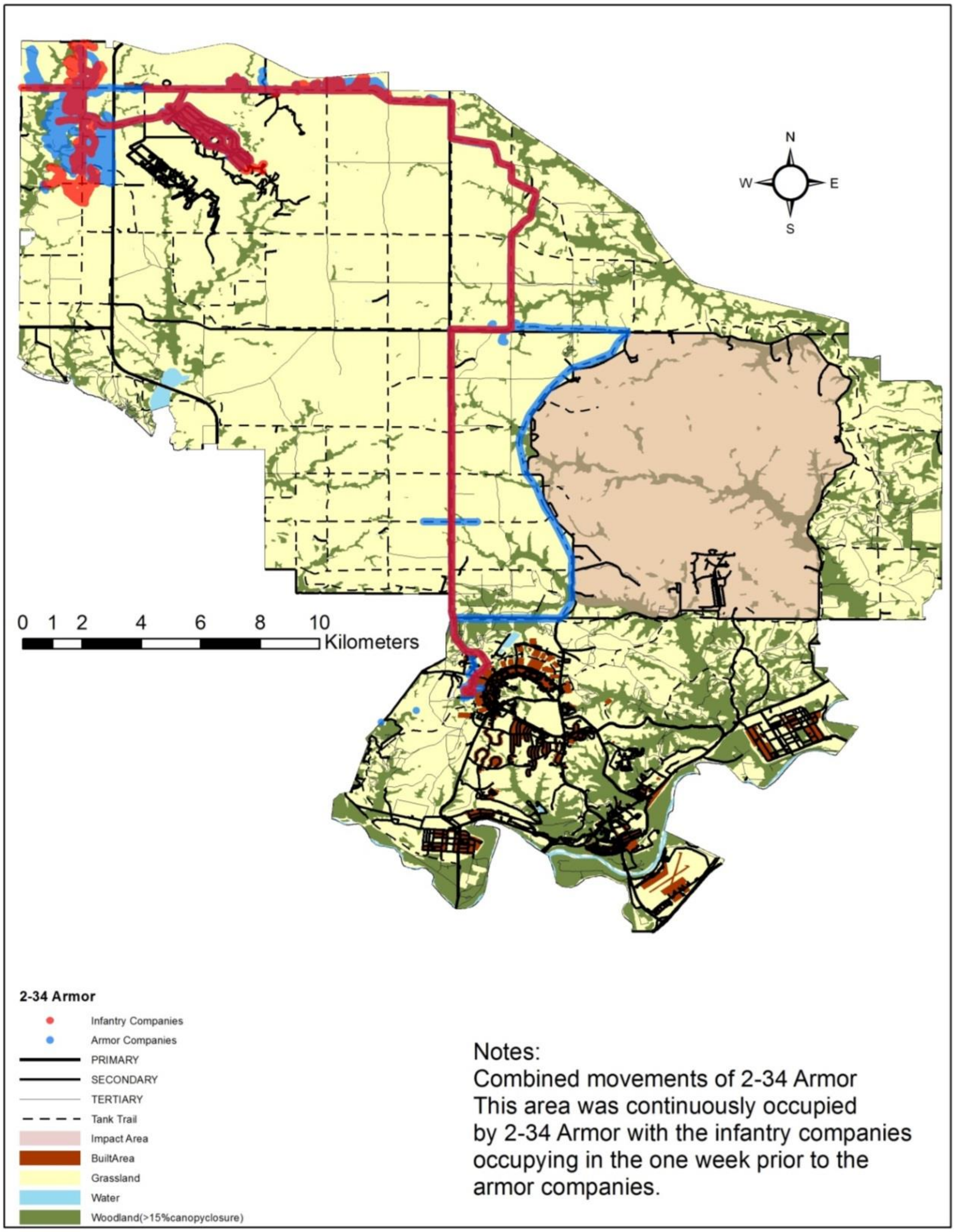


Figure A-2 All Points 4-4 Cavalry Squadron

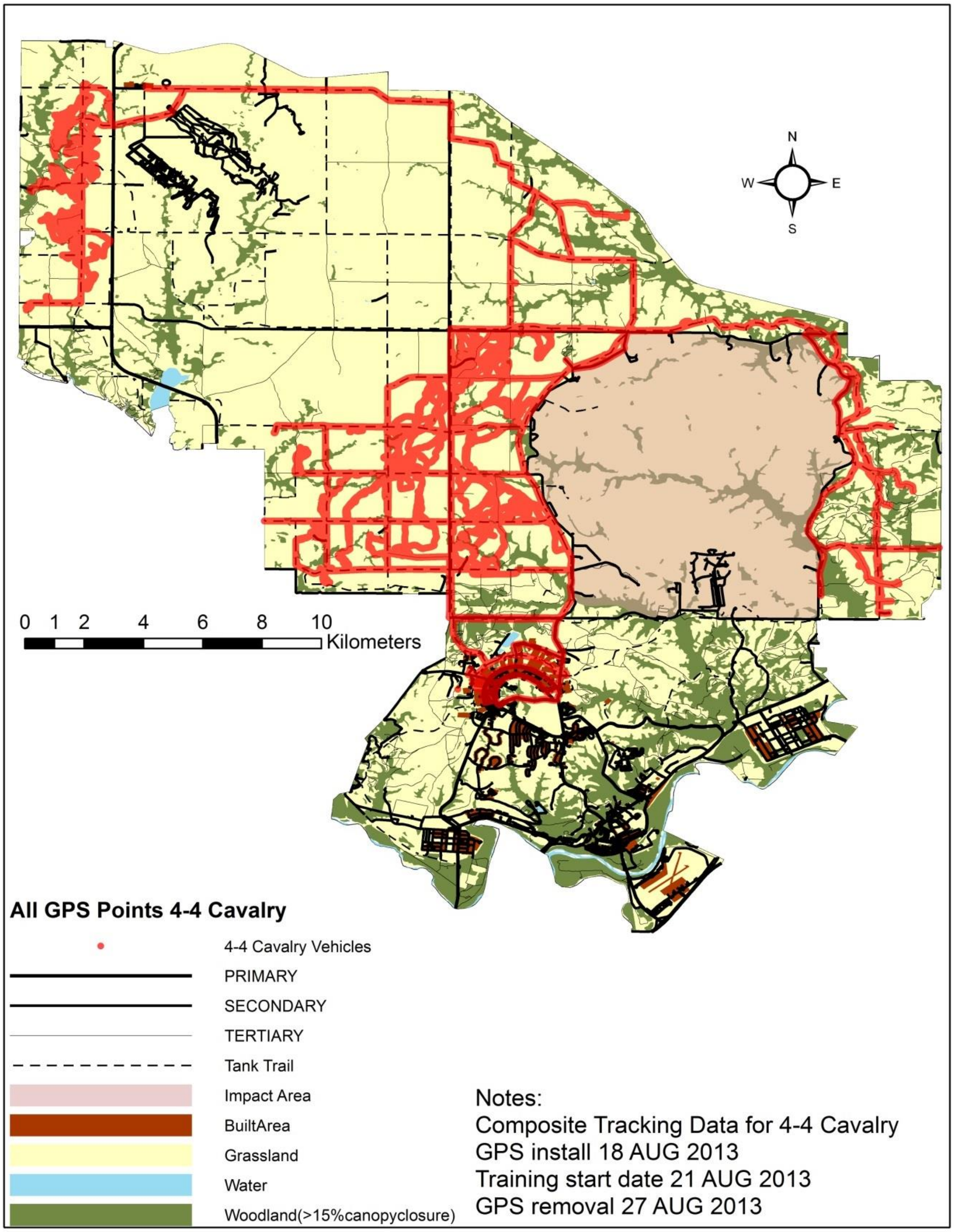
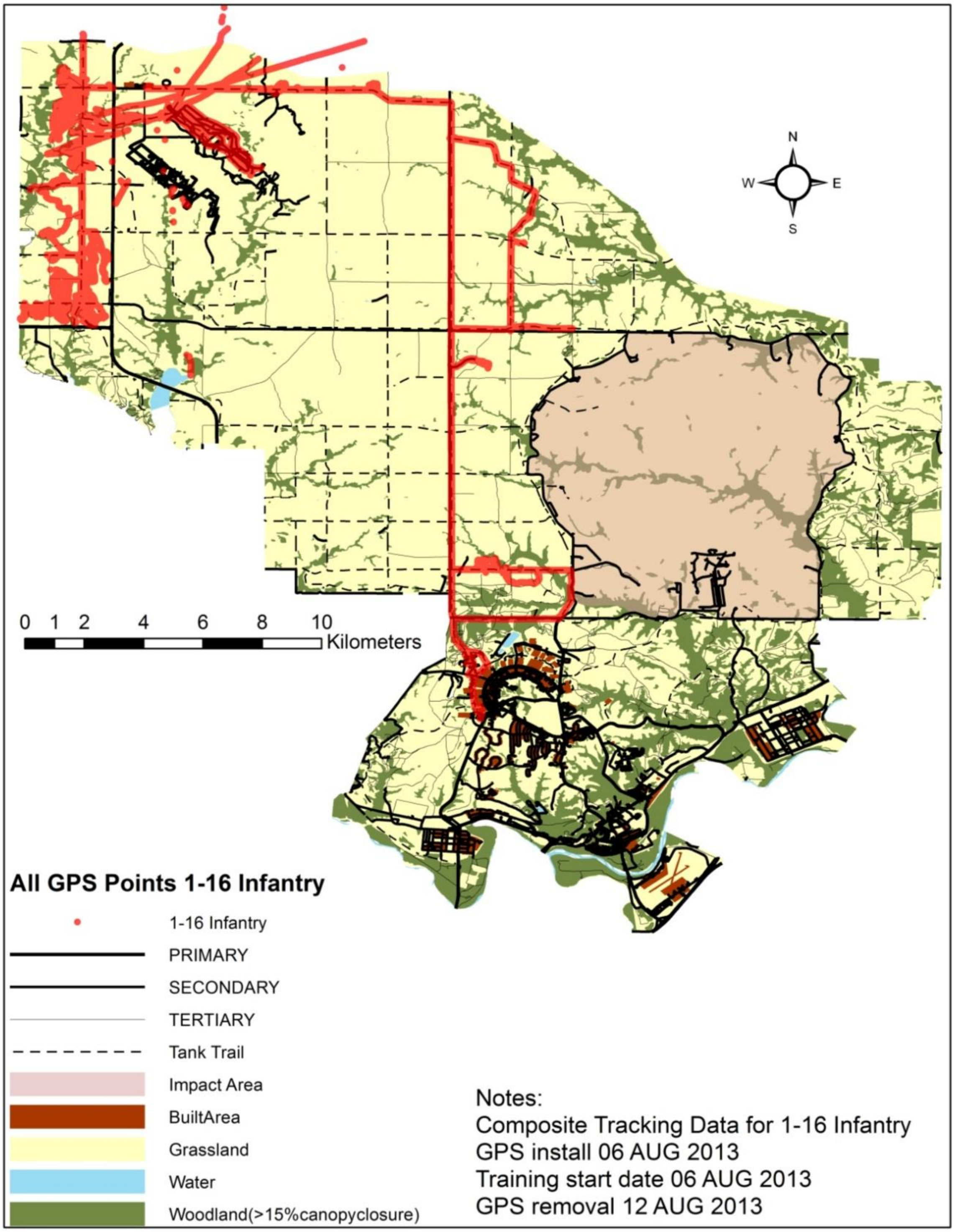


Figure A-3 All Points 1-16 Infantry Battalion



Appendix B - GPS Point Maps for Each Vehicle

Figure B-1 GPS Points A11 1-16 Infantry Battalion

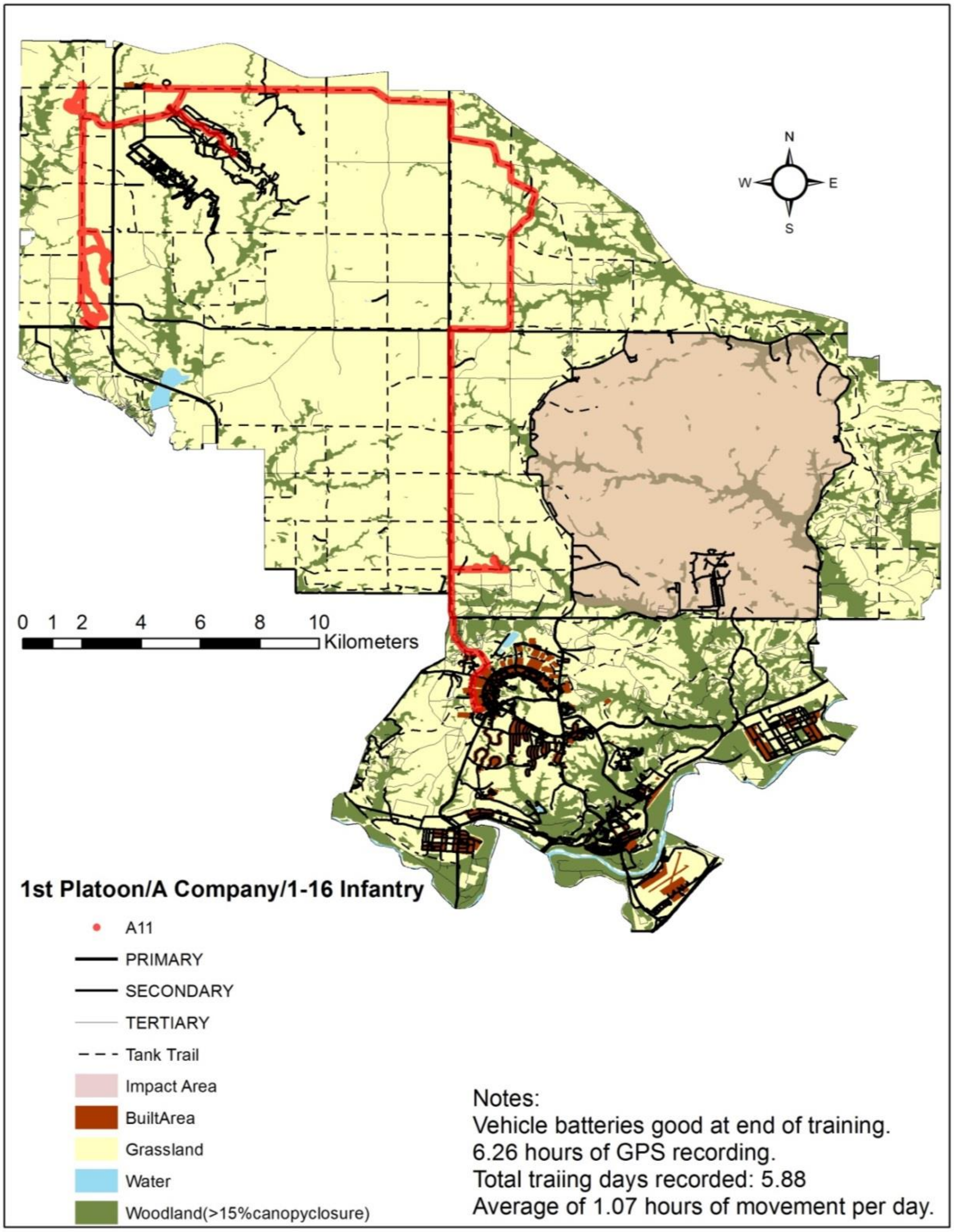


Figure B-2 GPS Points A13 1-16 Infantry Battalion

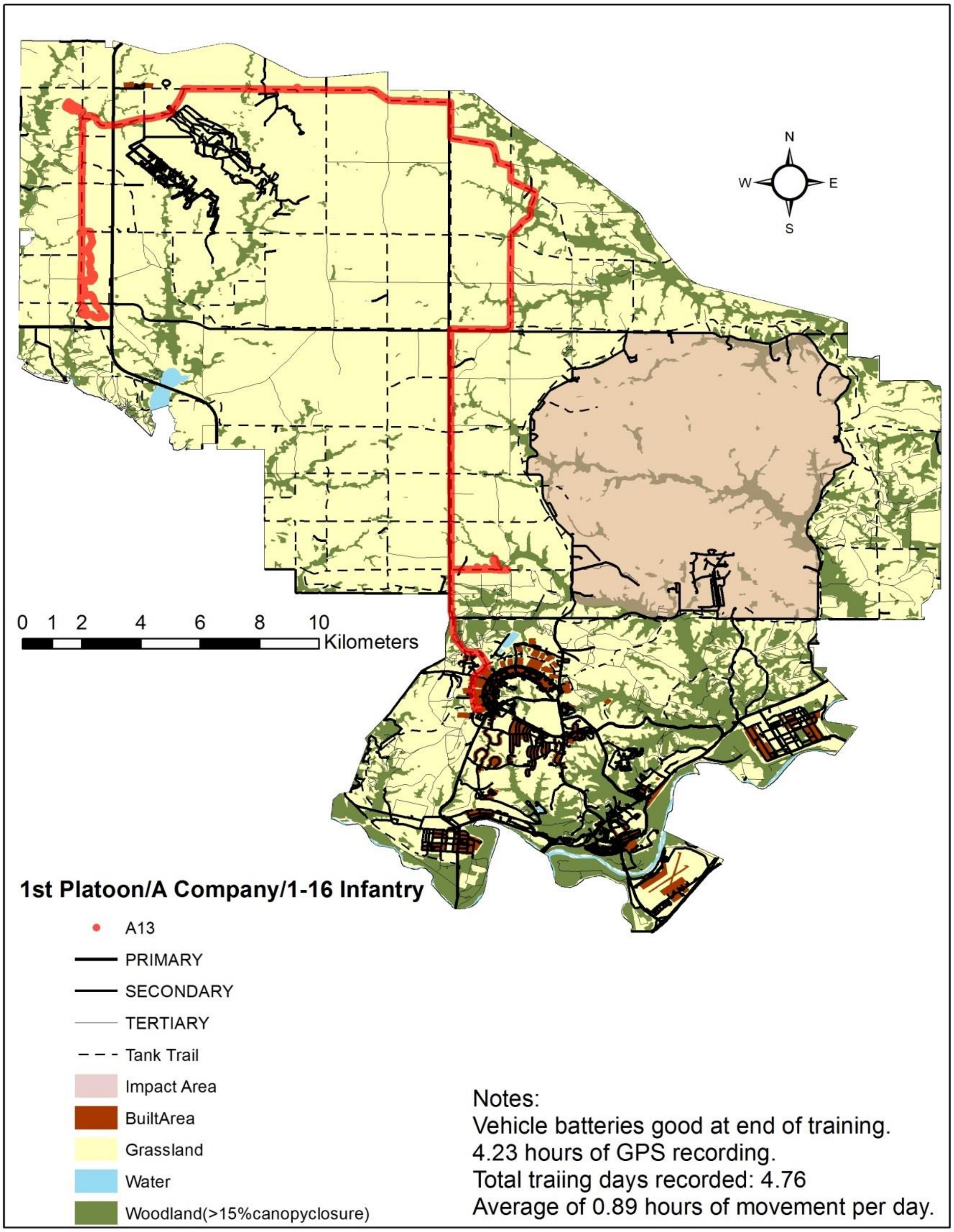


Figure B-3 GPS Points A14 1-16 Infantry Battalion

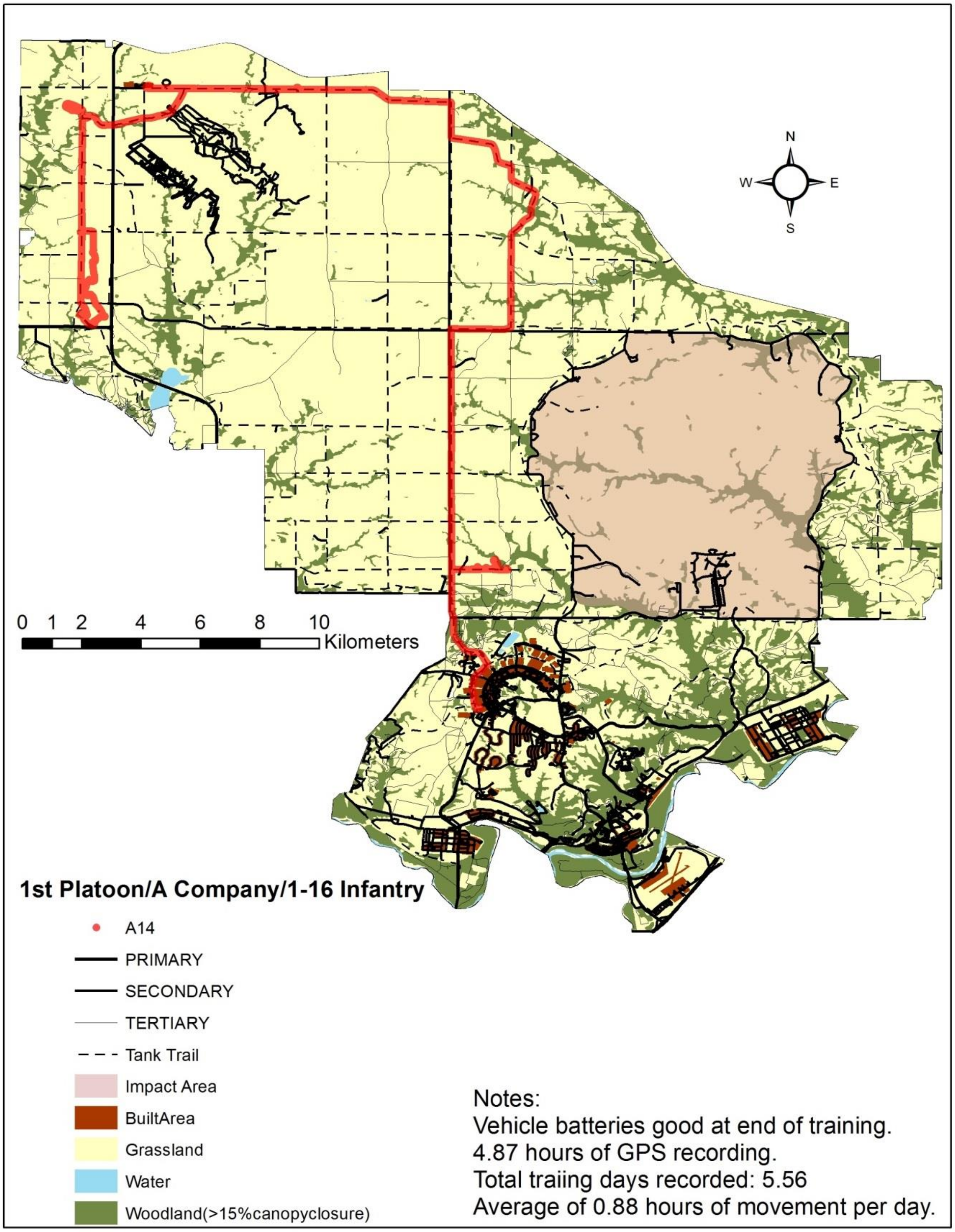
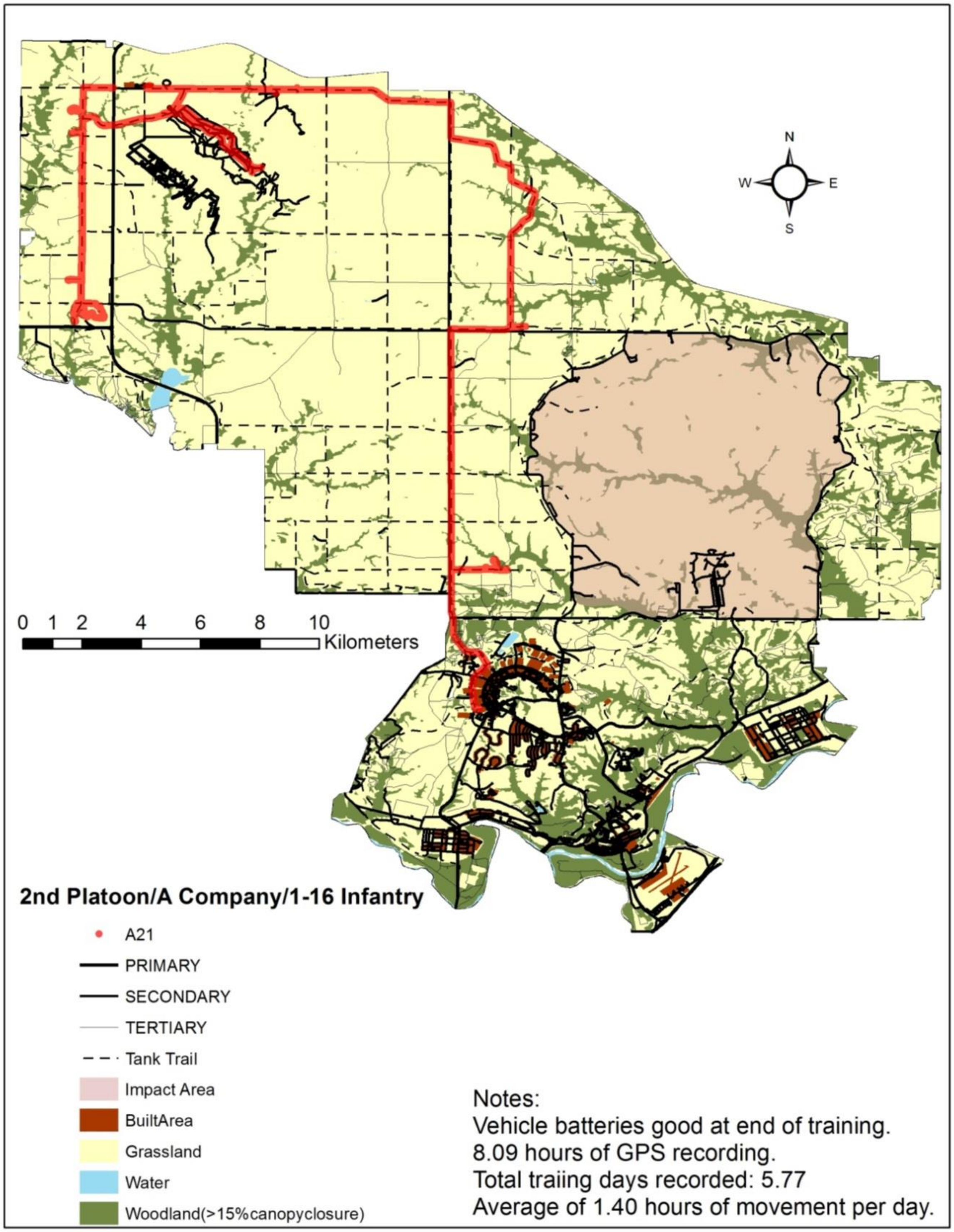


Figure B-4 GPS Points A21 1-16 Infantry Battalion



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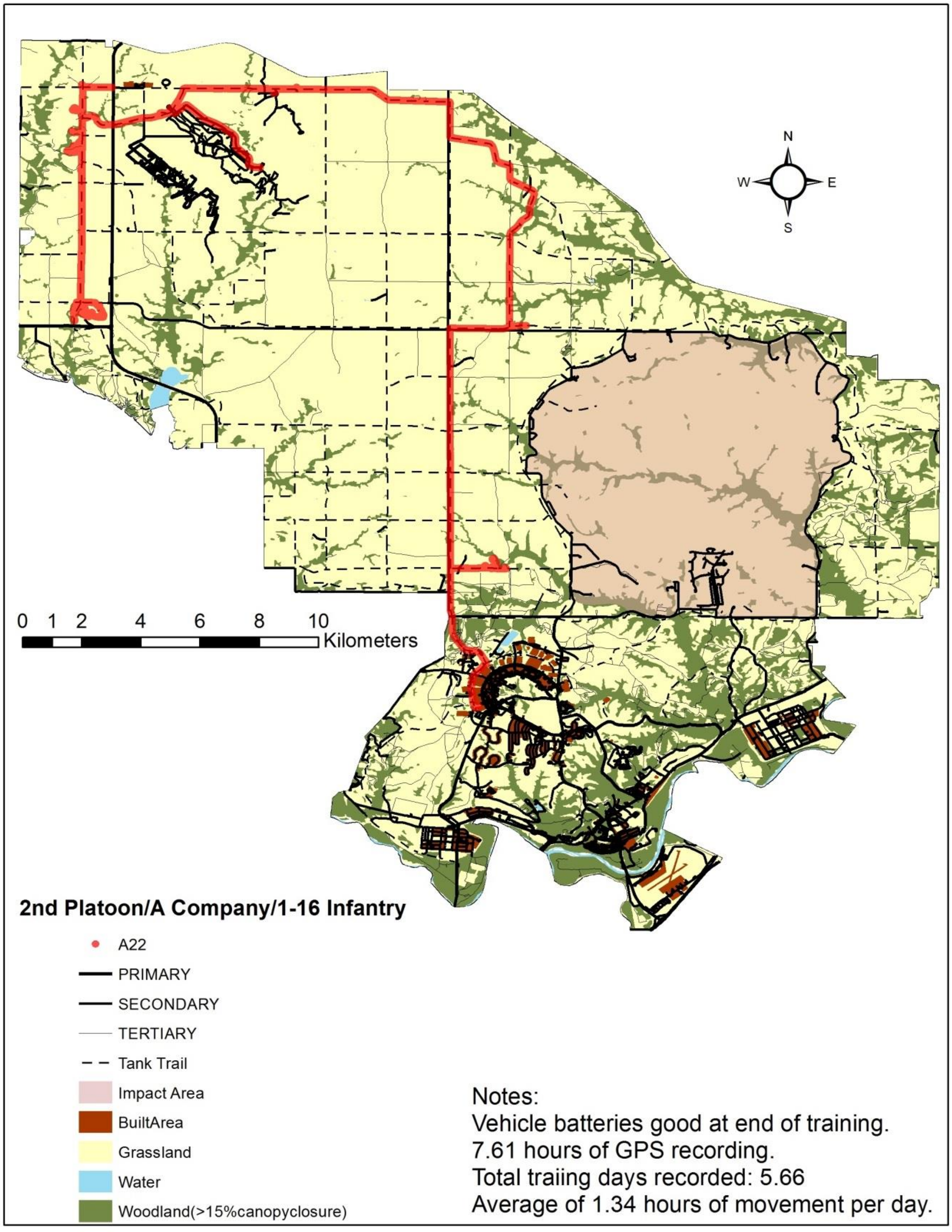


Figure B-6 GPS Points A23 1-16 Infantry Battalion

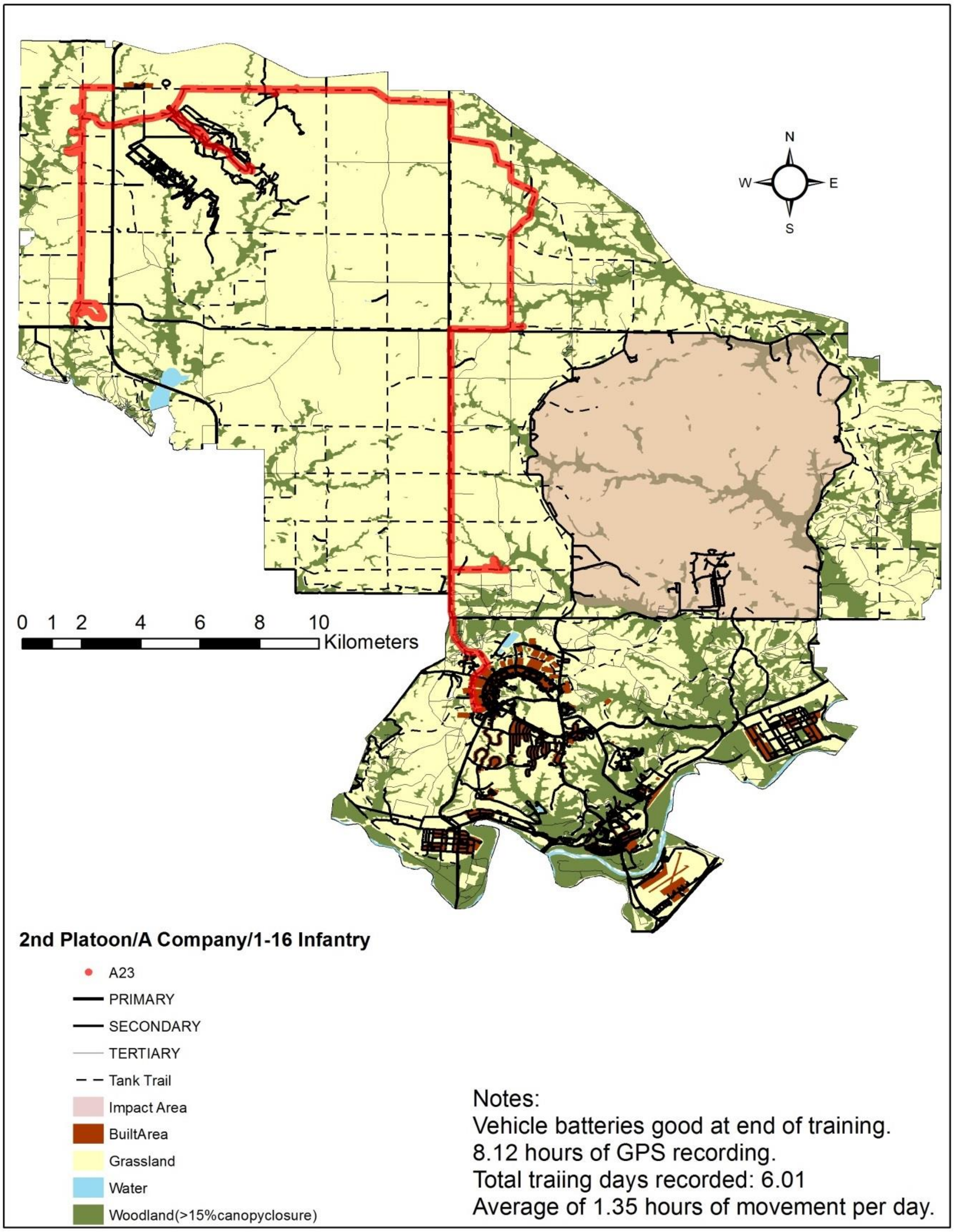


Figure B-7 GPS Points A24 1-16 Infantry Battalion

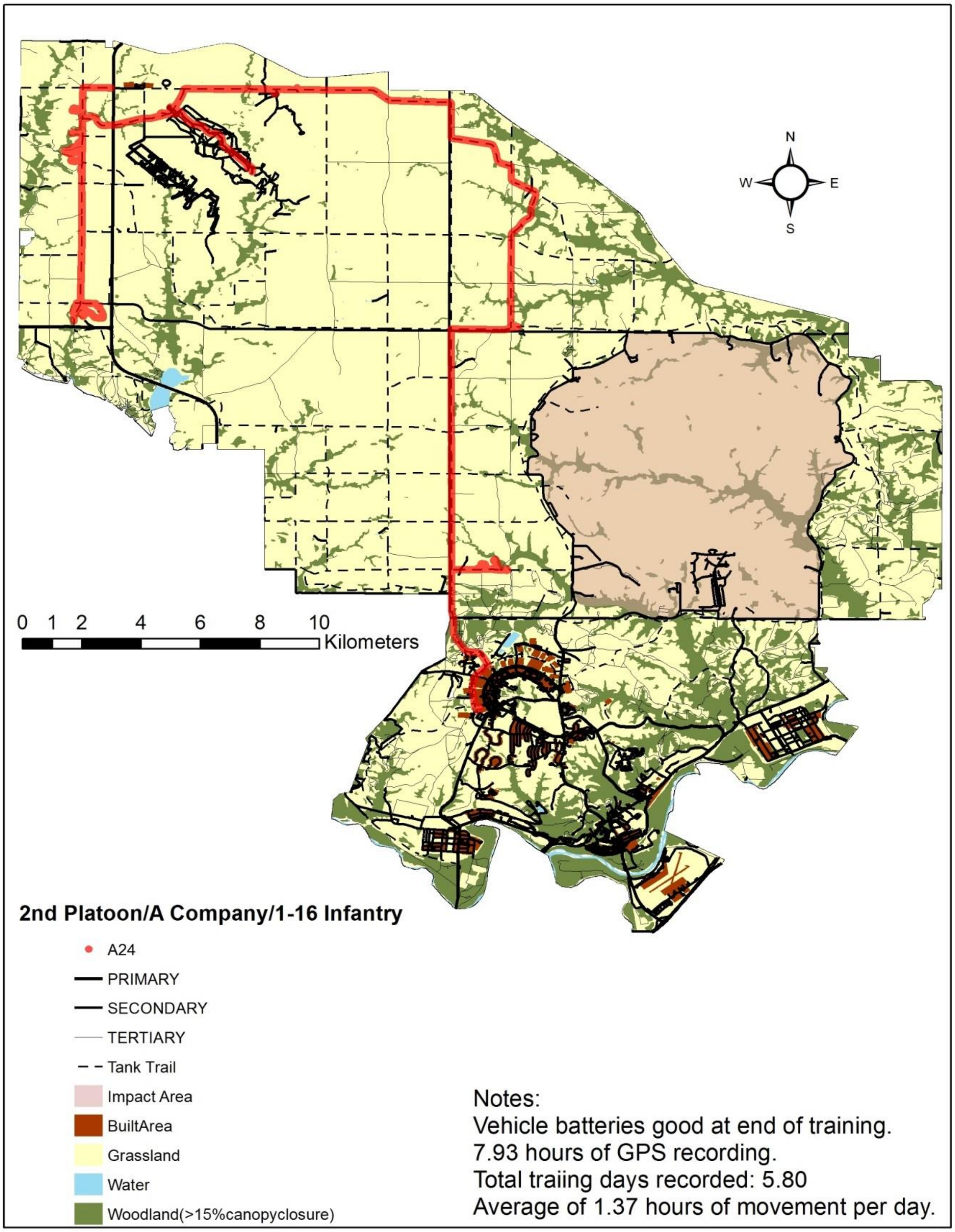


Figure B-8 GPS Points A31 1-16 Infantry Battalion

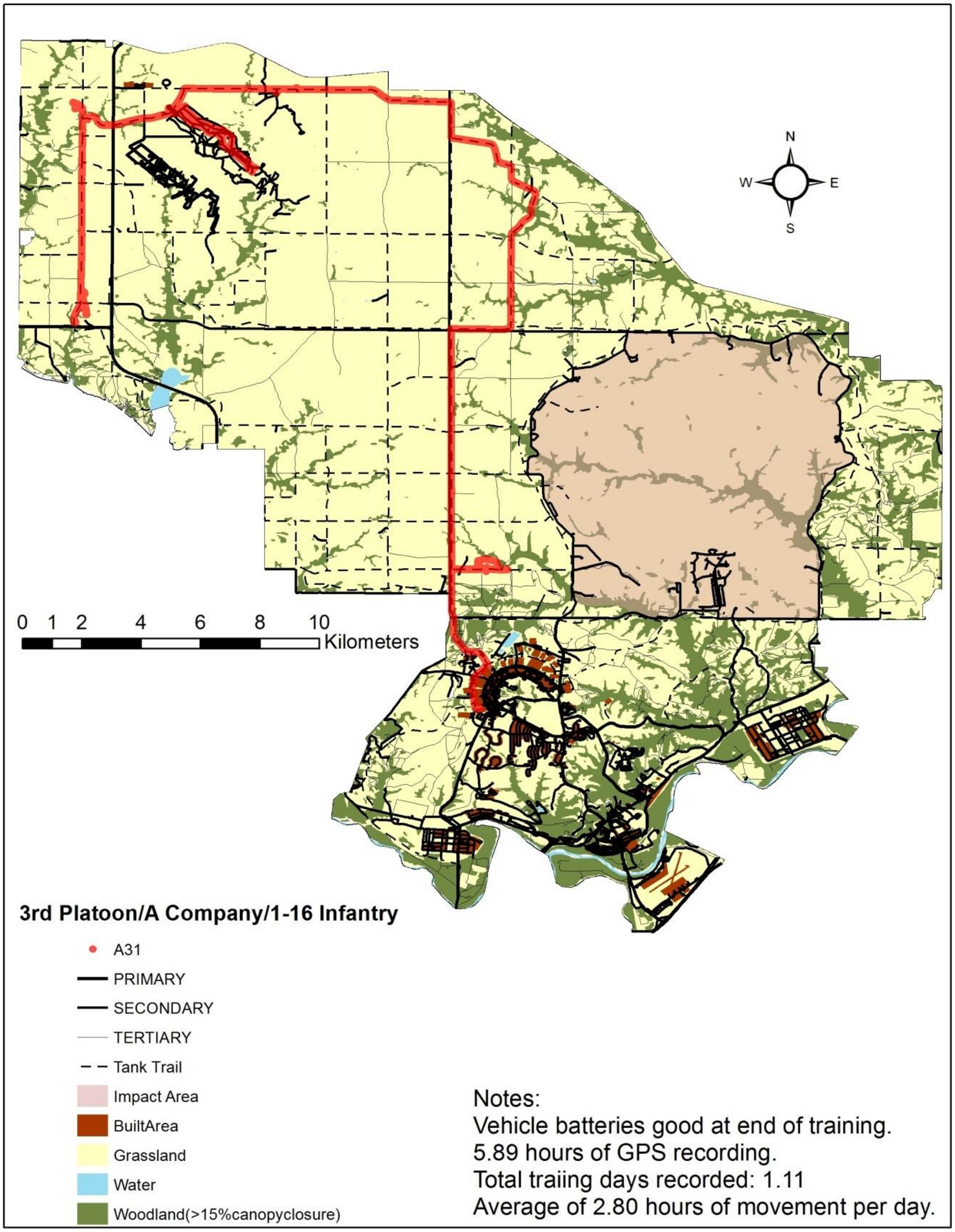


Figure B-9 GPS Points A34 1-16 Infantry Battalion

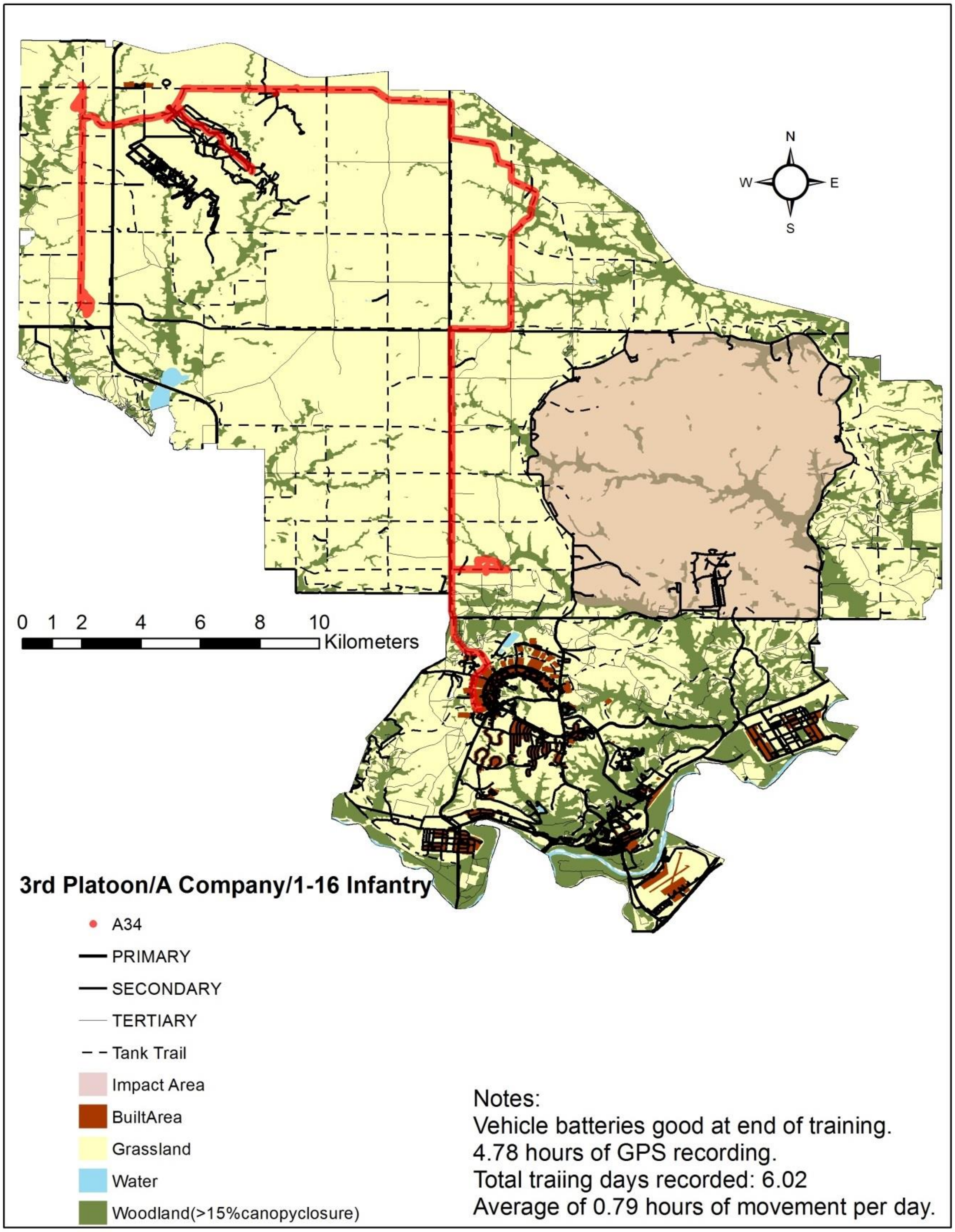


Figure B-10 GPS Points B11 1-16 Infantry Battalion

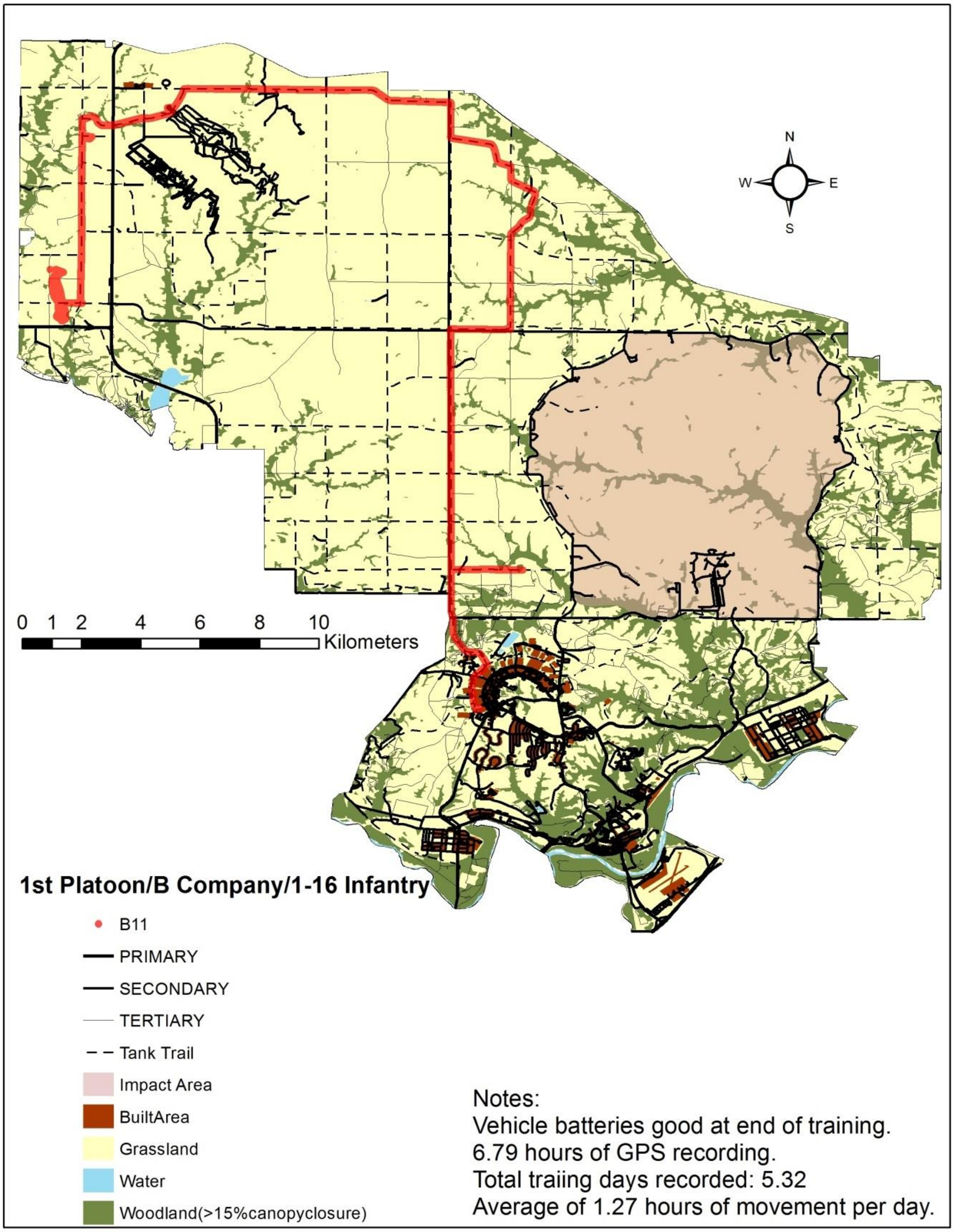


Figure B-11 GPS Points B12 1-16 Infantry Battalion

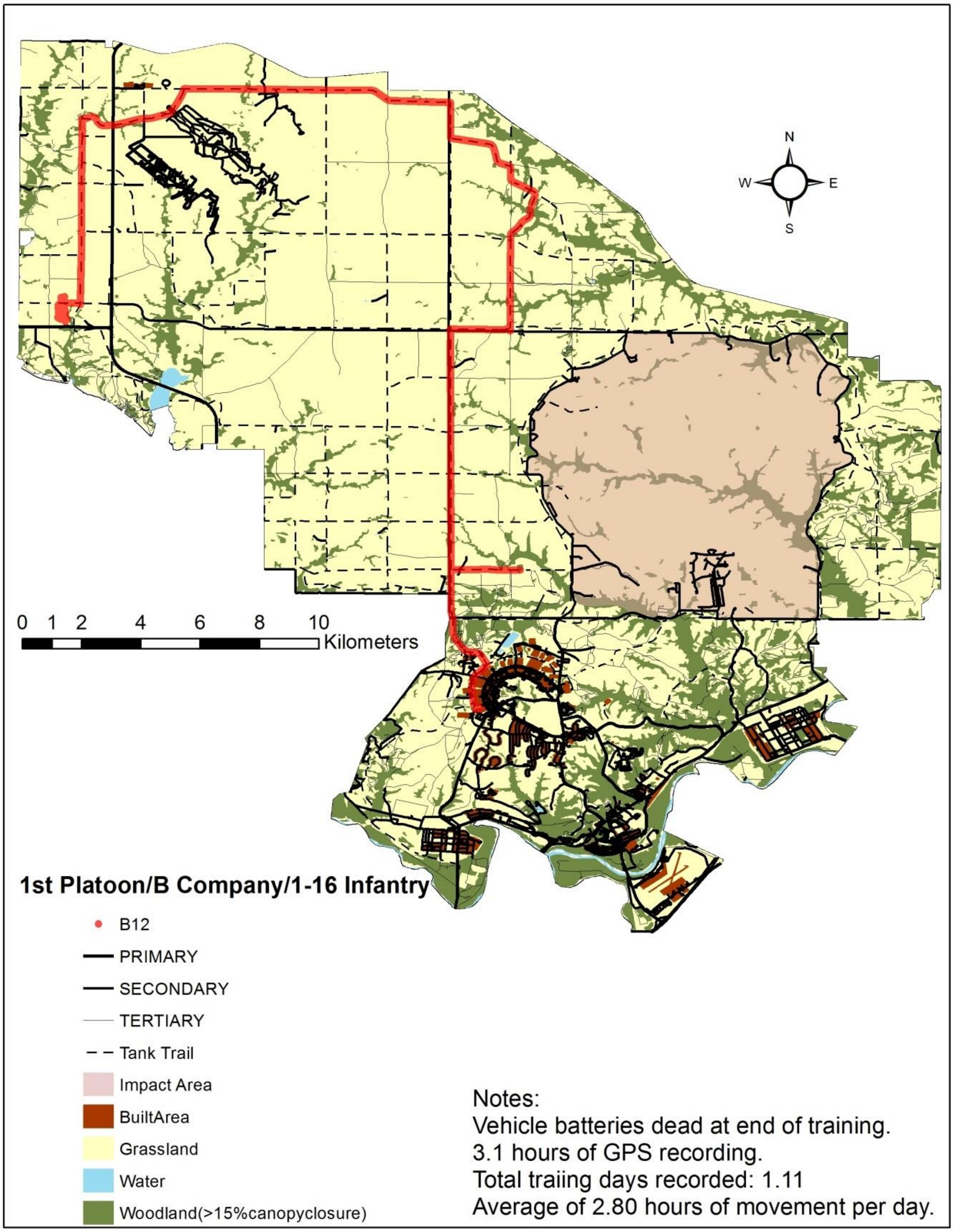


Figure B-12 GPS Points B13 1-16 Infantry Battalion

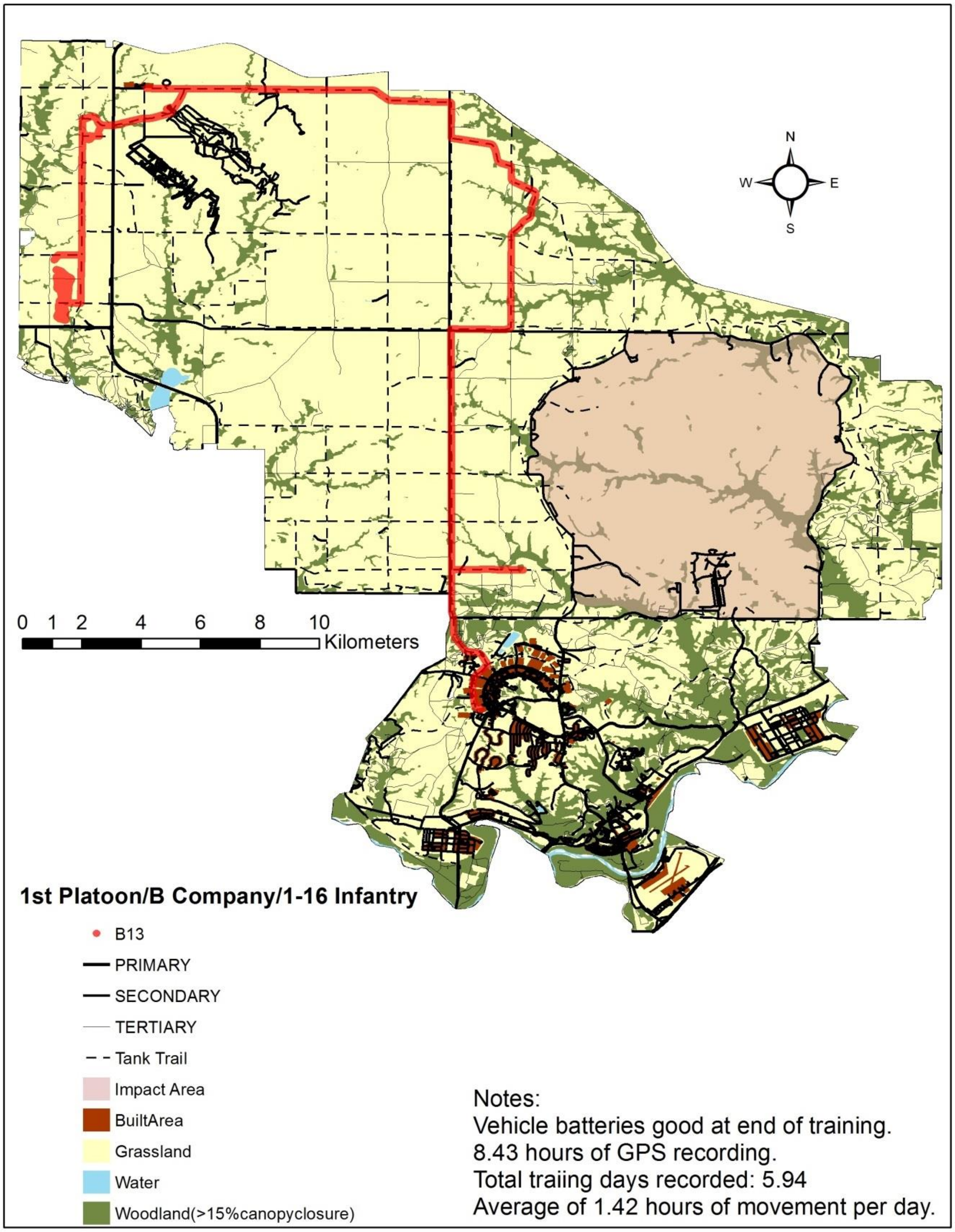


Figure B-13 GPS Points B14 1-16 Infantry Battalion

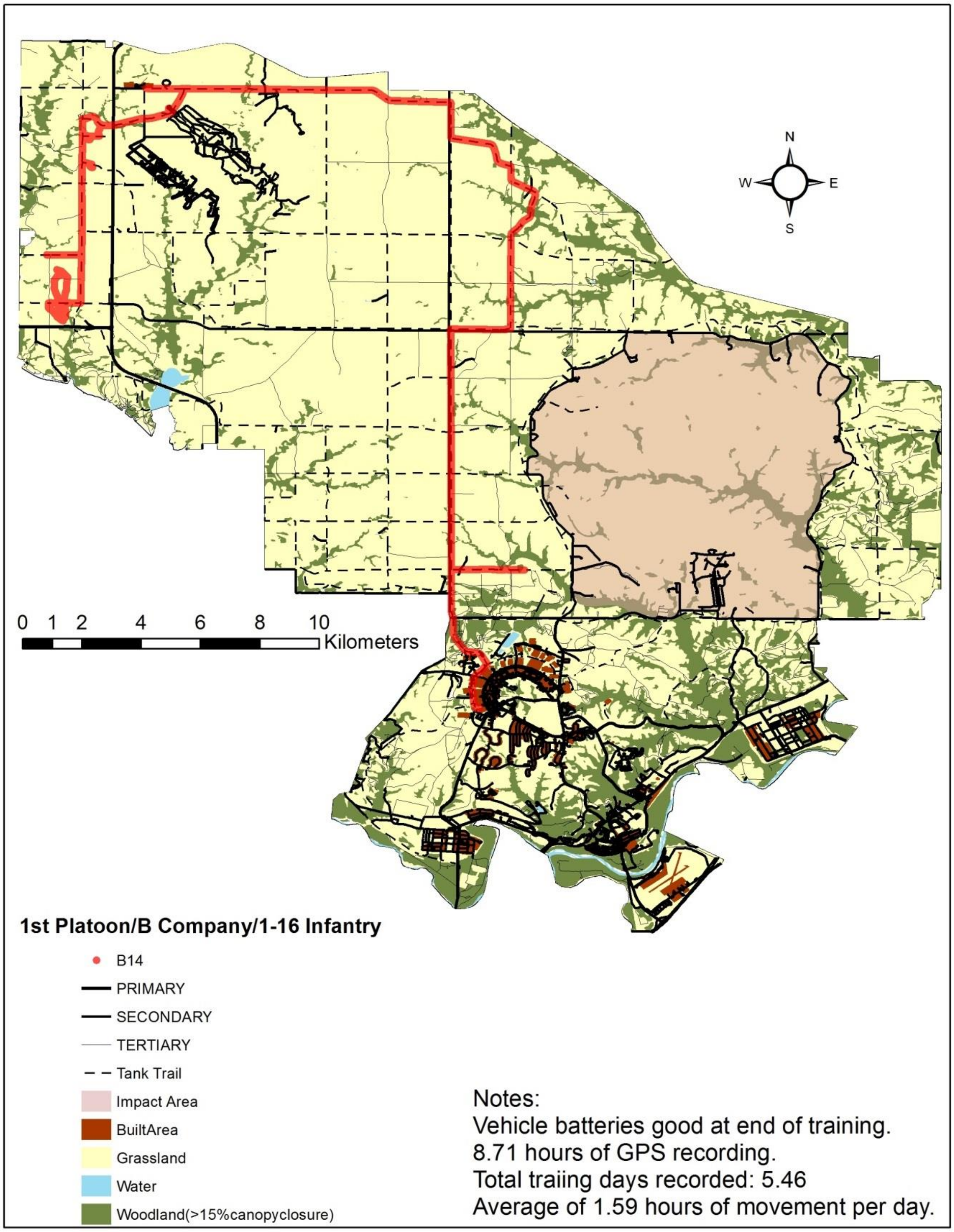


Figure B-14 GPS Points B21 1-16 Infantry Battalion

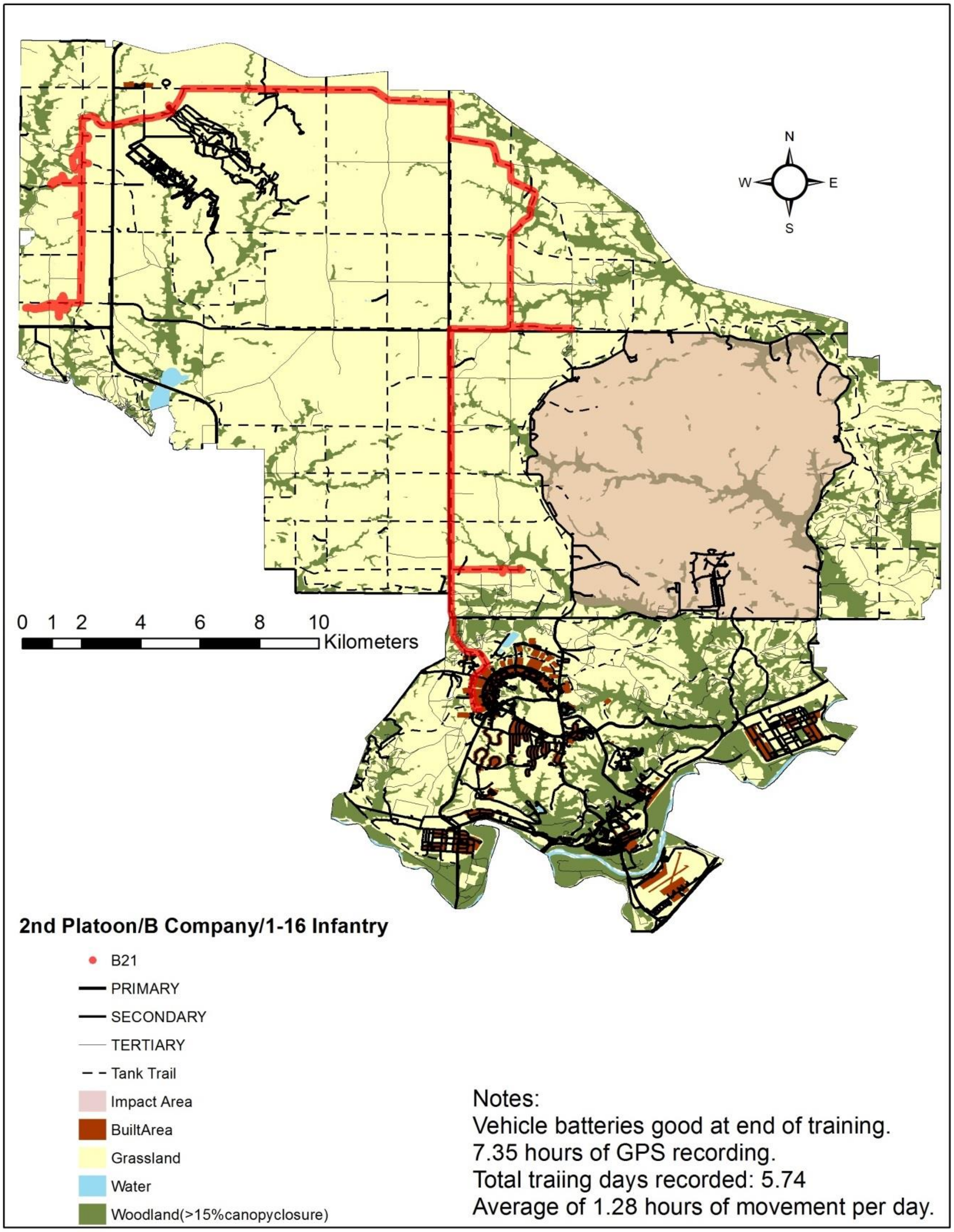


Figure B-15 GPS Points B22 1-16 Infantry Battalion

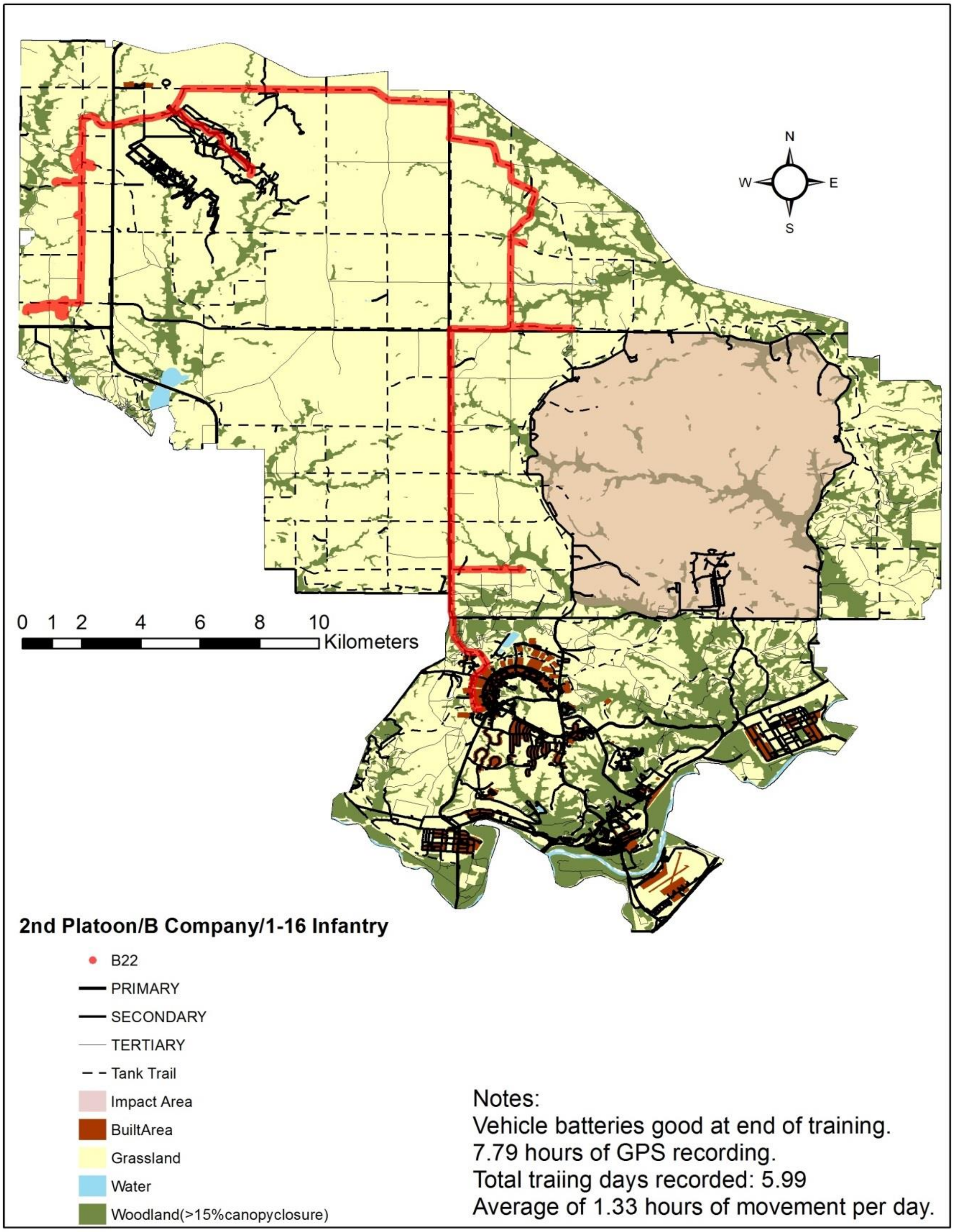


Figure B-16 GPS Points B23 1-16 Infantry Battalion

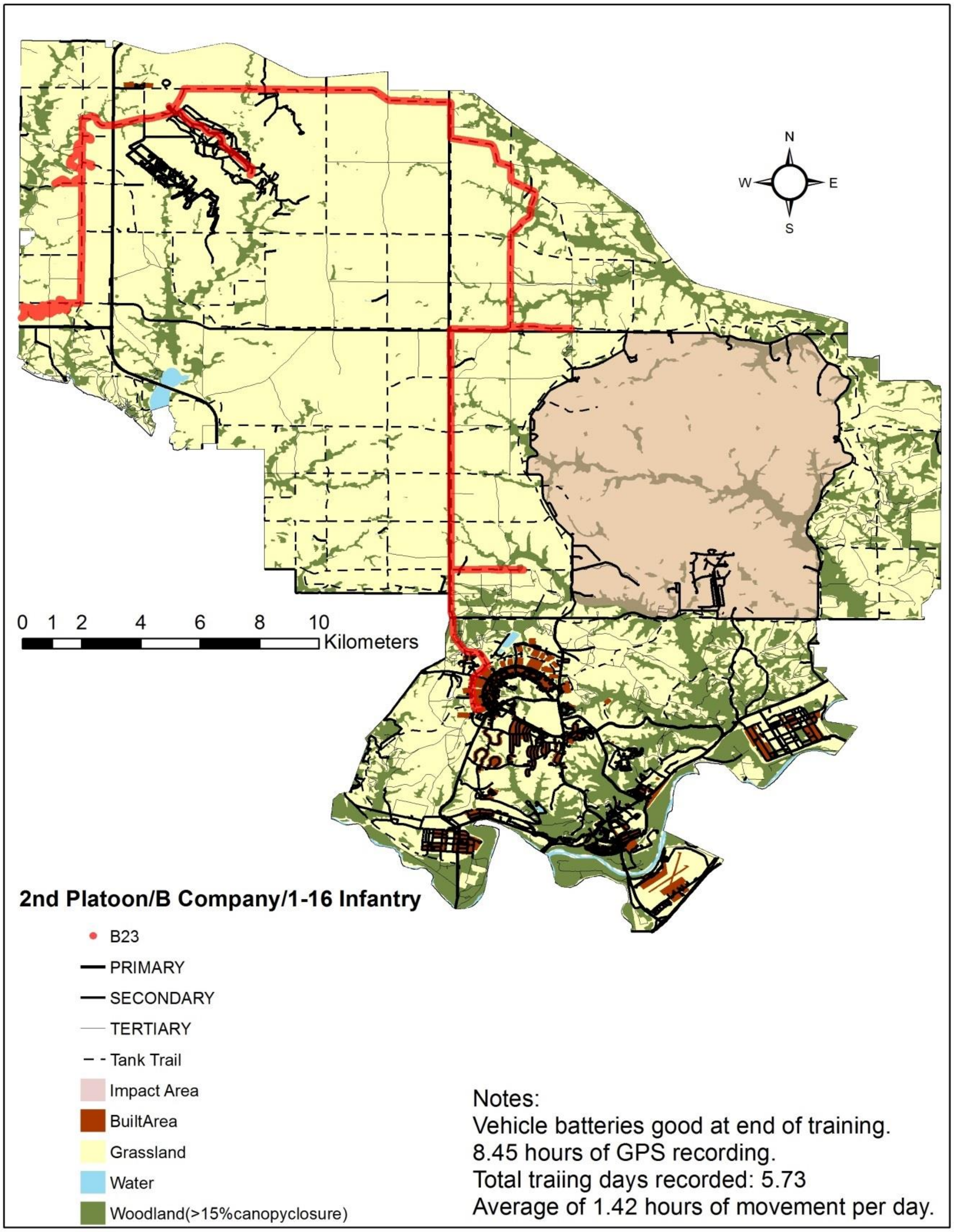


Figure B-17 GPS Points B24 1-16 Infantry Battalion

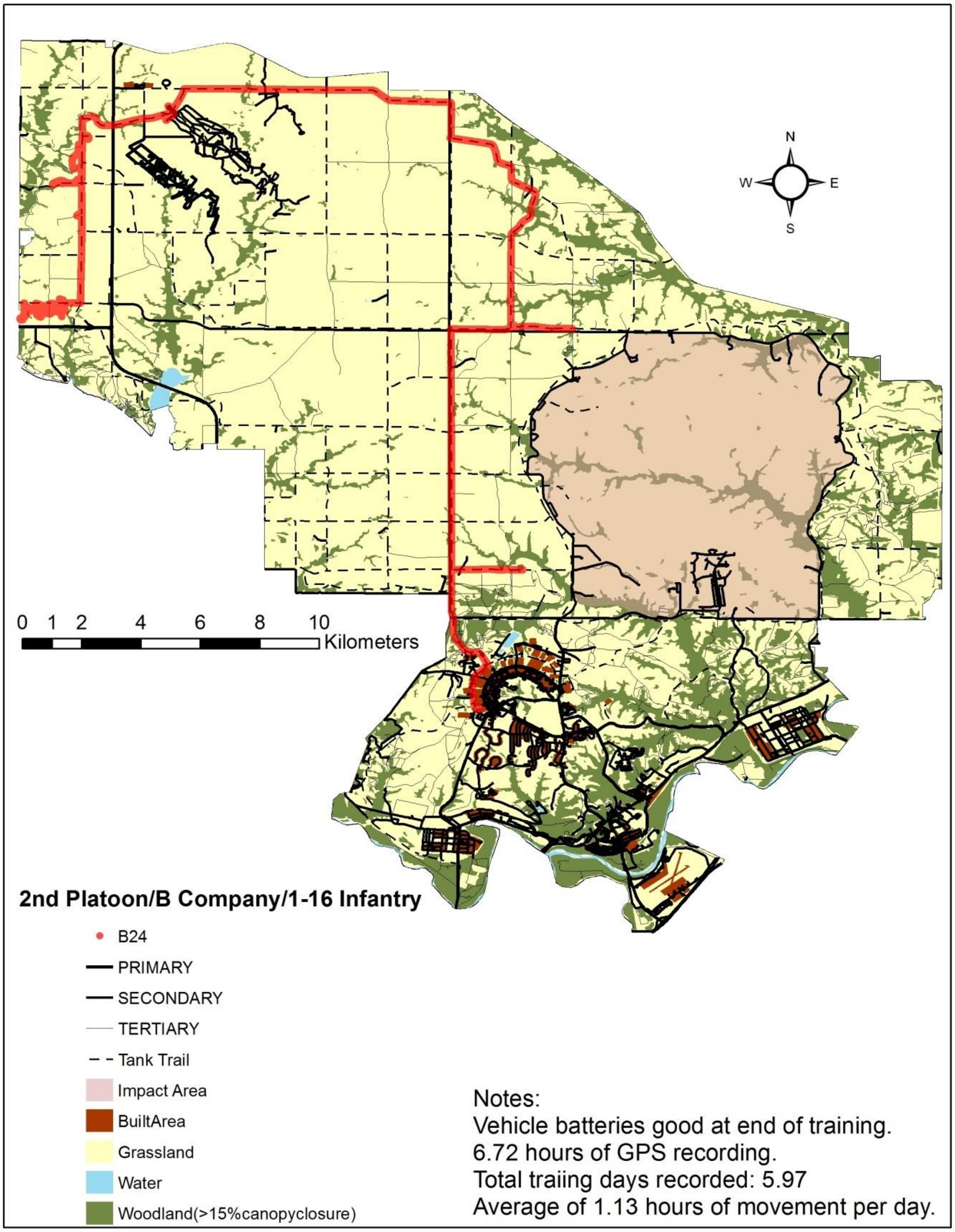


Figure B-18 GPS Points B31 1-16 Infantry Battalion

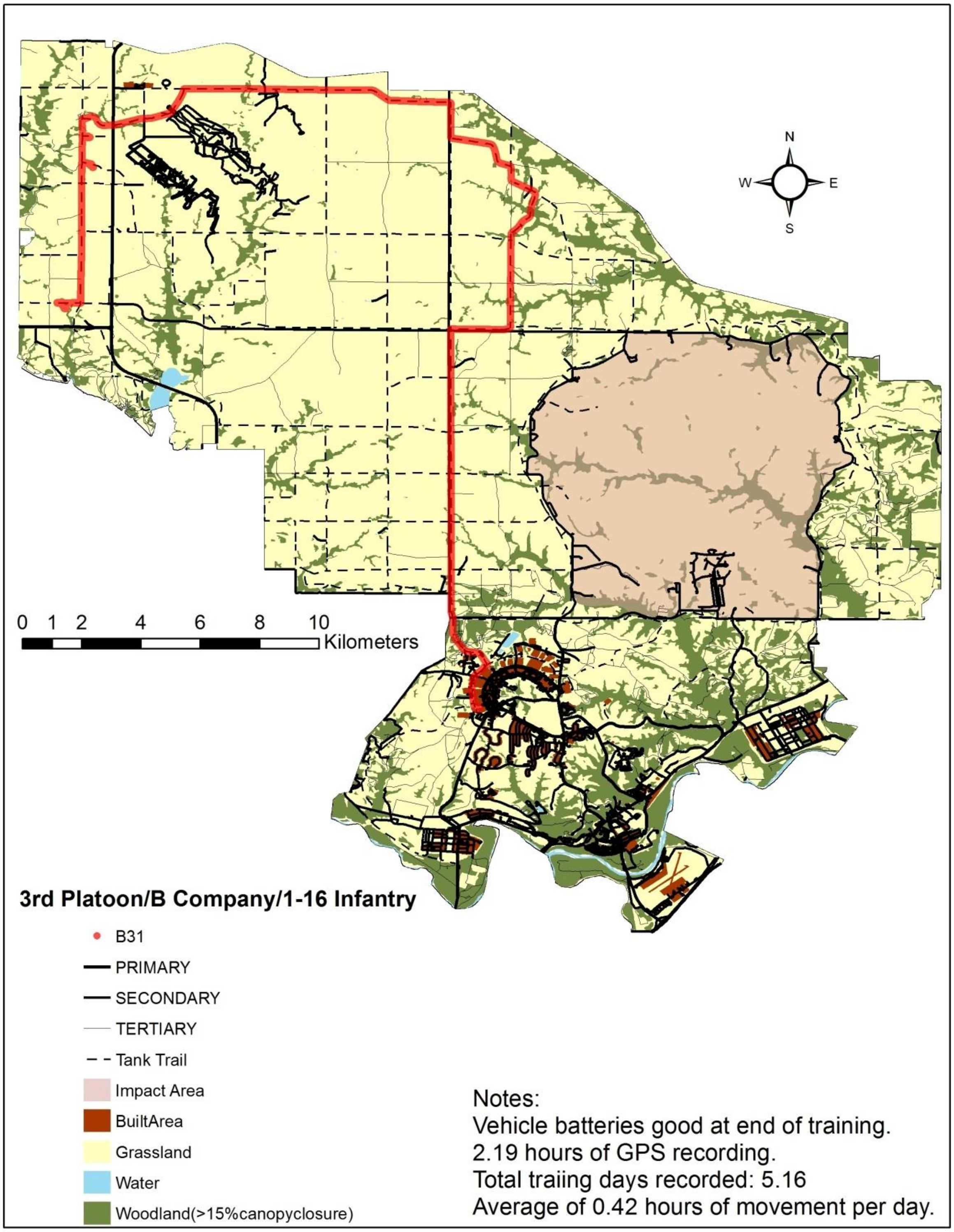


Figure B-19 GPS Points B34 1-16 Infantry Battalion

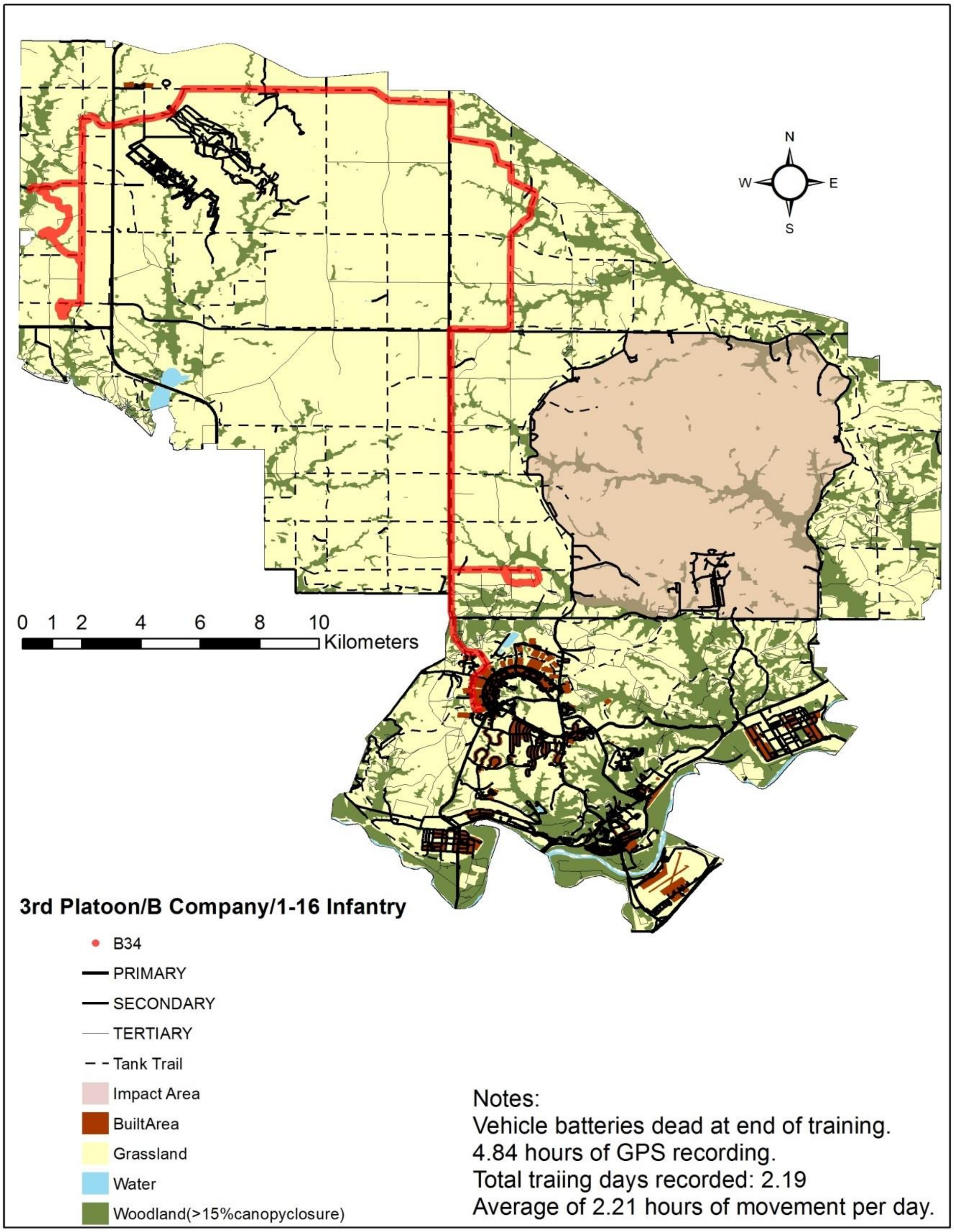


Figure B-20 GPS Points D11 1-16 Infantry Battalion

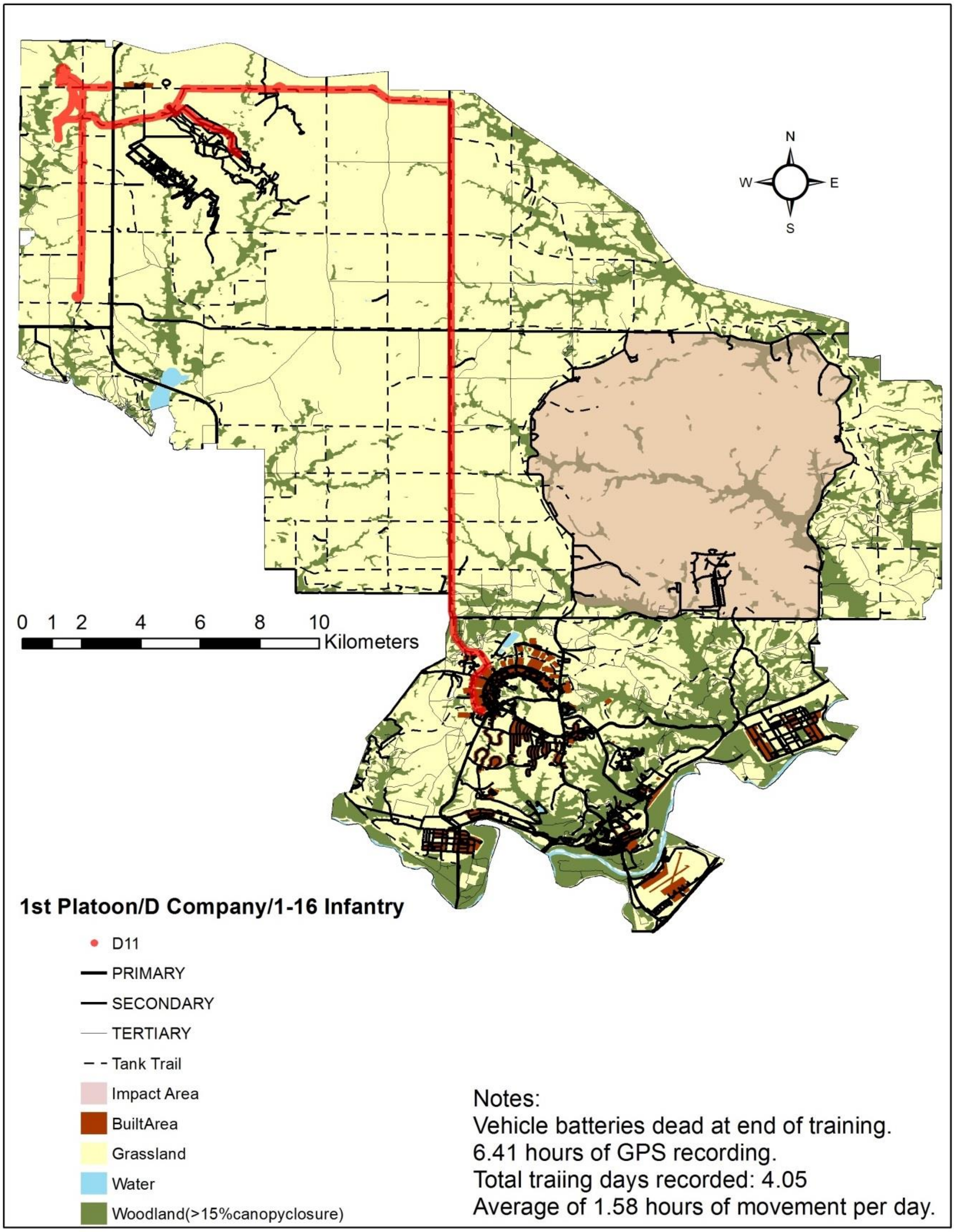


Figure B-21 GPS Points D12 1-16 Infantry Battalion

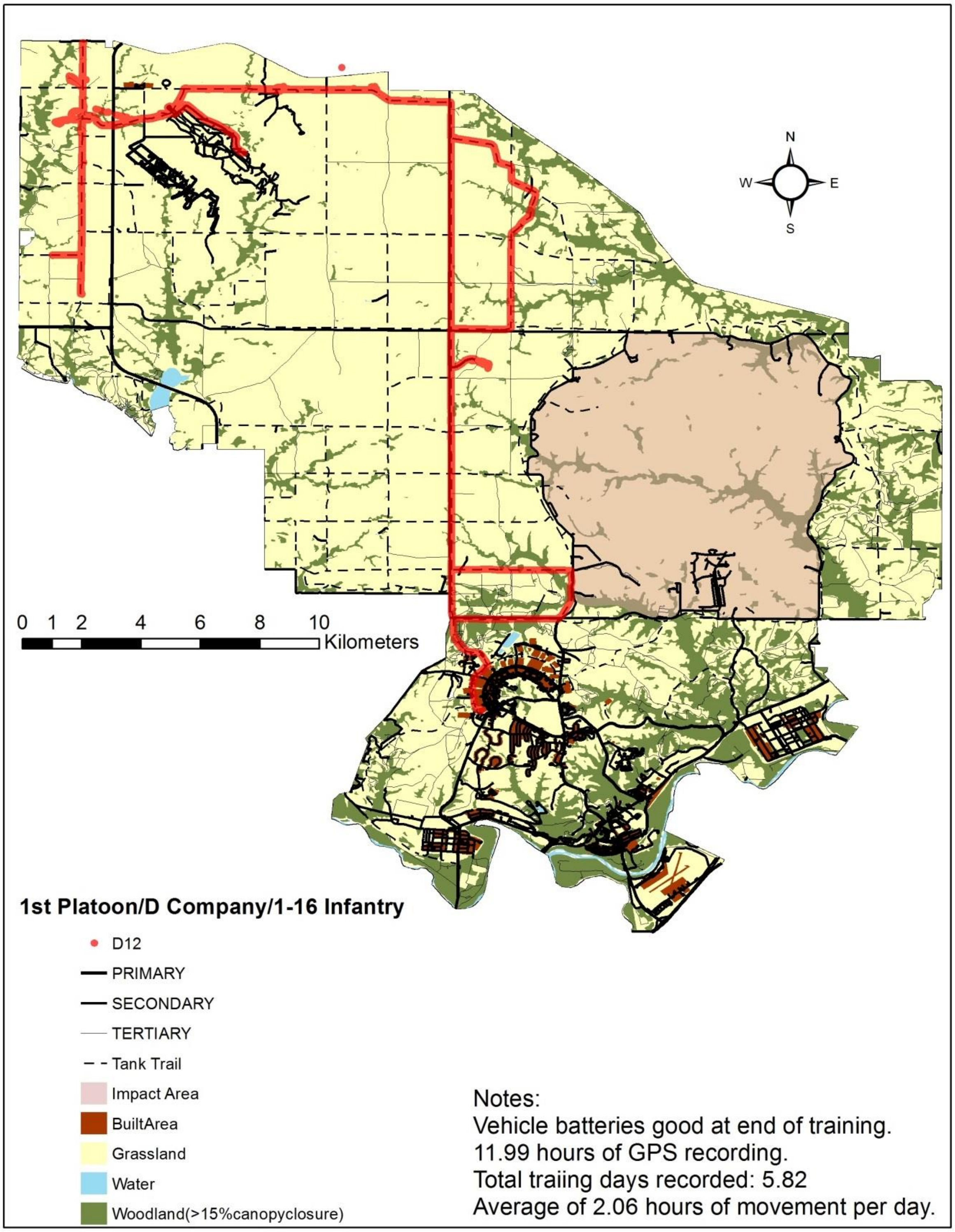


Figure B-22 GPS Points D13 1-16 Infantry Battalion

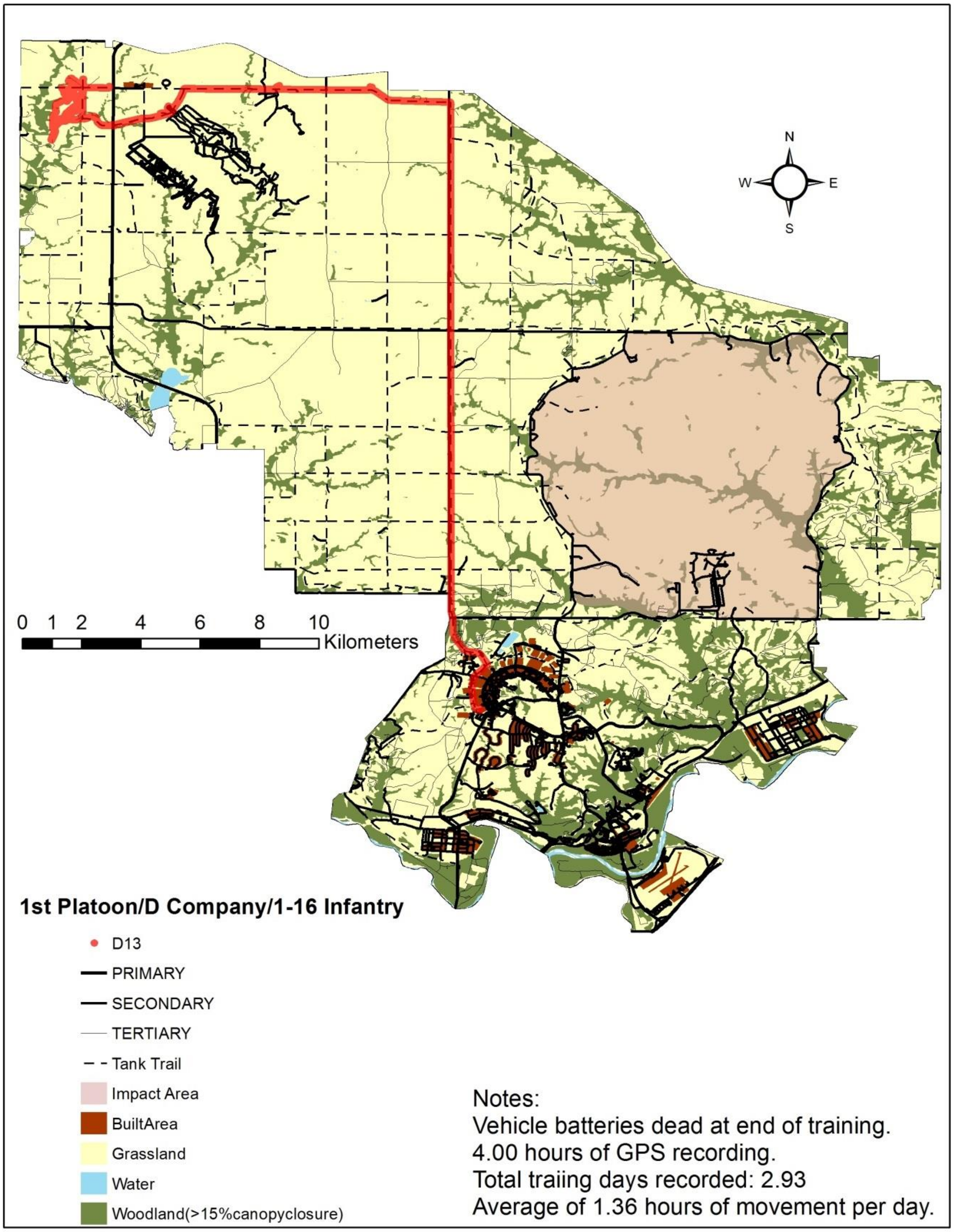


Figure B-23 GPS Points D14 1-16 Infantry Battalion

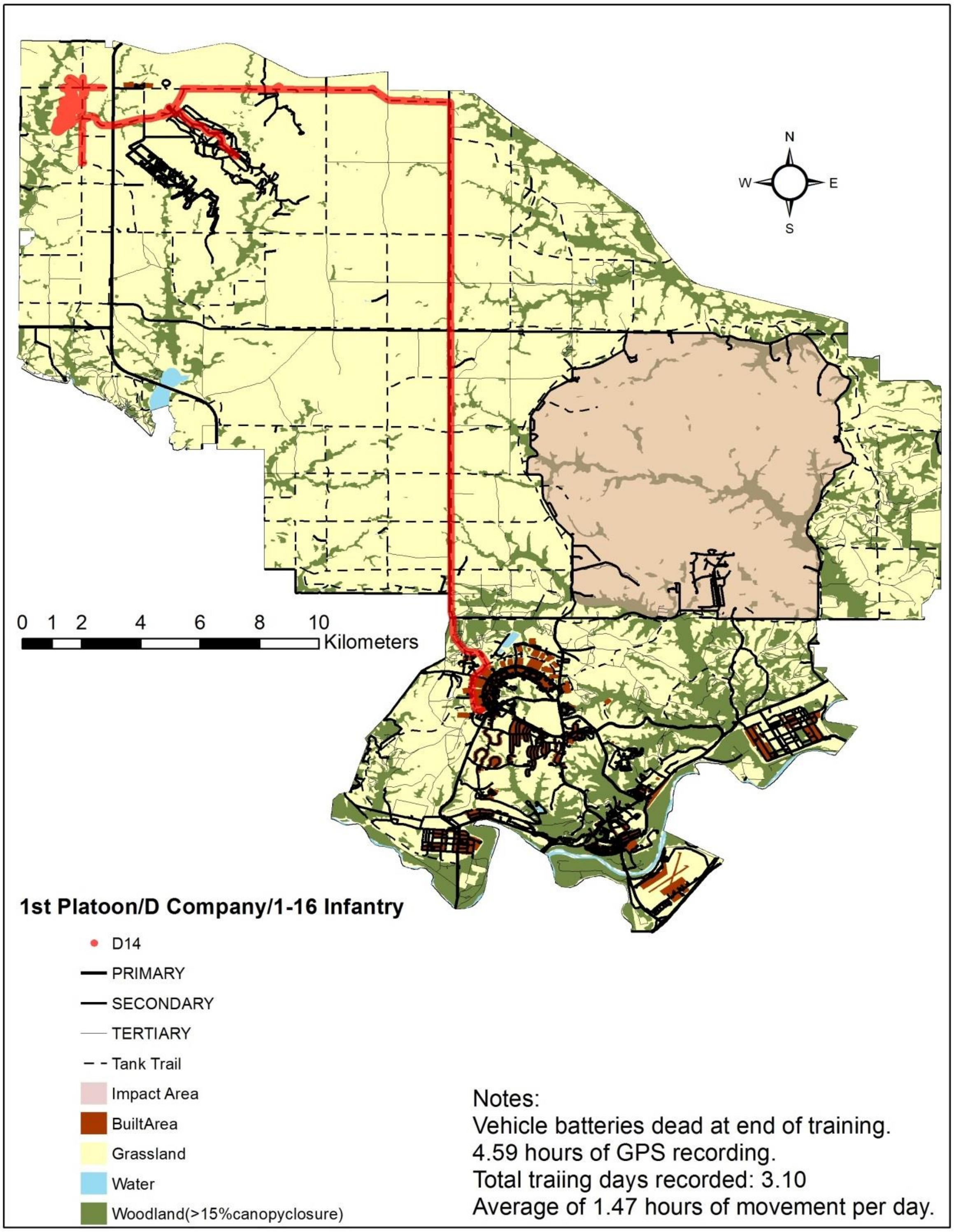
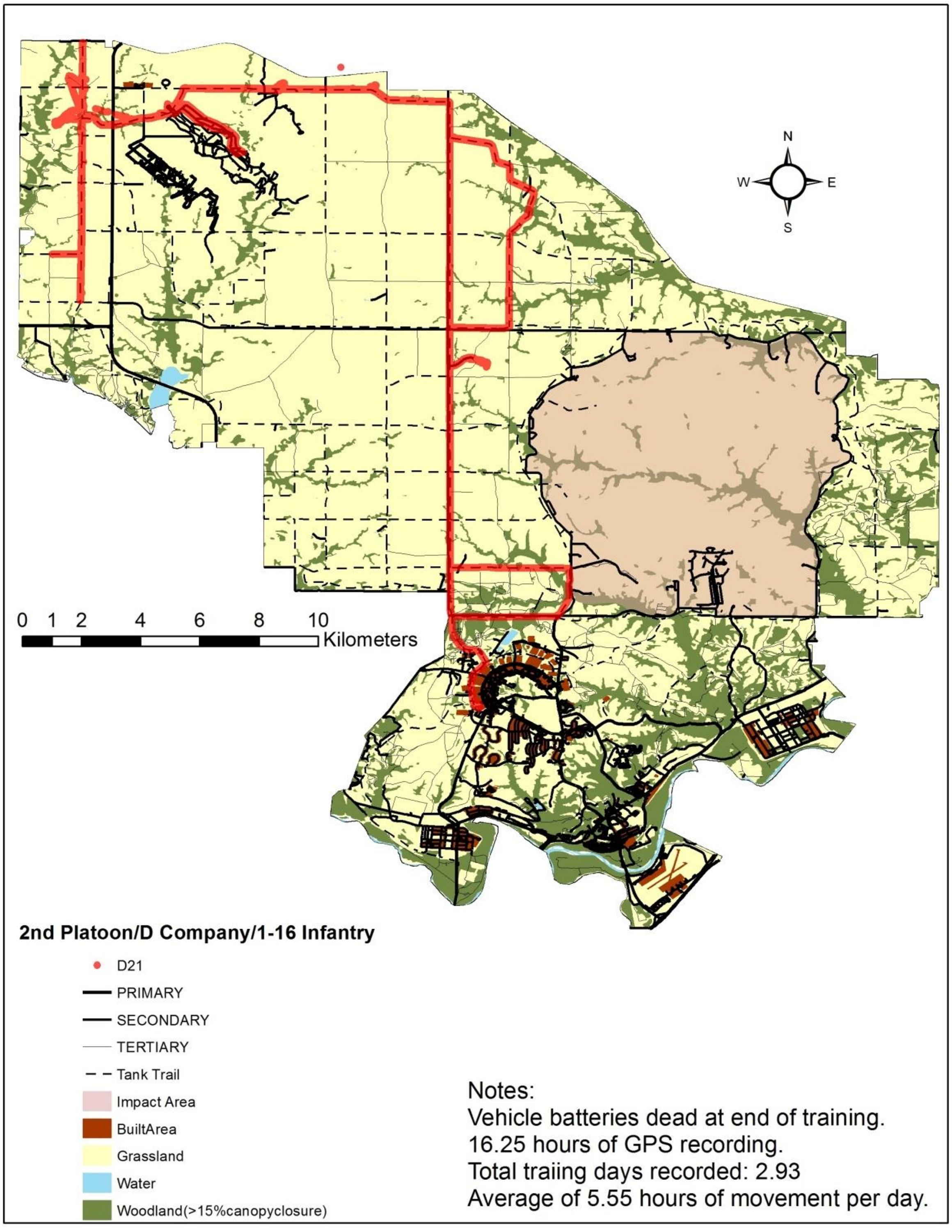


Figure B-24 GPS Points D21 1-16 Infantry Battalion



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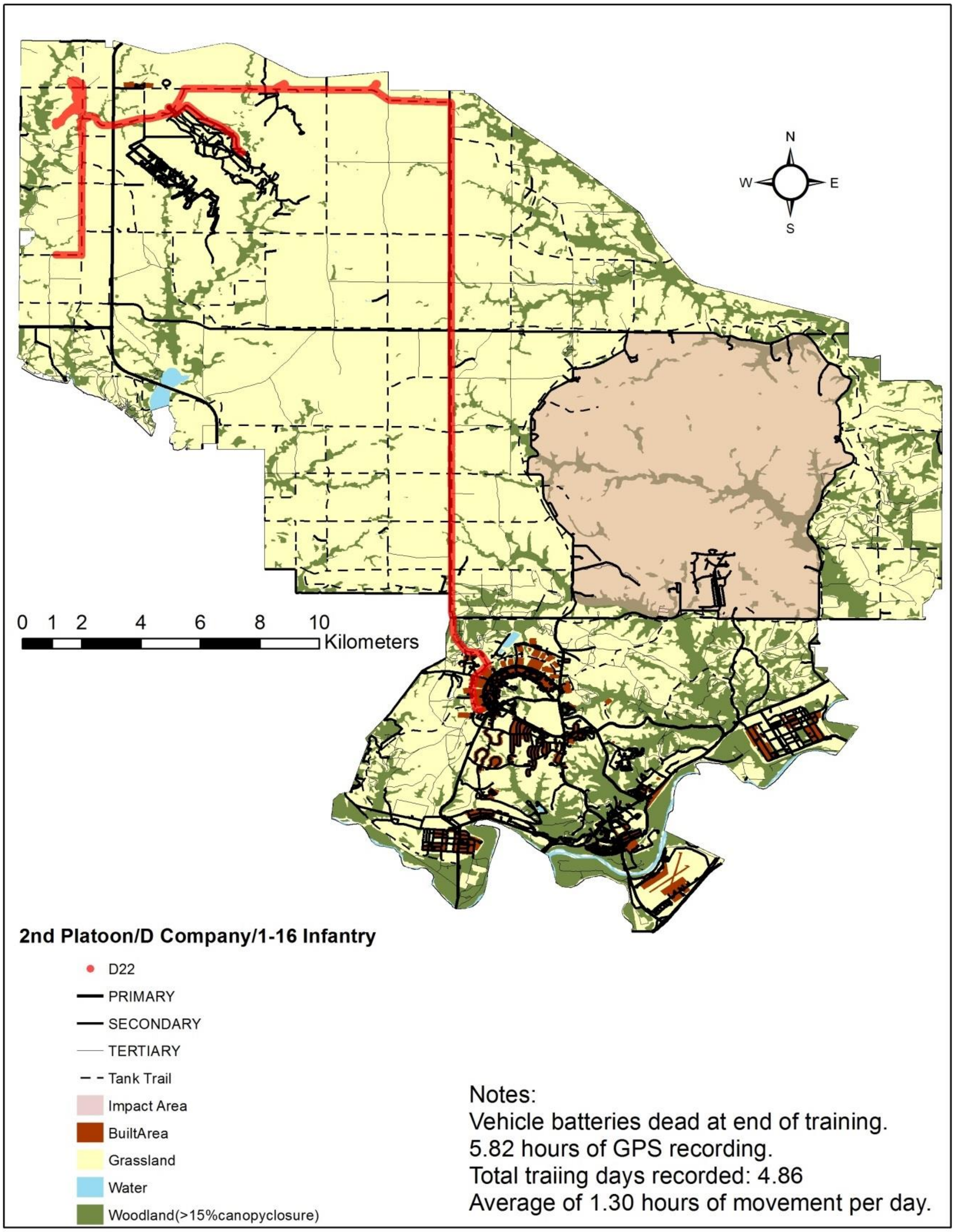


Figure B-26 GPS Points D23 1-16 Infantry Battalion

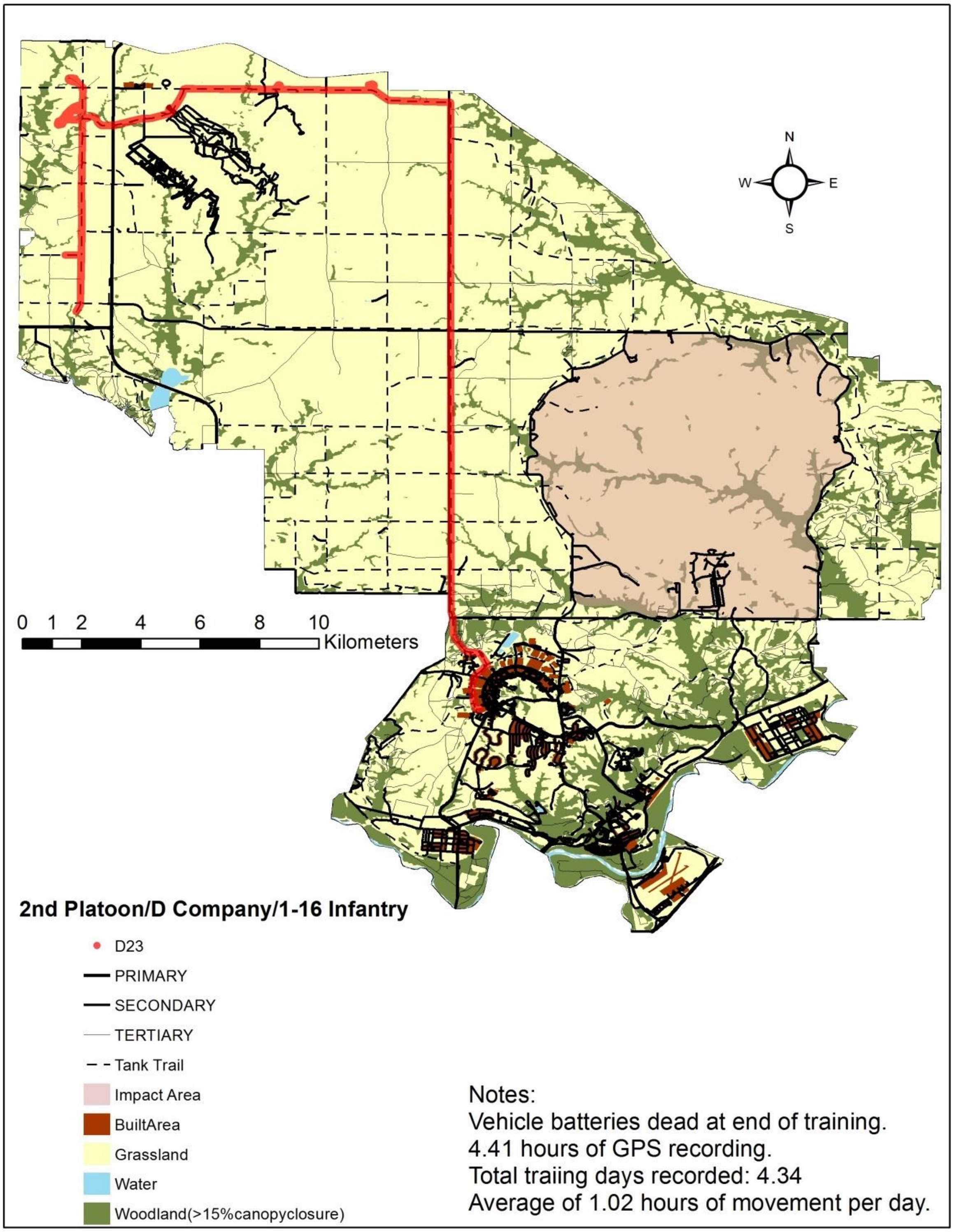


Figure B-27 GPS Points D24 1-16 Infantry Battalion

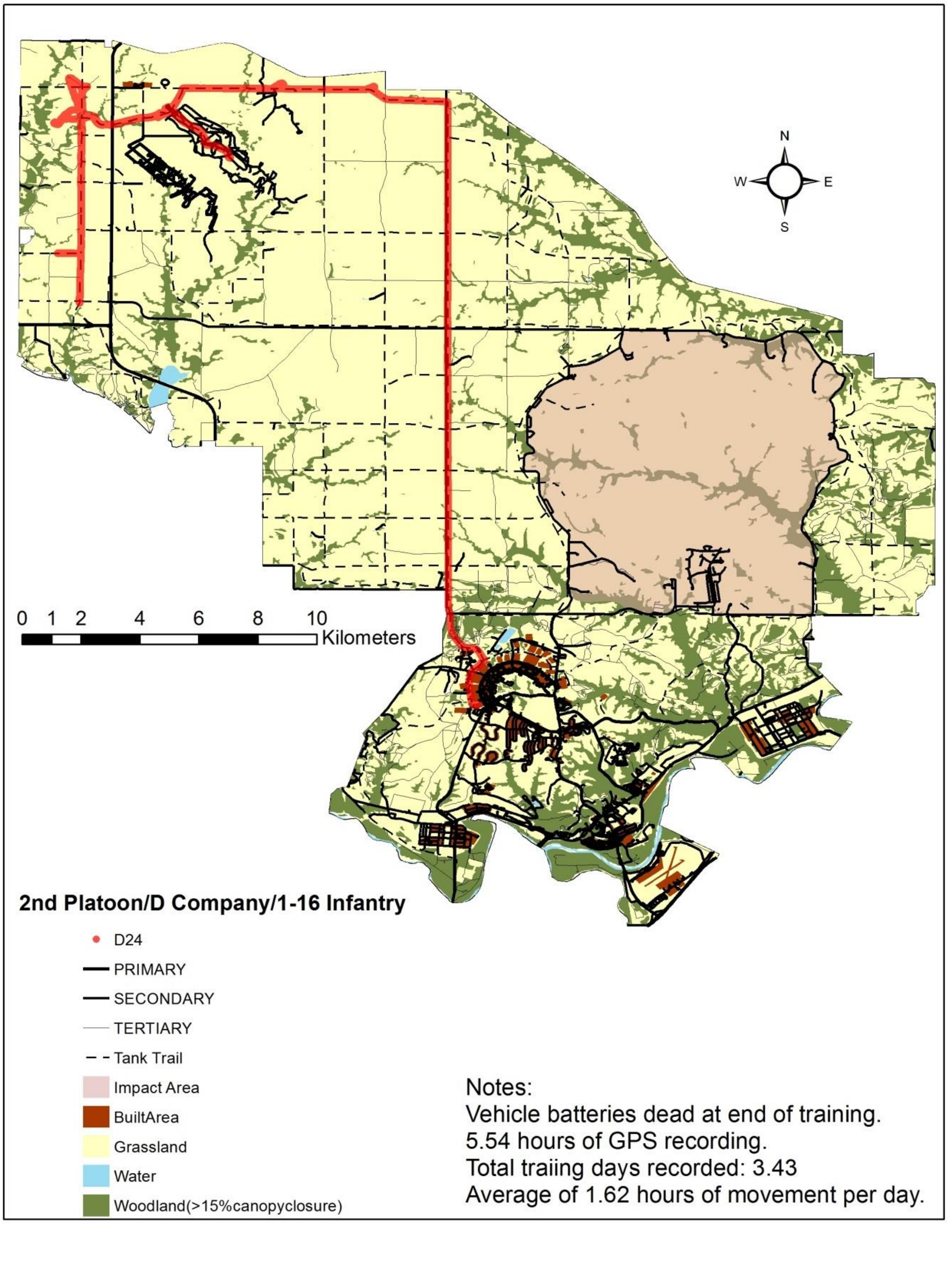


Figure B-28 GPS Points D31 1-16 Infantry Battalion

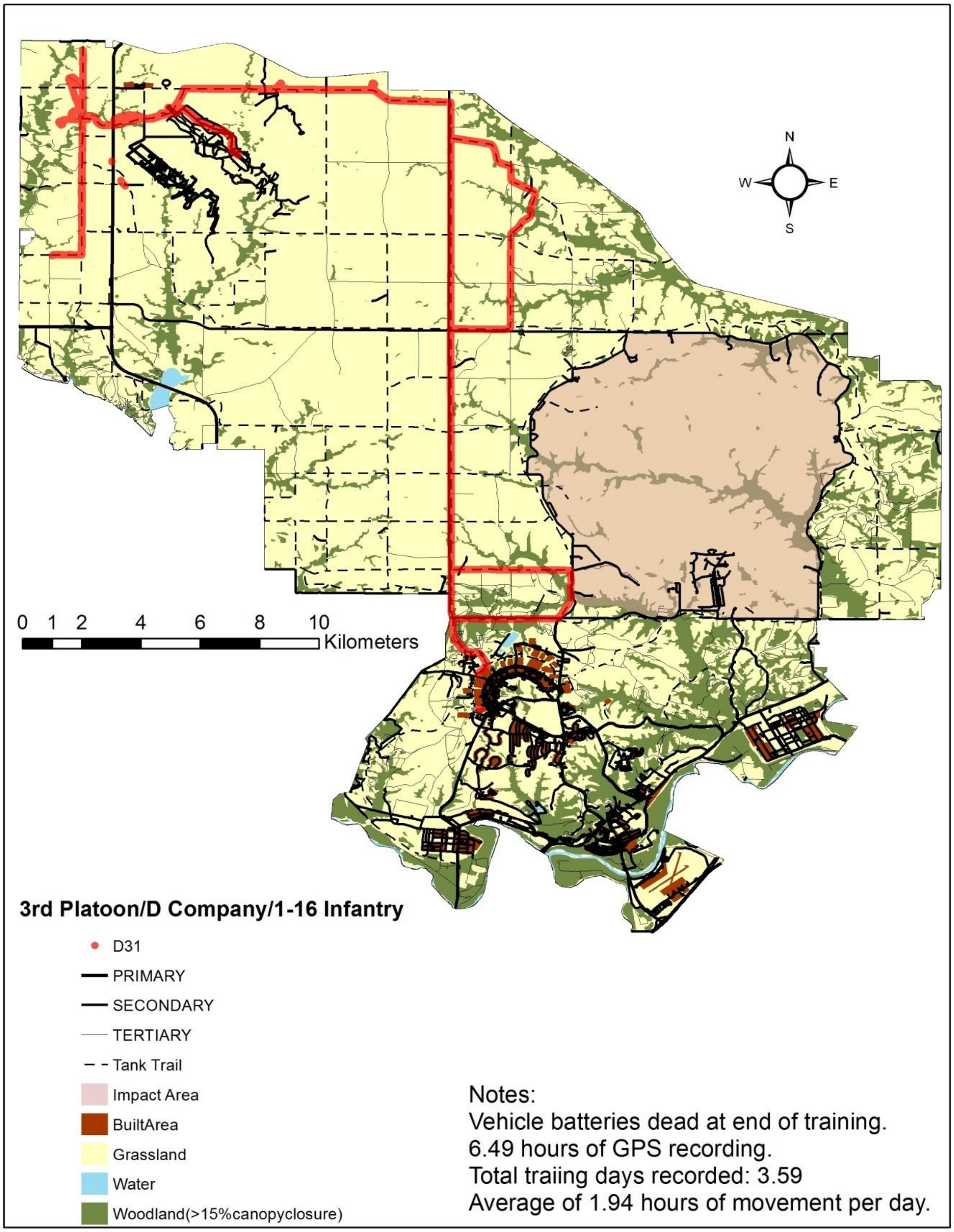


Figure B-29 GPS Points D40 1-16 Infantry Battalion

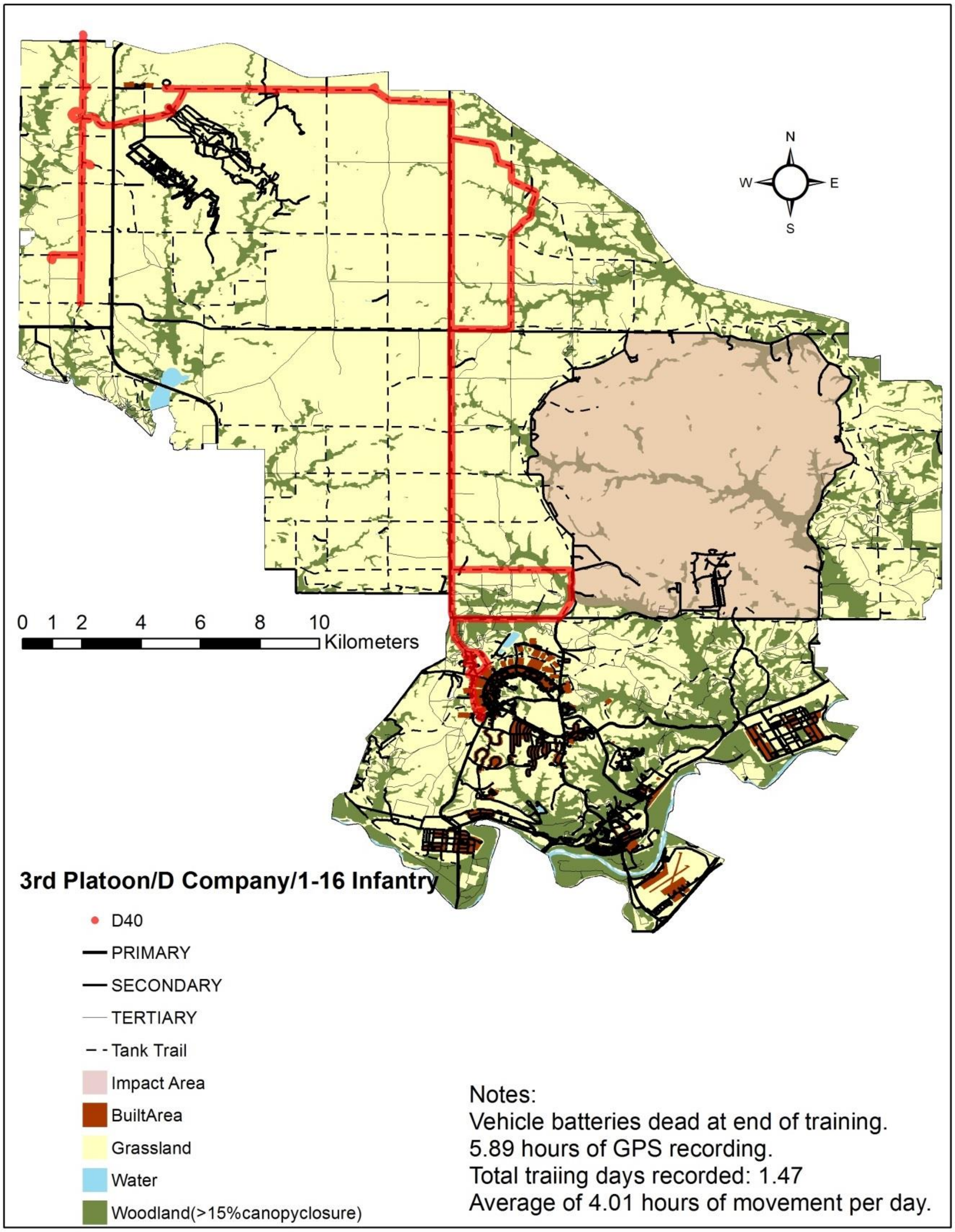


Figure B-30 GPS Points D65 1-16 Infantry Battalion

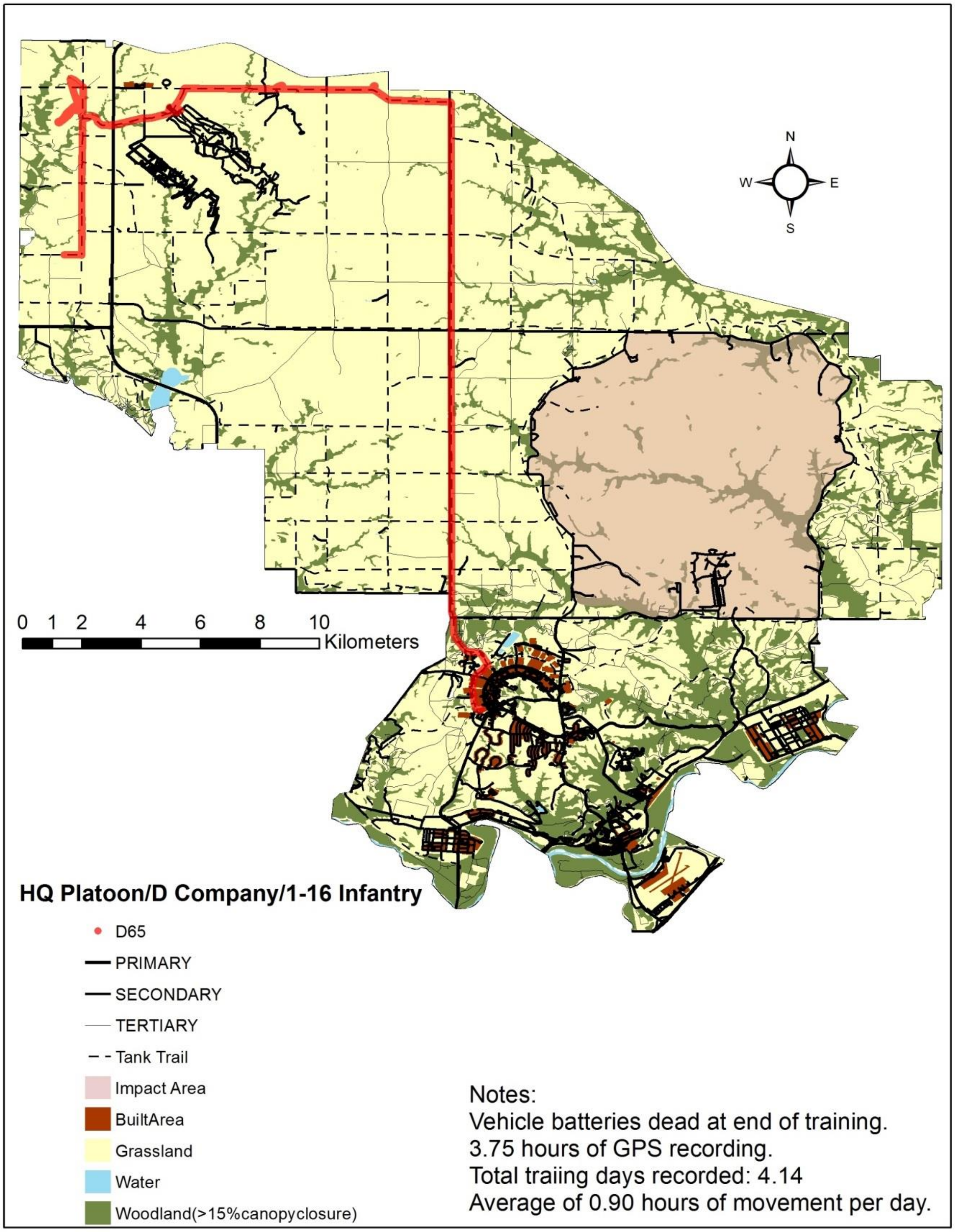


Figure B-31 GPS Points D66 1-16 Infantry Battalion

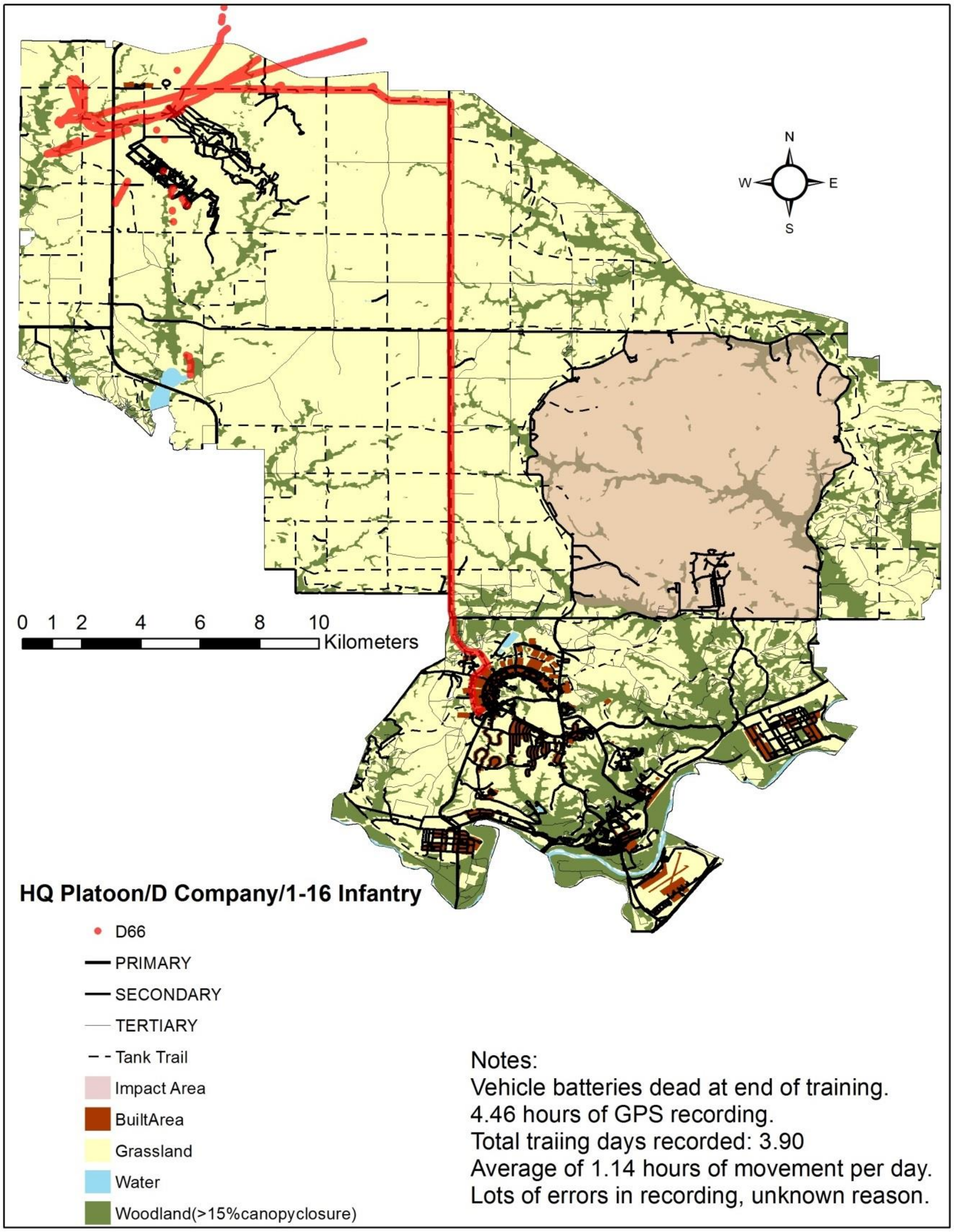


Figure B-32 GPS Points A11 2-34 Armor Battalion

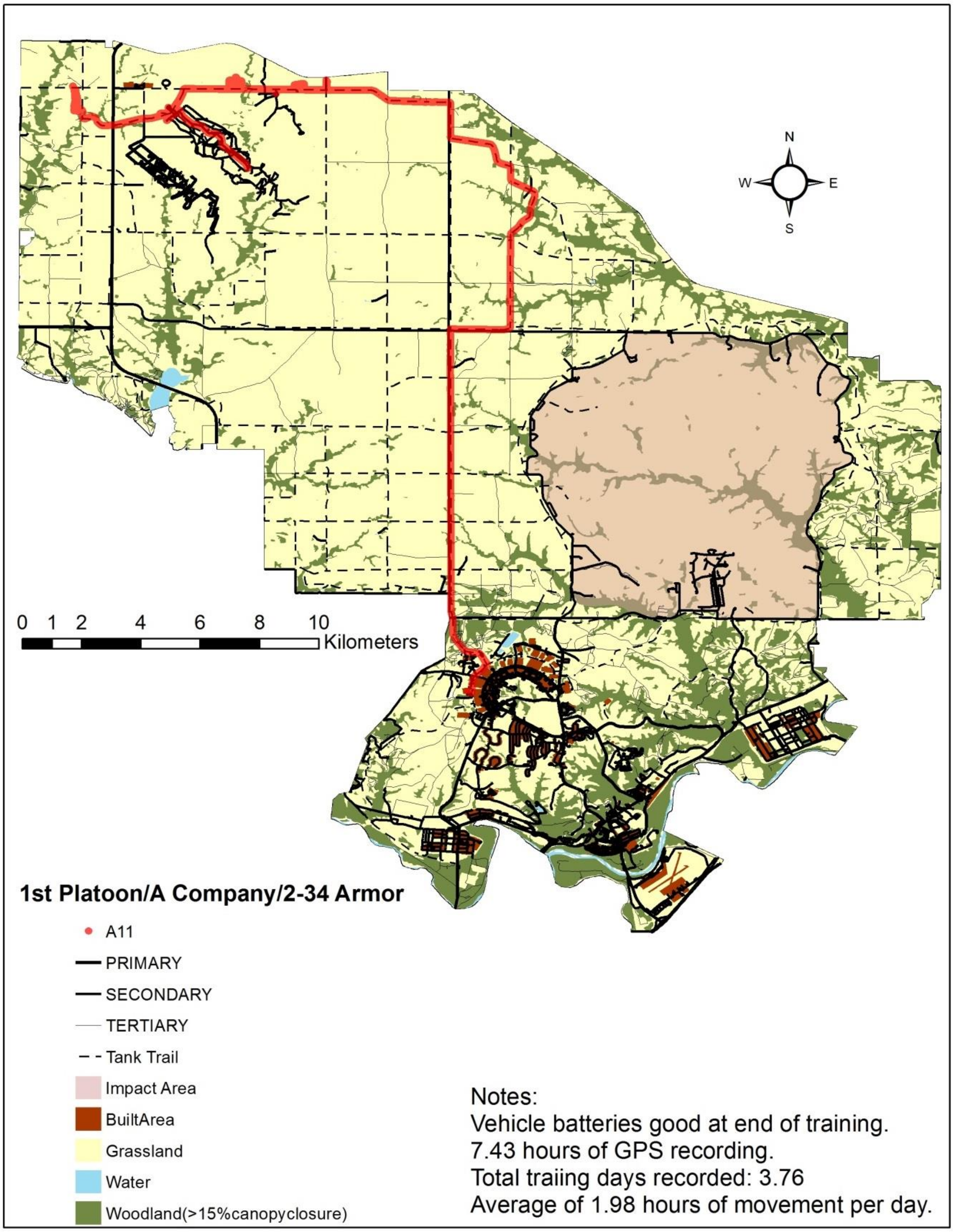


Figure B-33 GPS Points A12 2-34 Armor Battalion

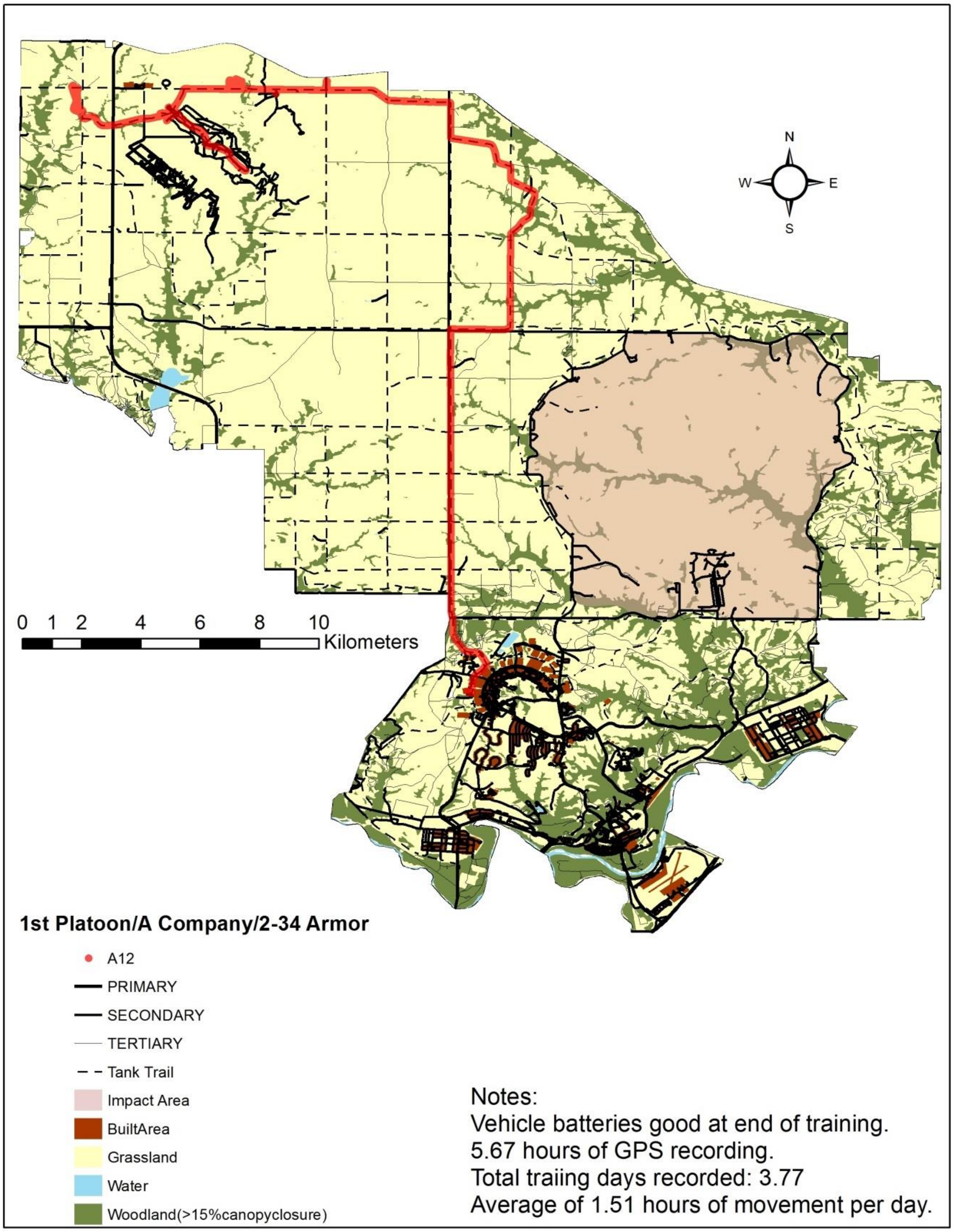


Figure B-34 GPS Points A13 2-34 Armor Battalion

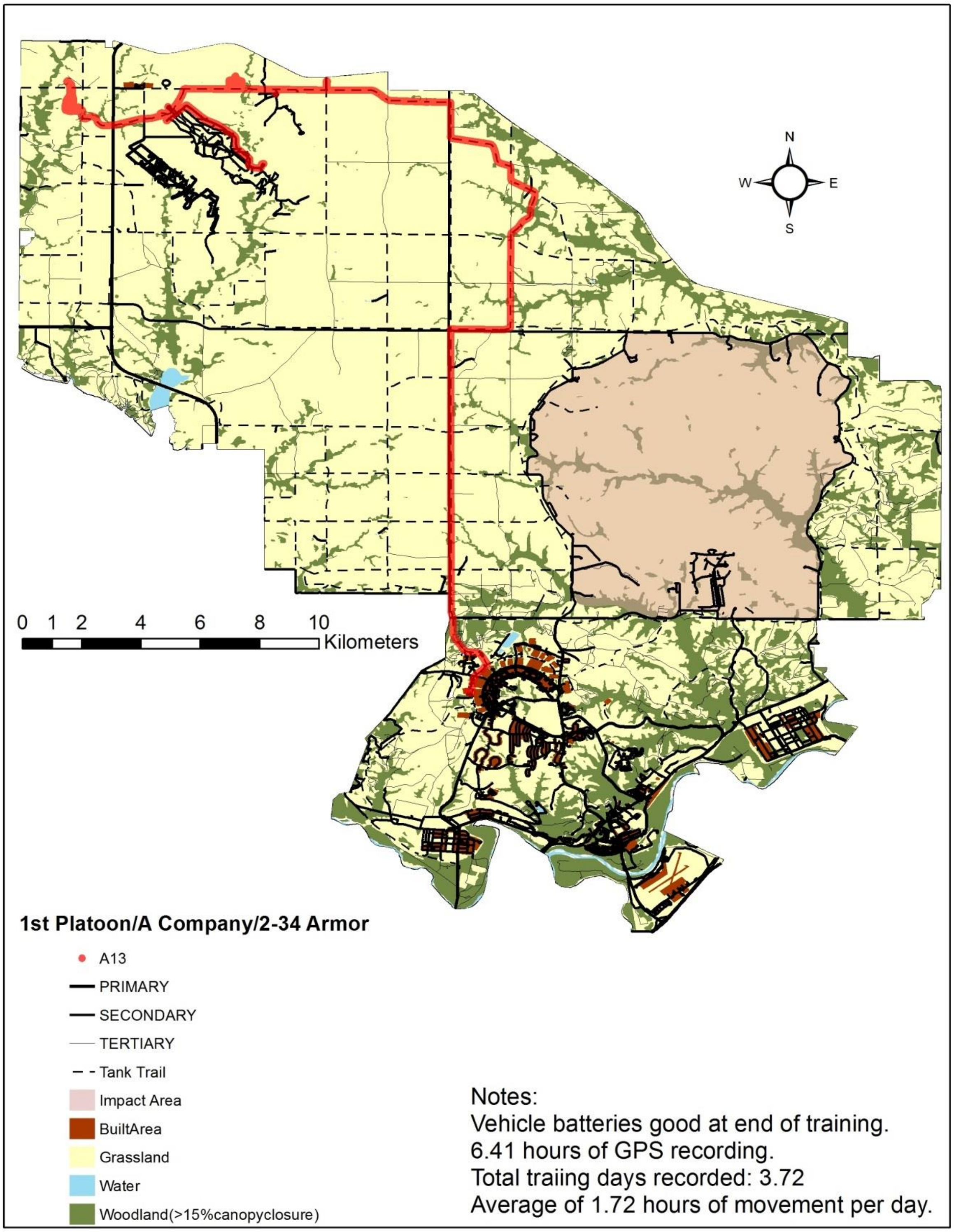


Figure B-35 GPS Points A14 2-34 Armor Battalion

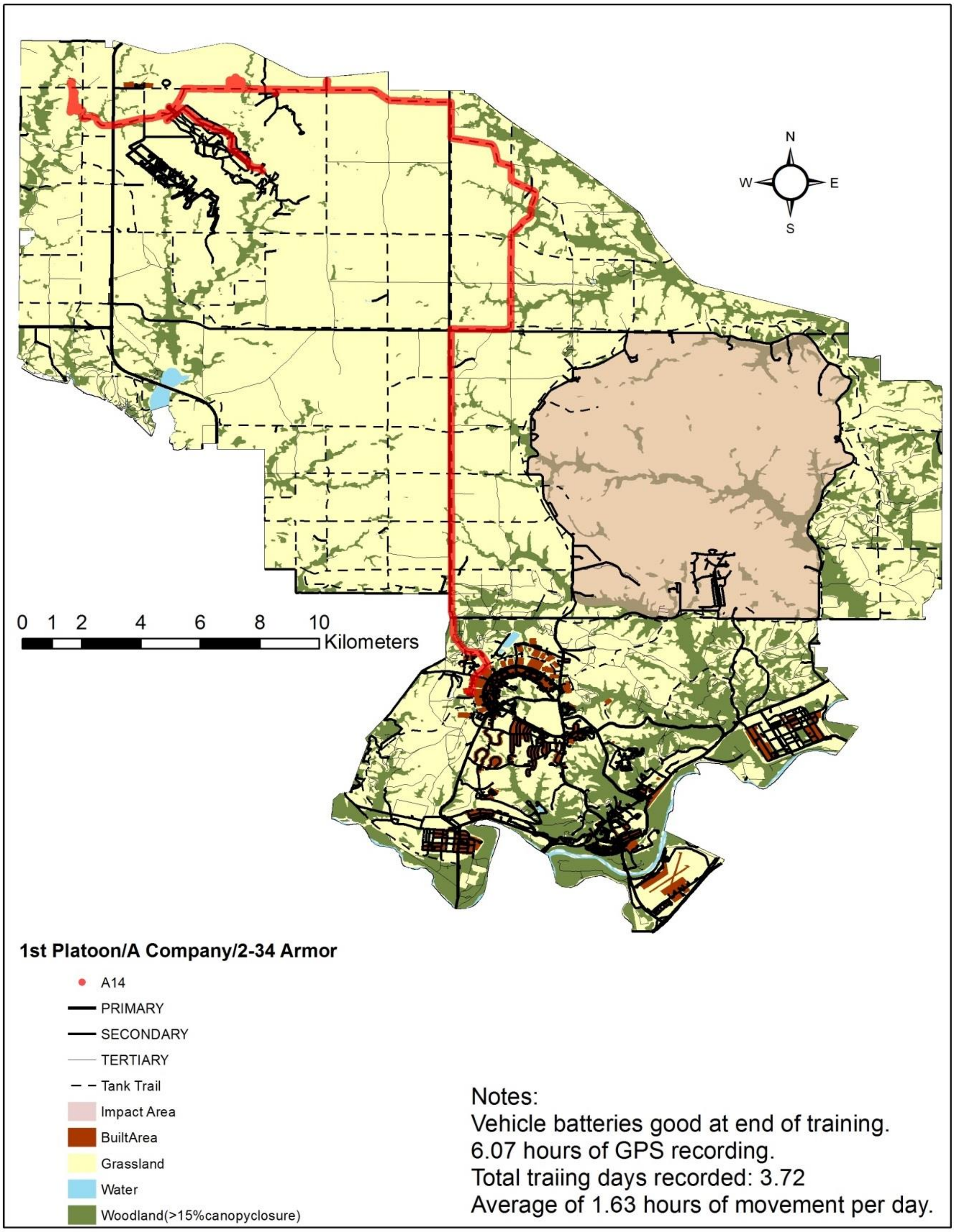


Figure B-36 GPS Points A21 2-34 Armor Battalion

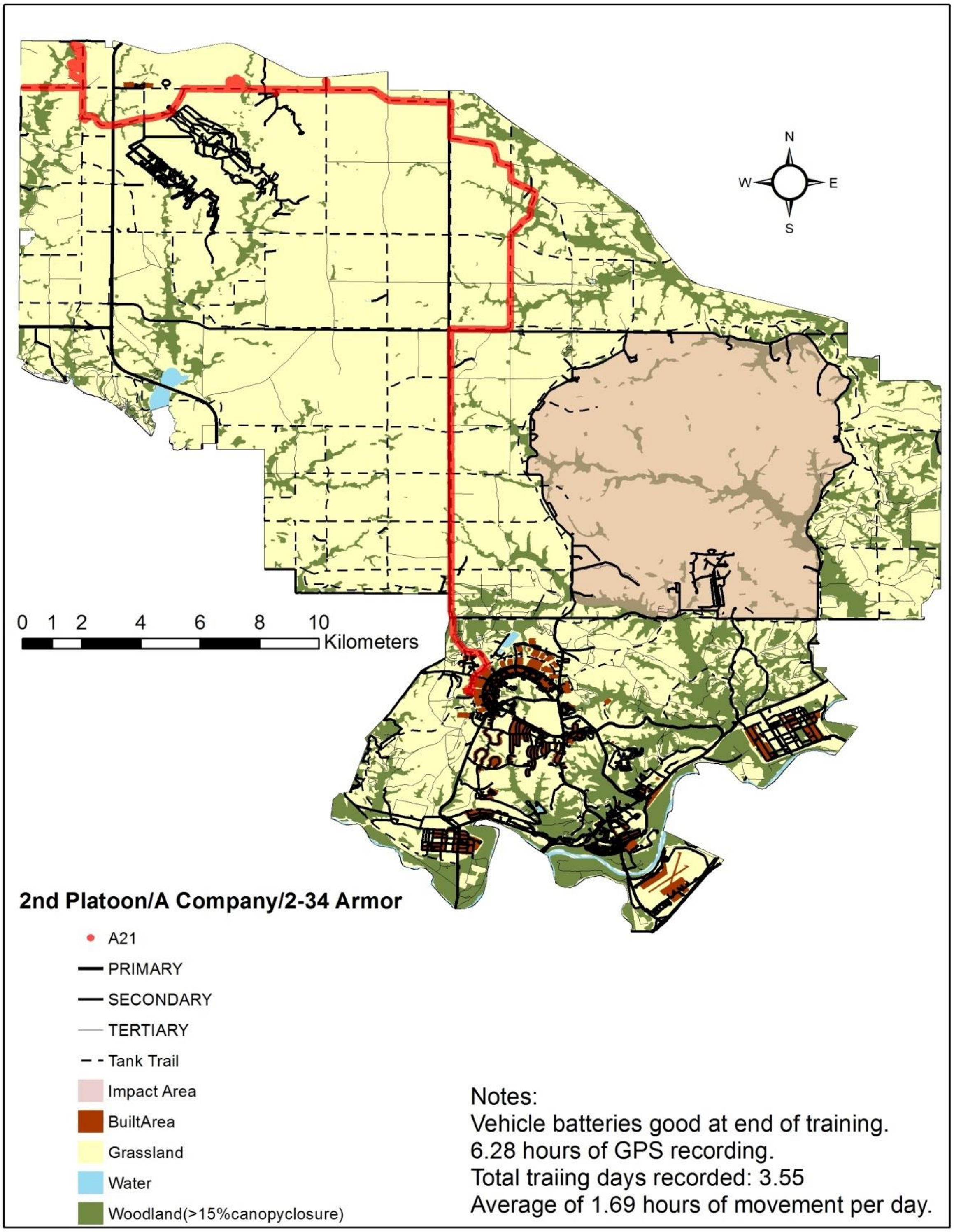


Figure B-37 GPS Points A22 2-34 Armor Battalion

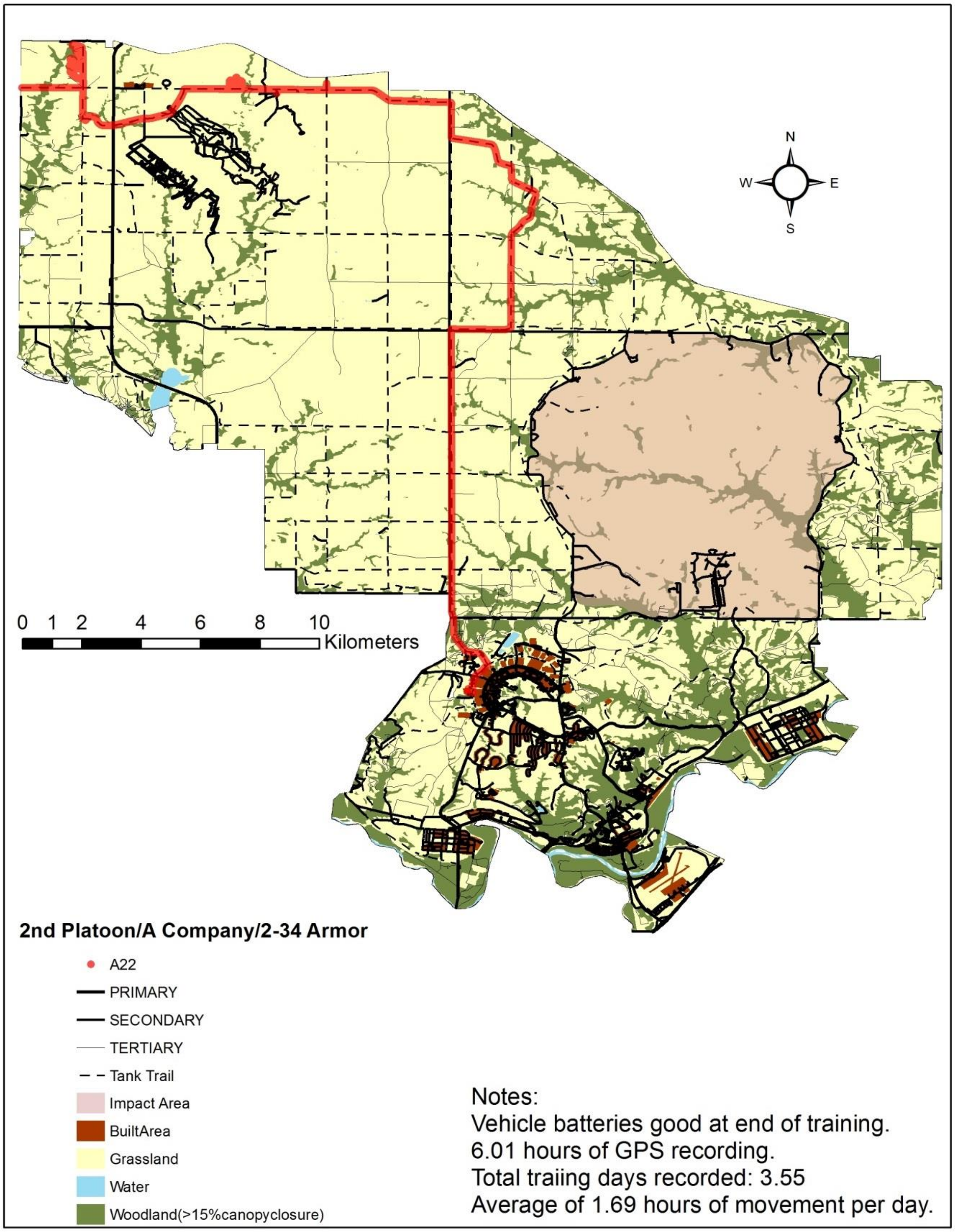


Figure B-38 GPS Points A23 2-34 Armor Battalion

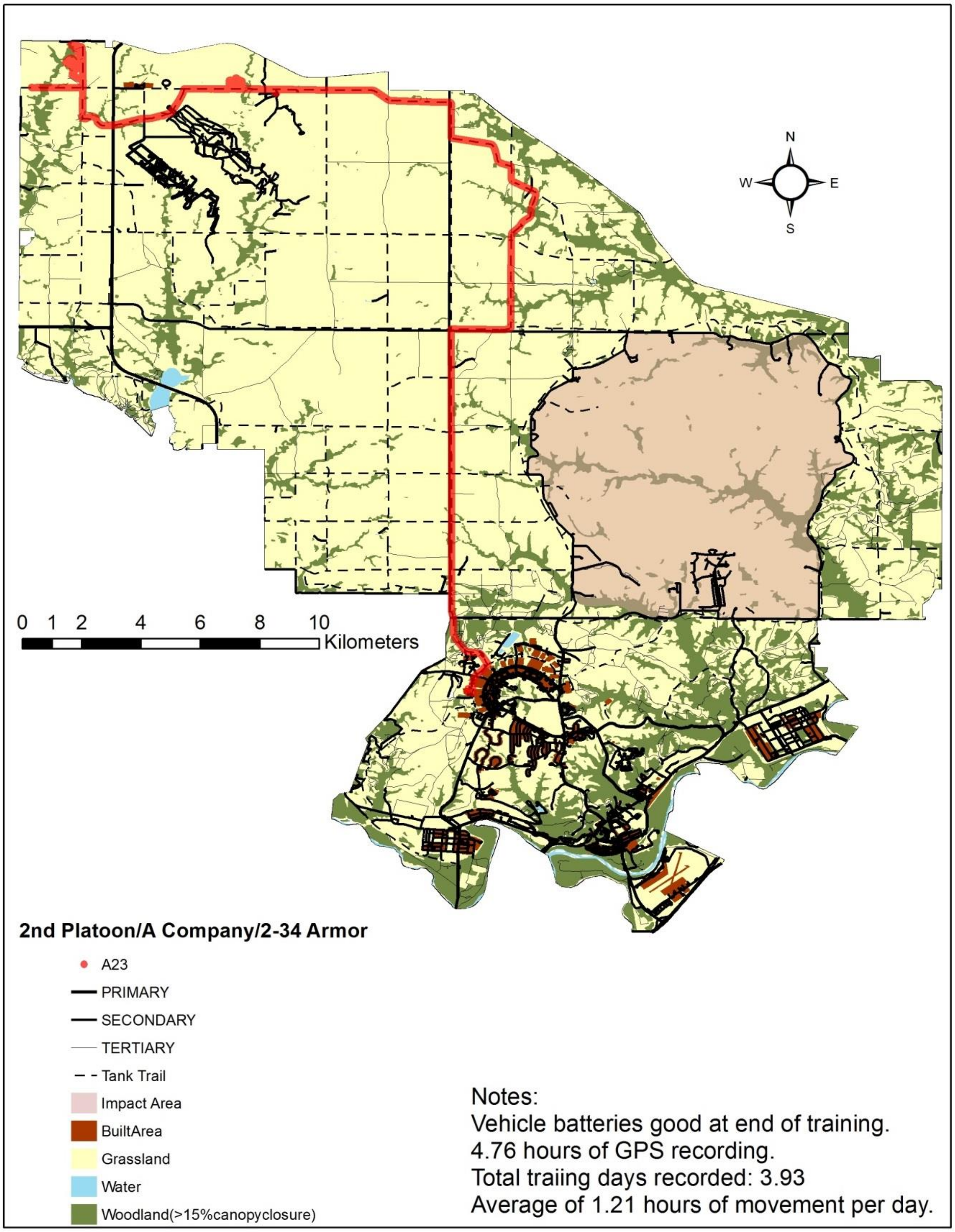


Figure B-39 GPS Points A24 2-34 Armor Battalion

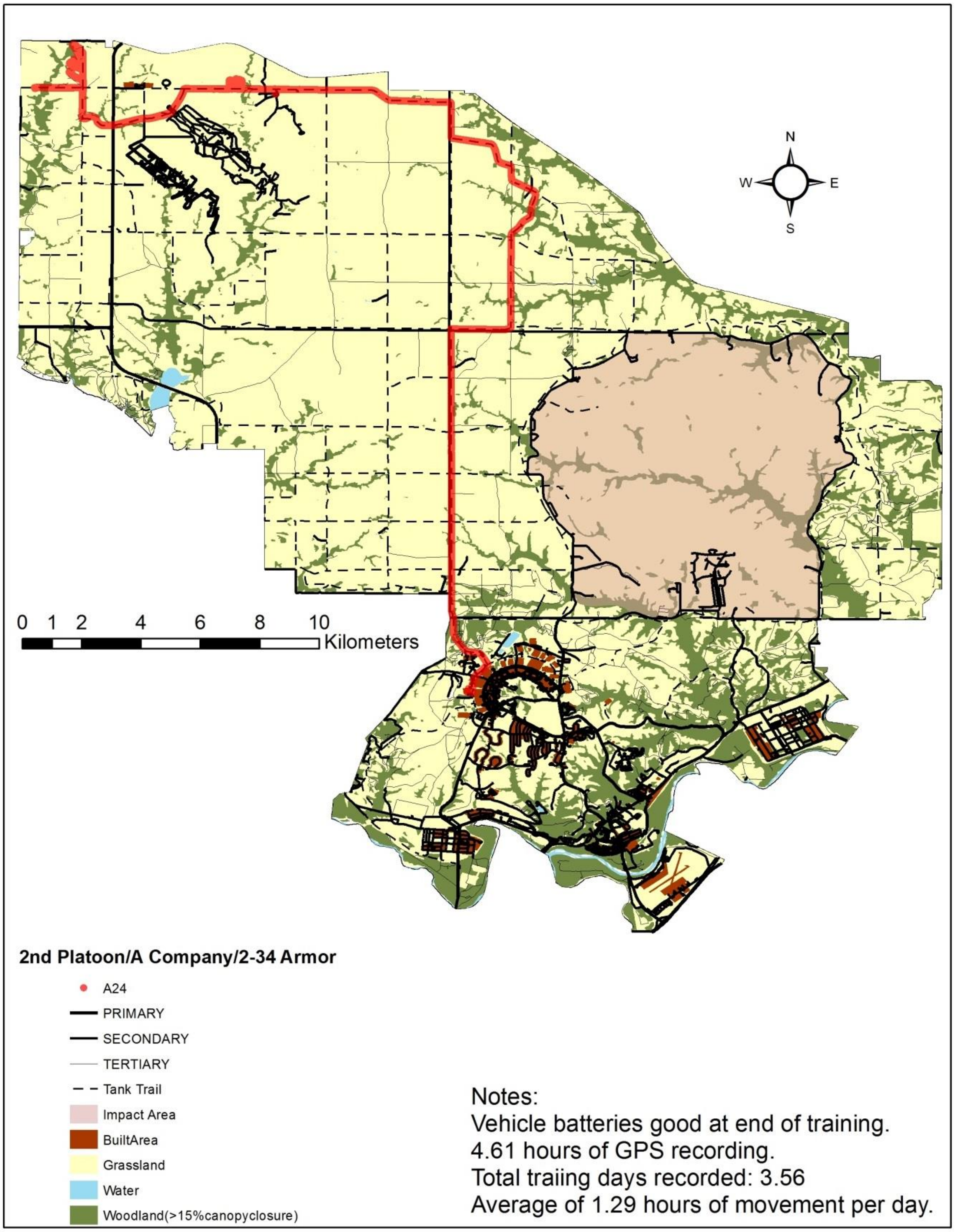


Figure B-40 GPS Points A30 2-34 Armor Battalion

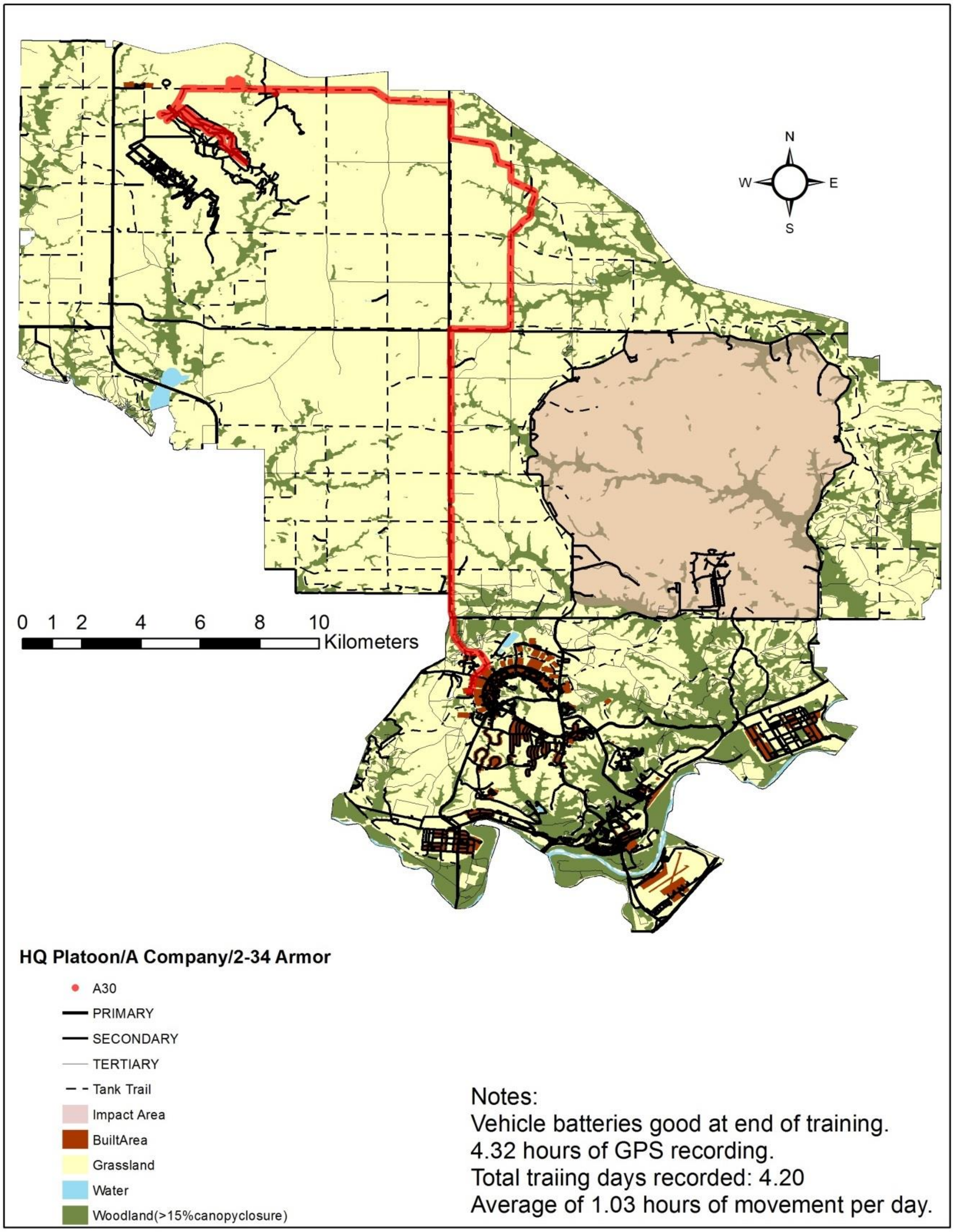
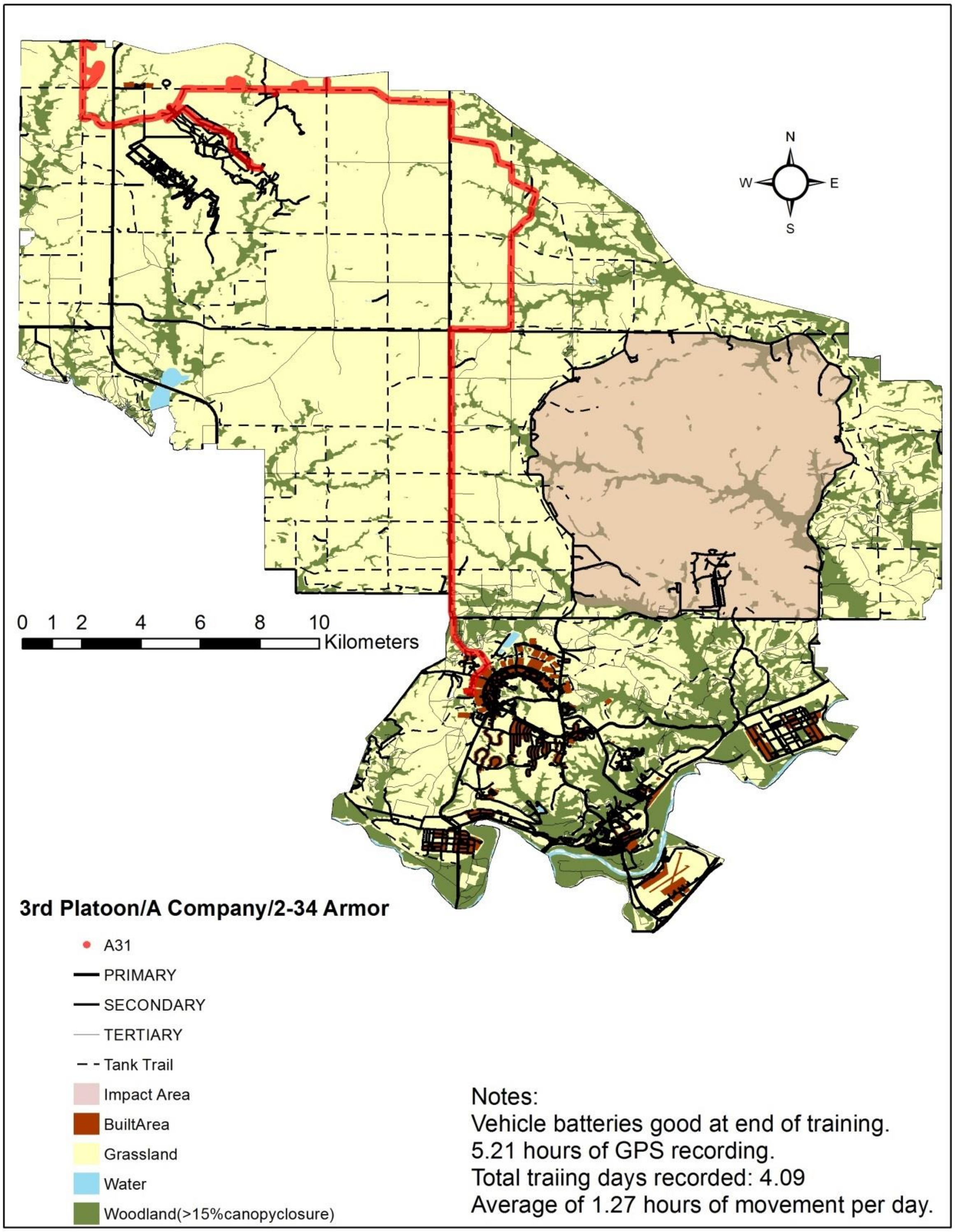


Figure B-41 GPS Points A31 2-34 Armor Battalion



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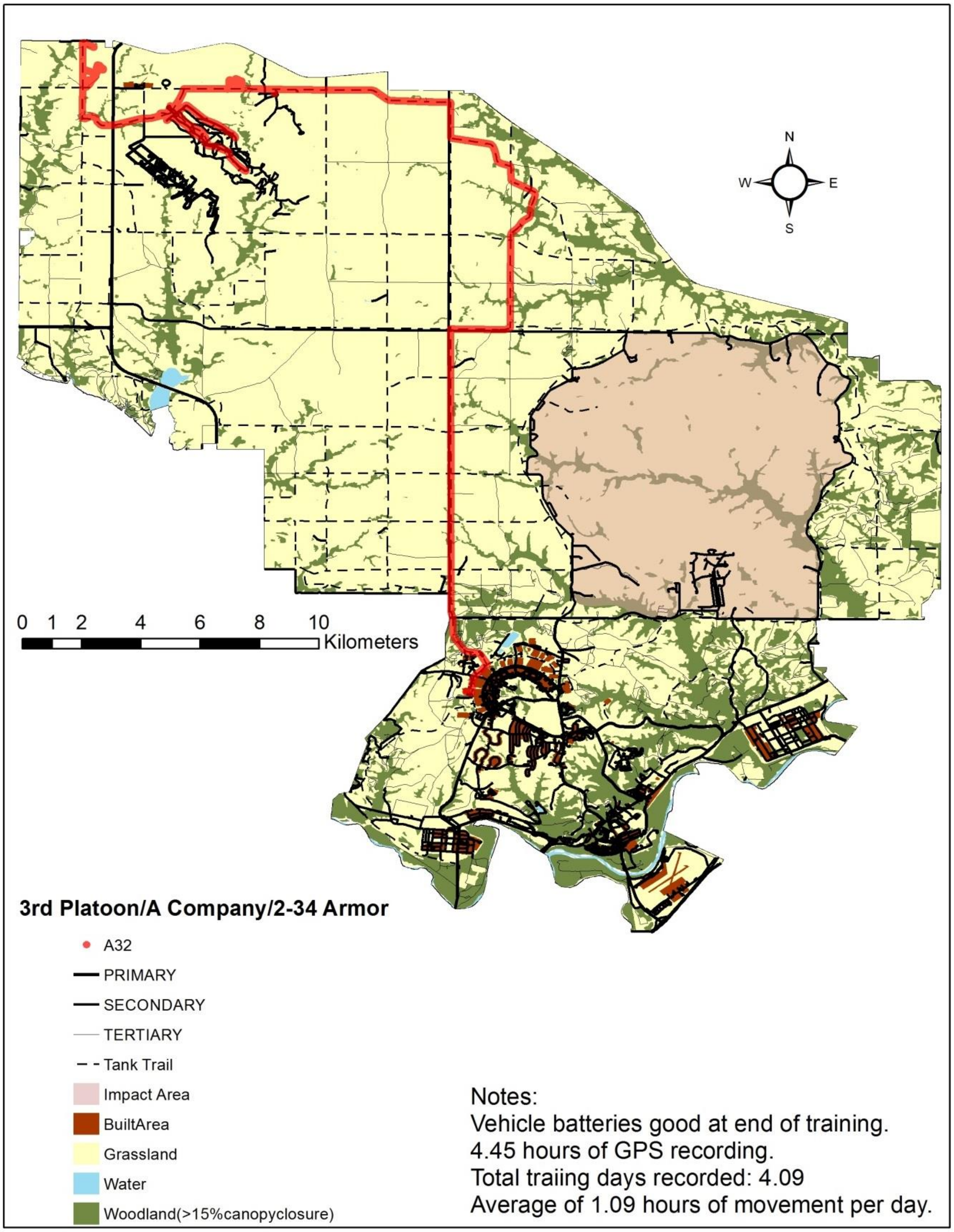


Figure B-43 GPS Points A33 2-34 Armor Battalion

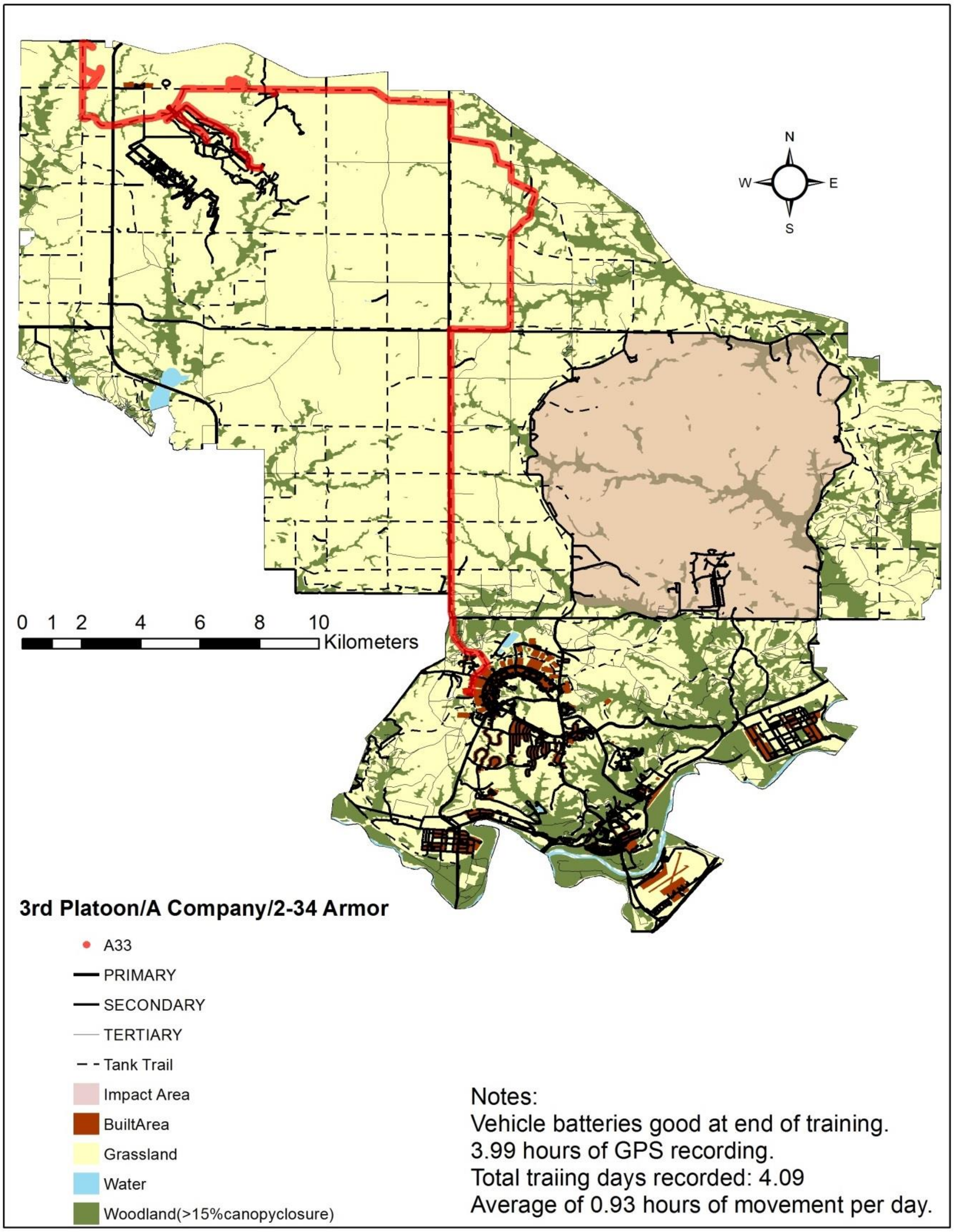


Figure B-44 GPS Points A34 2-34 Armor Battalion

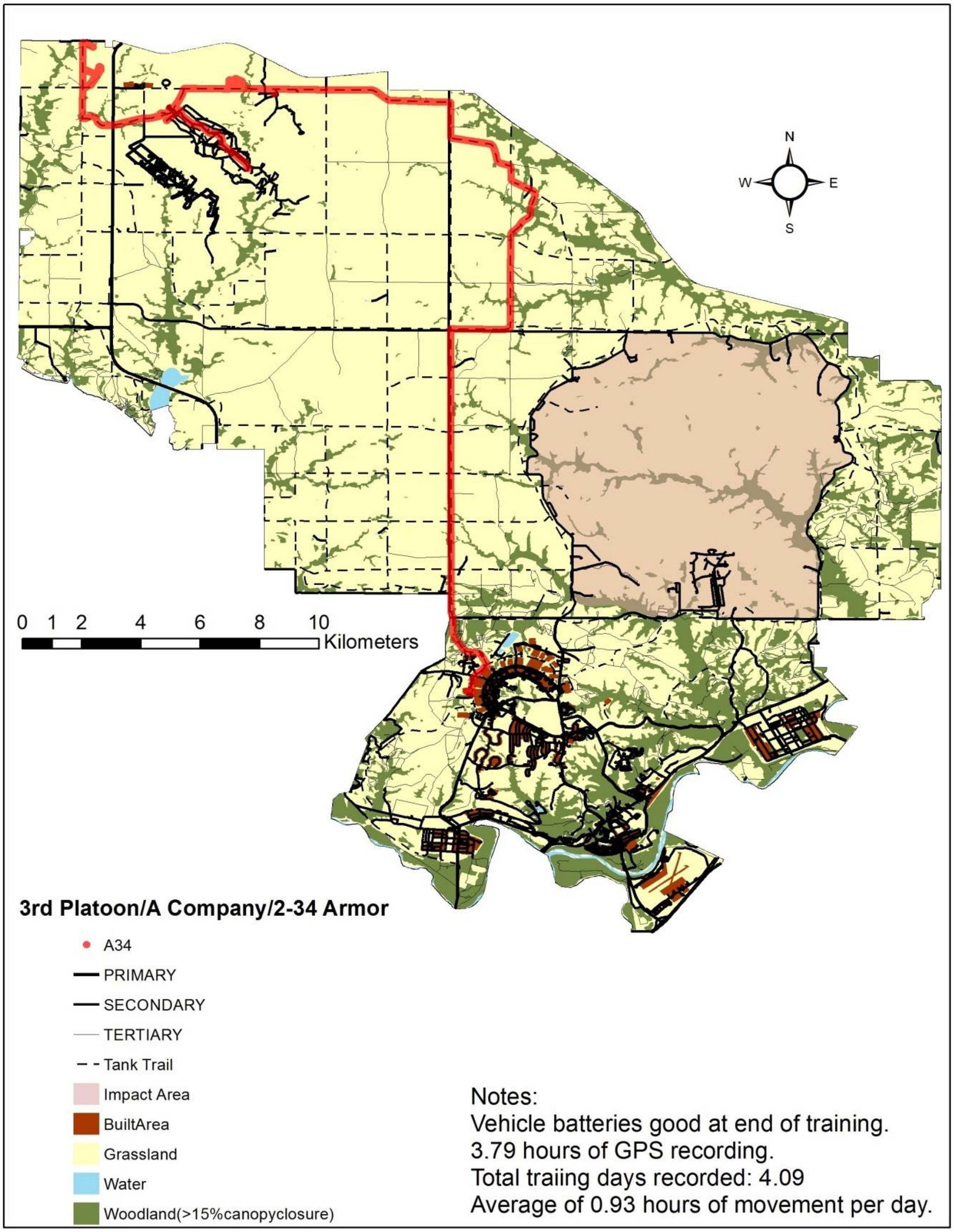


Figure B-45 GPS Points A65 2-34 Armor Battalion

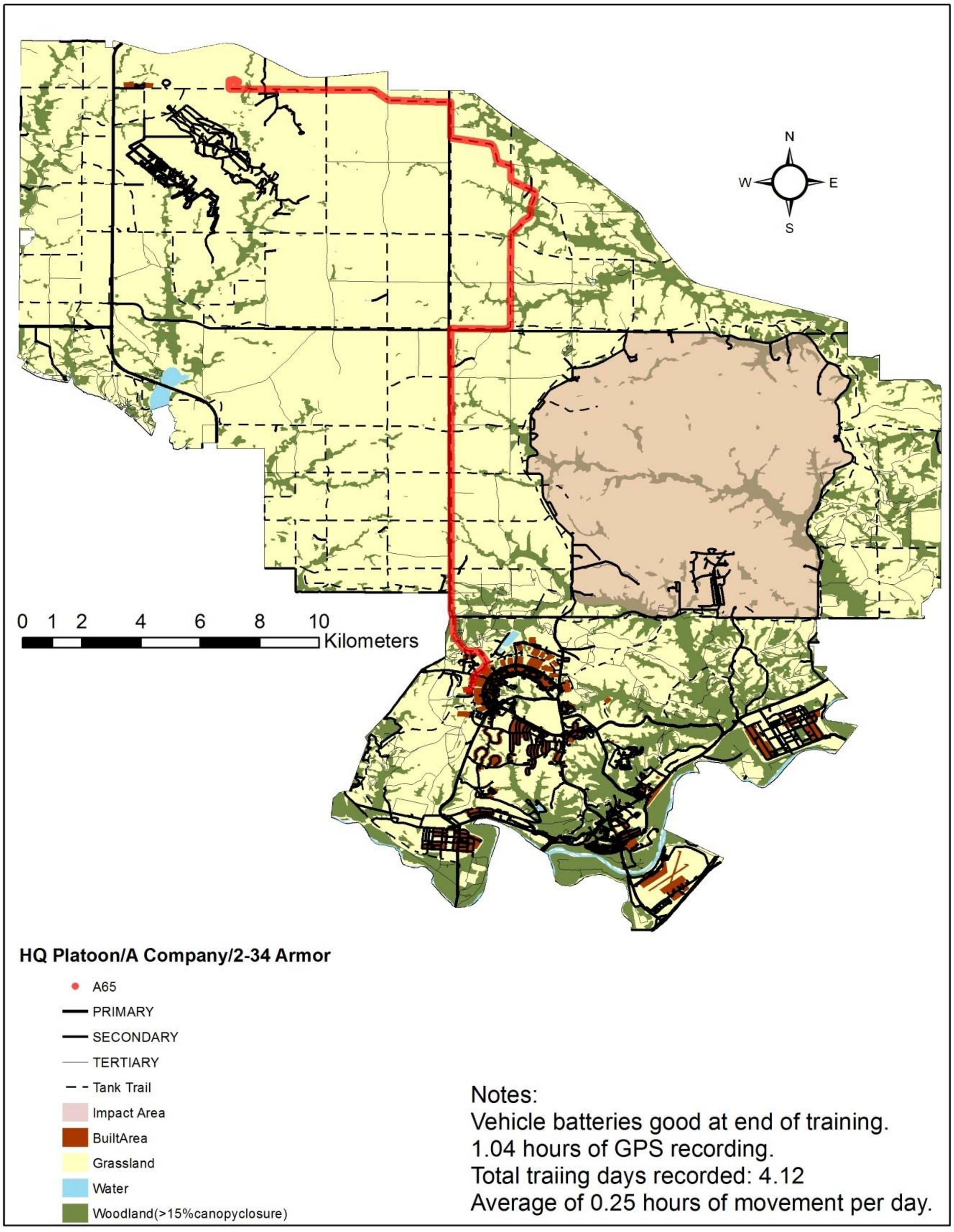


Figure B-46 GPS Points A66 2-34 Armor Battalion

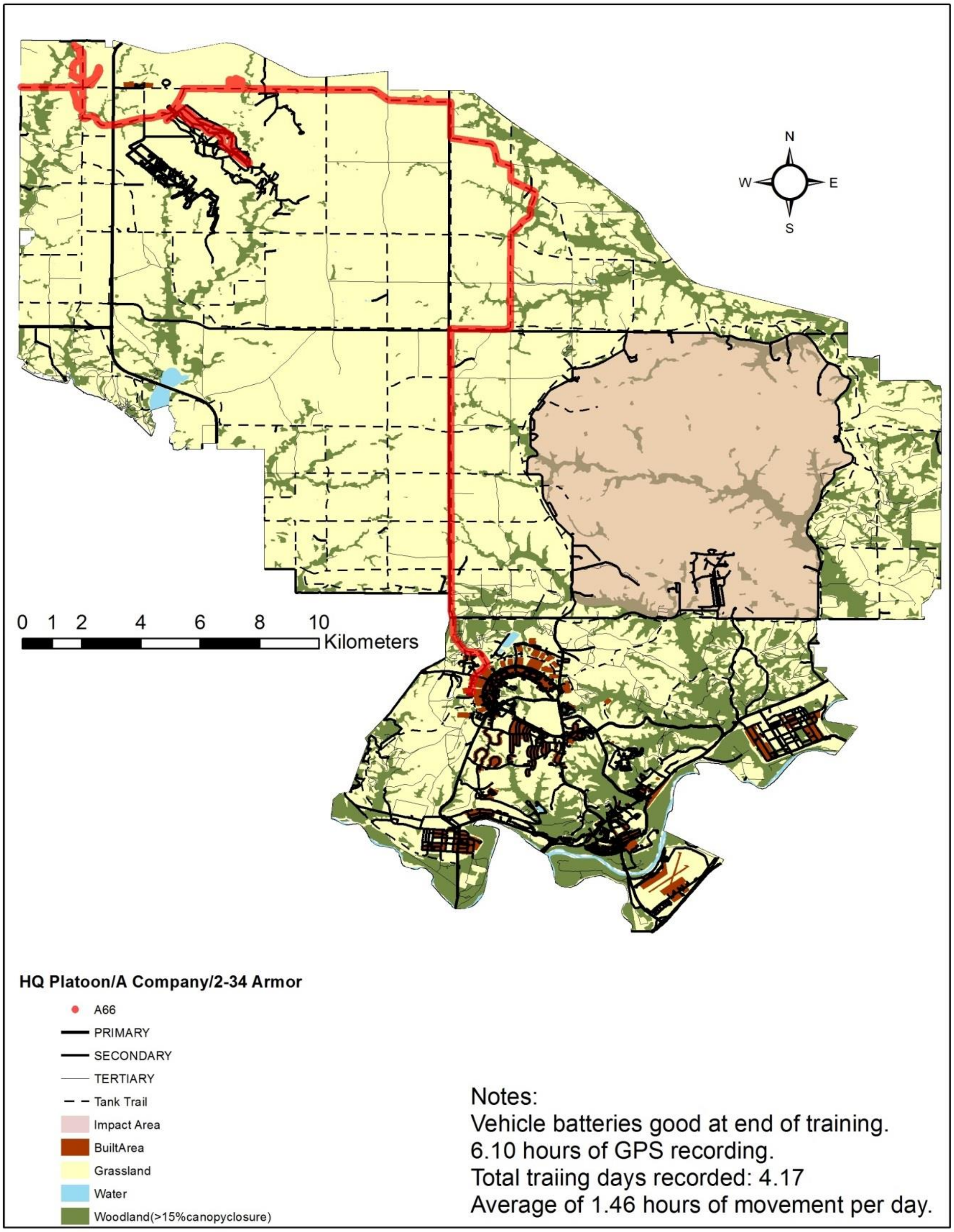


Figure B-47 GPS Points B11 2-34 Armor Battalion

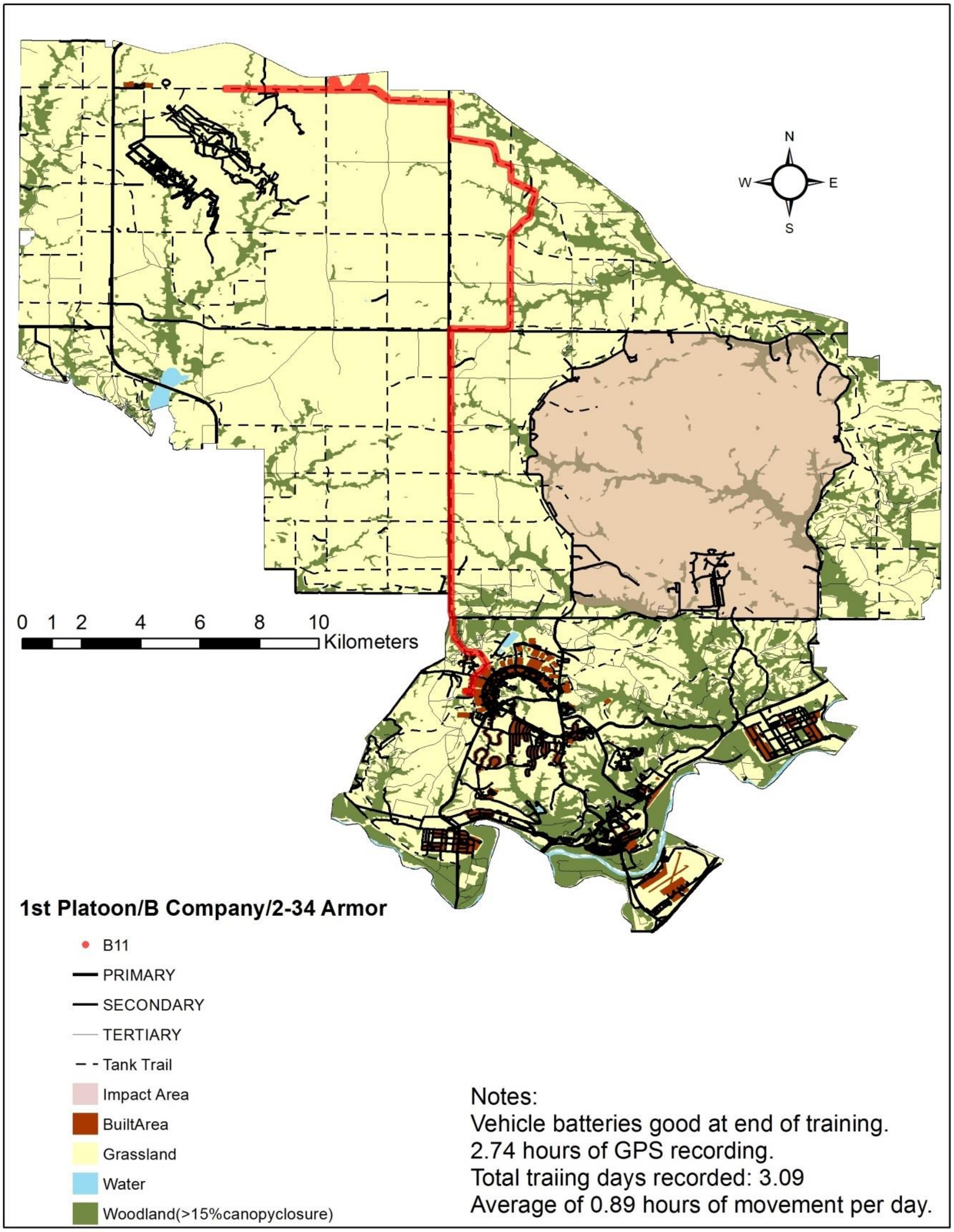


Figure B-48 GPS Points B12 2-34 Armor Battalion

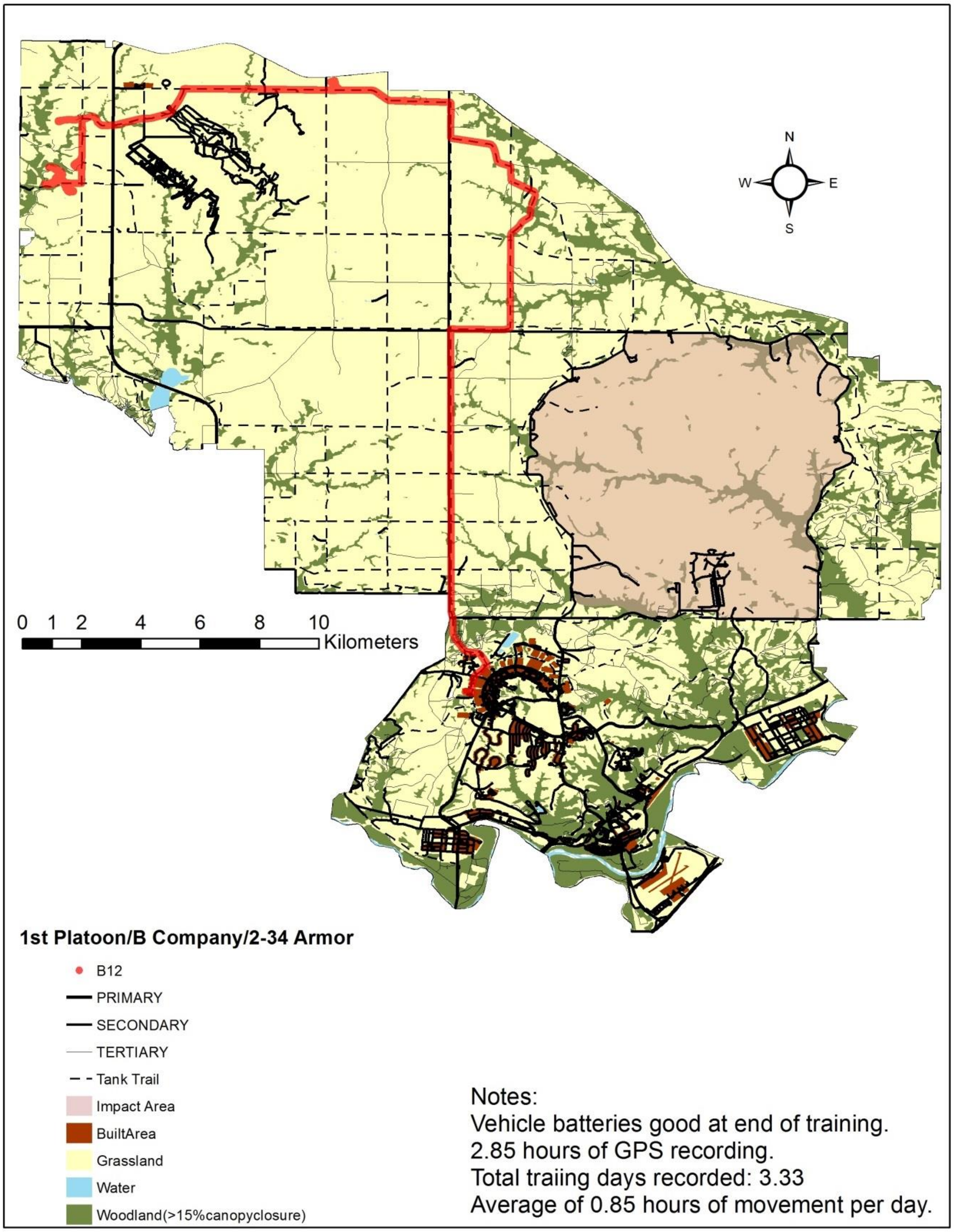


Figure B-49 GPS Points B13 2-34 Armor Battalion

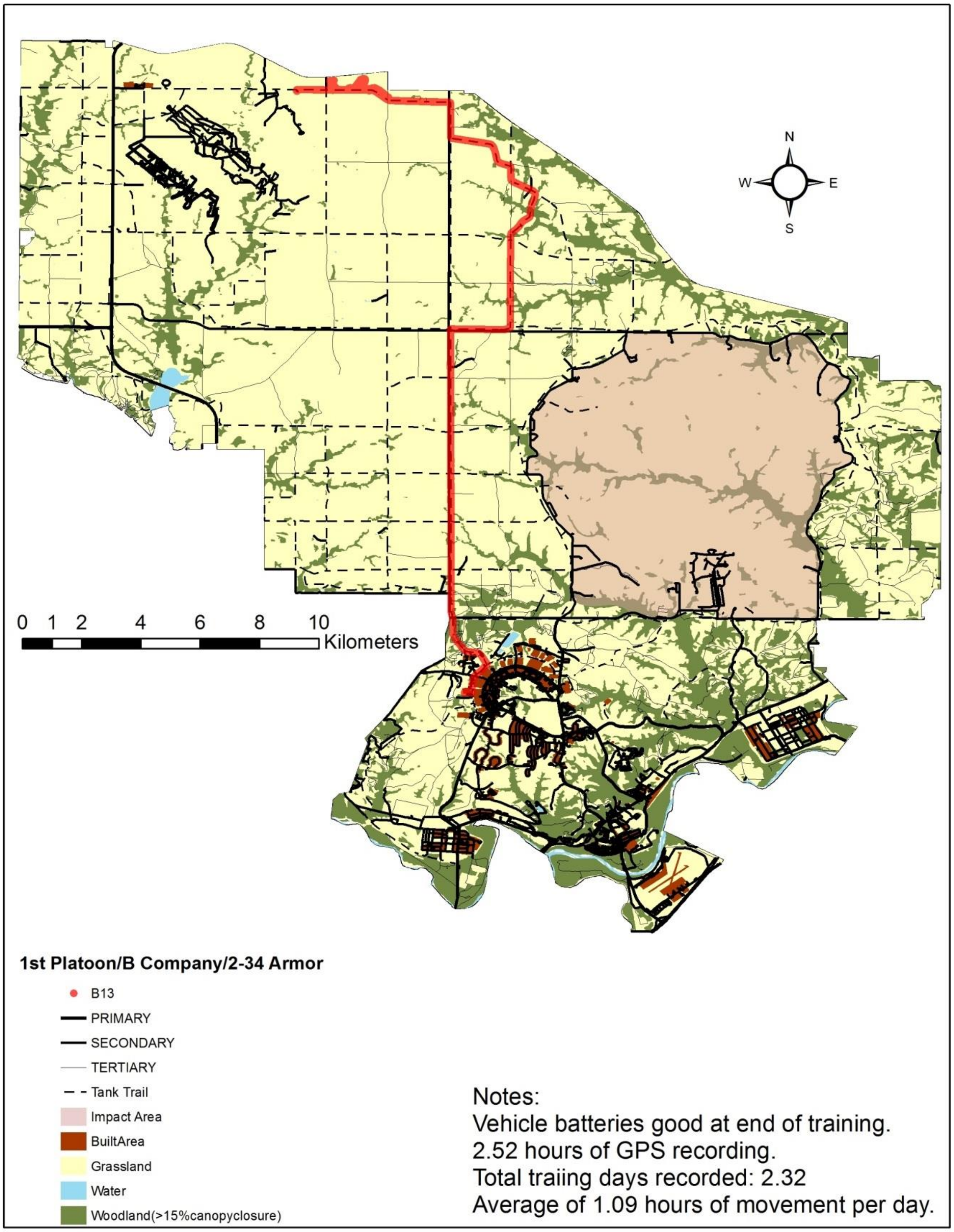


Figure B-50 GPS Points B14 2-34 Armor Battalion

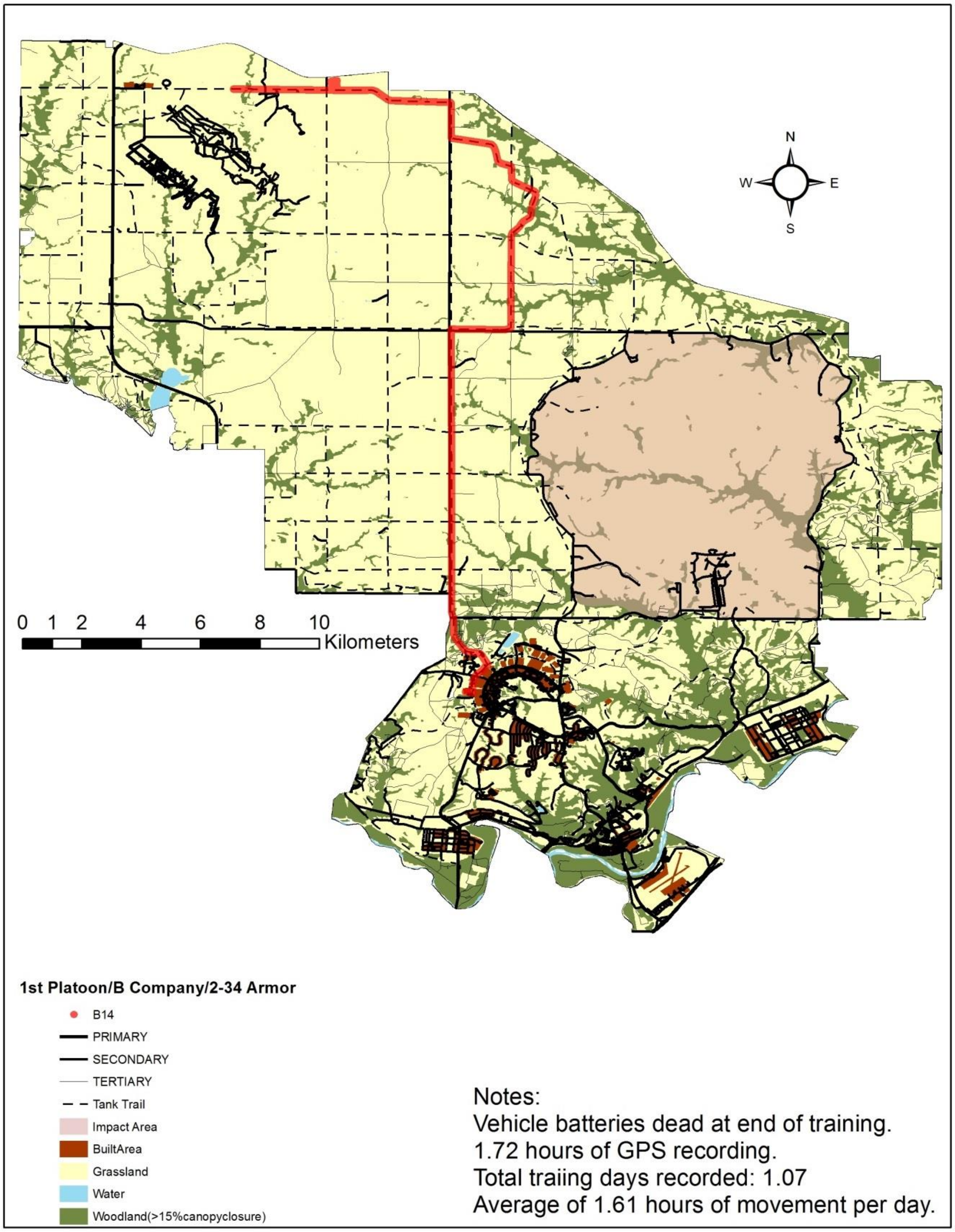


Figure B-51 GPS Points B21 2-34 Armor Battalion

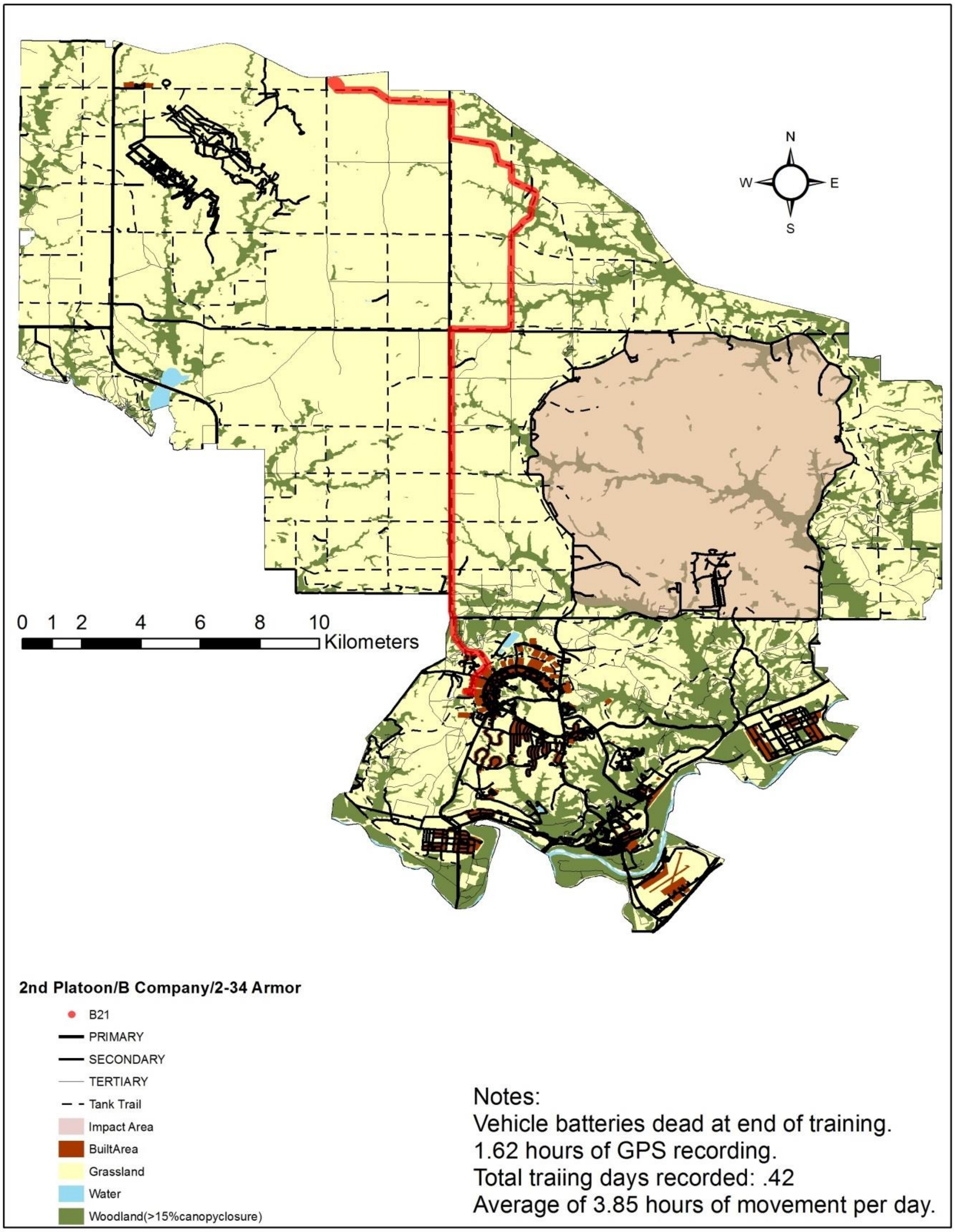


Figure B-52 GPS Points B22 2-34 Armor Battalion

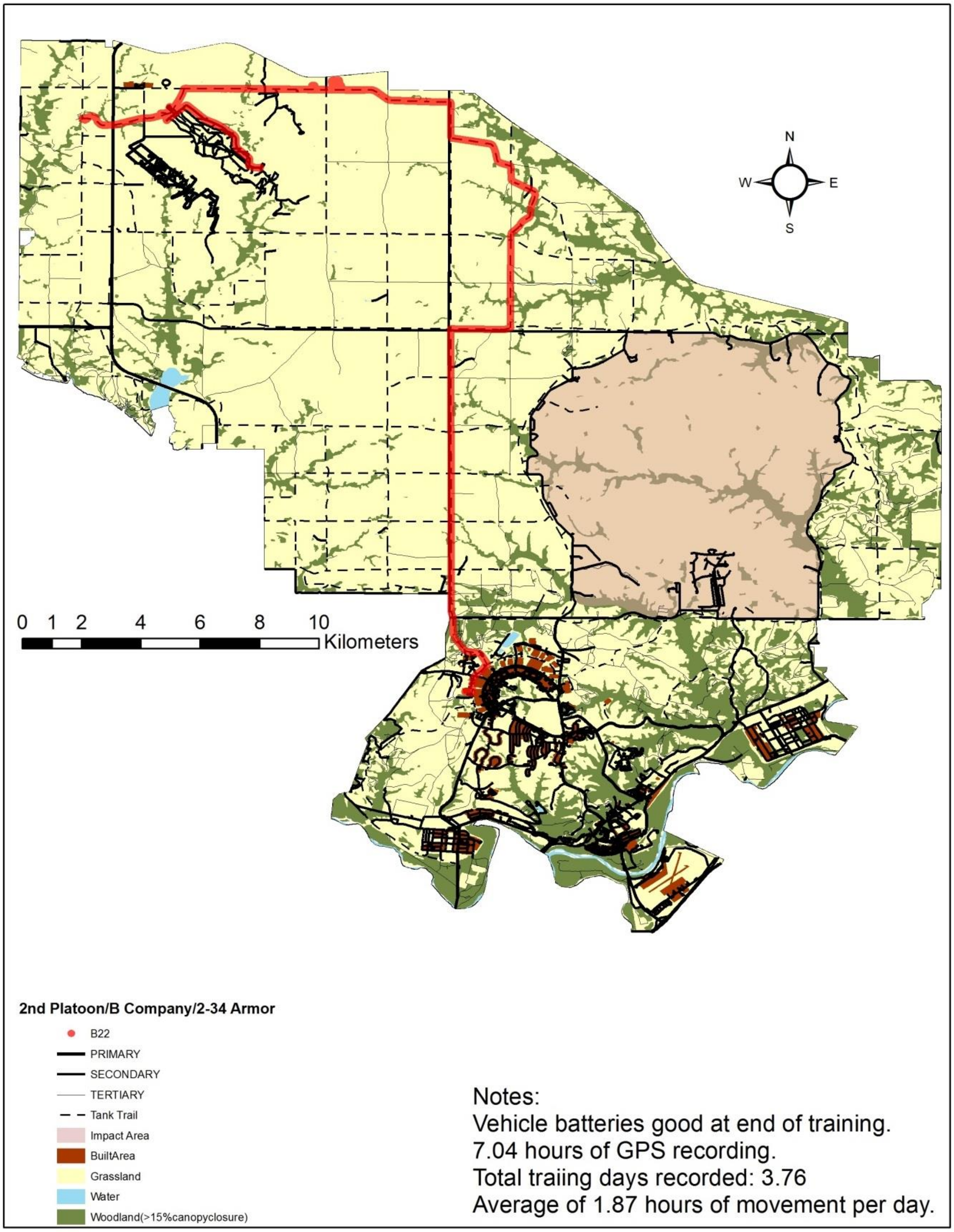


Figure B-53 GPS Points B23 2-34 Armor Battalion

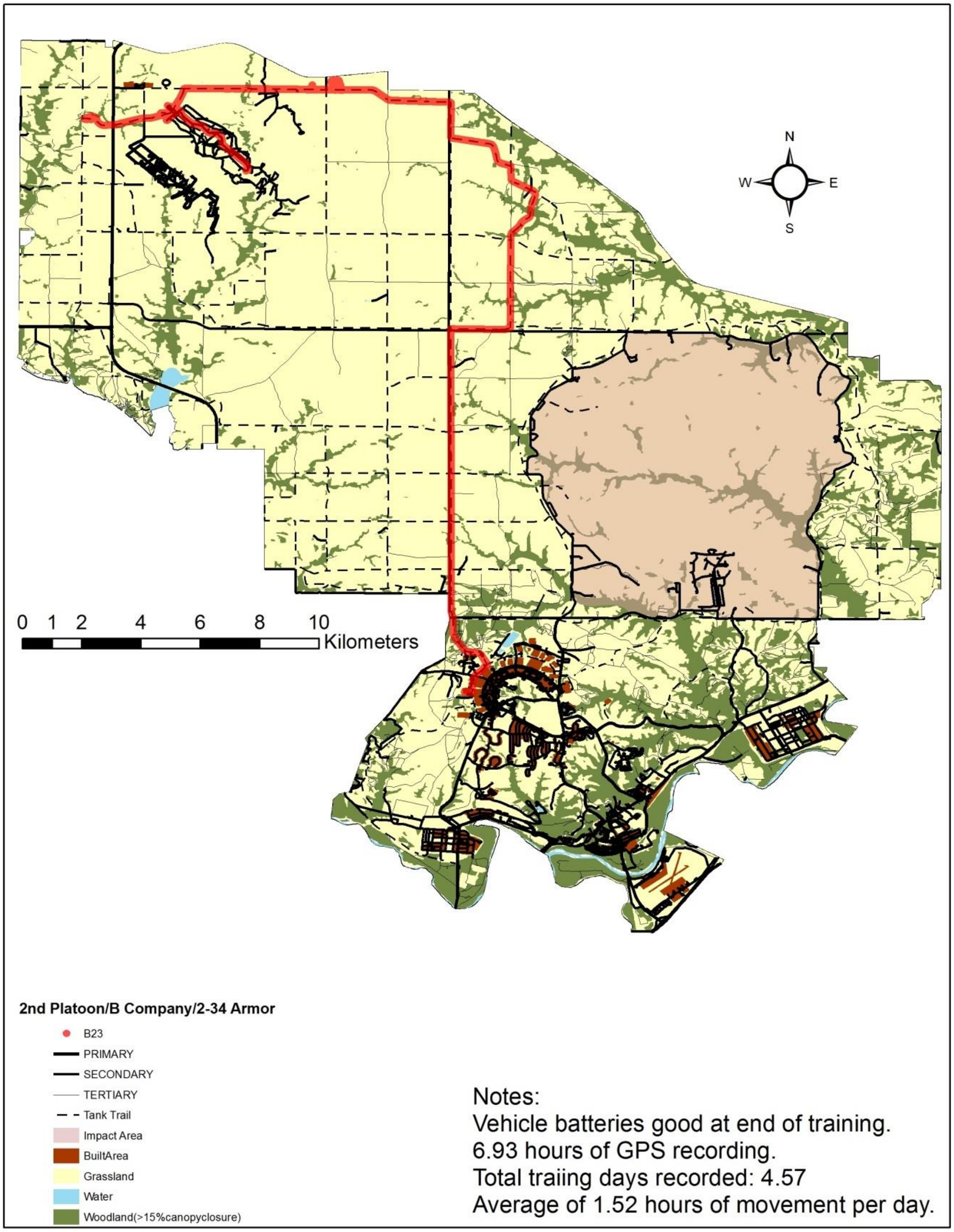


Figure B-54 GPS Points B24 2-34 Armor Battalion

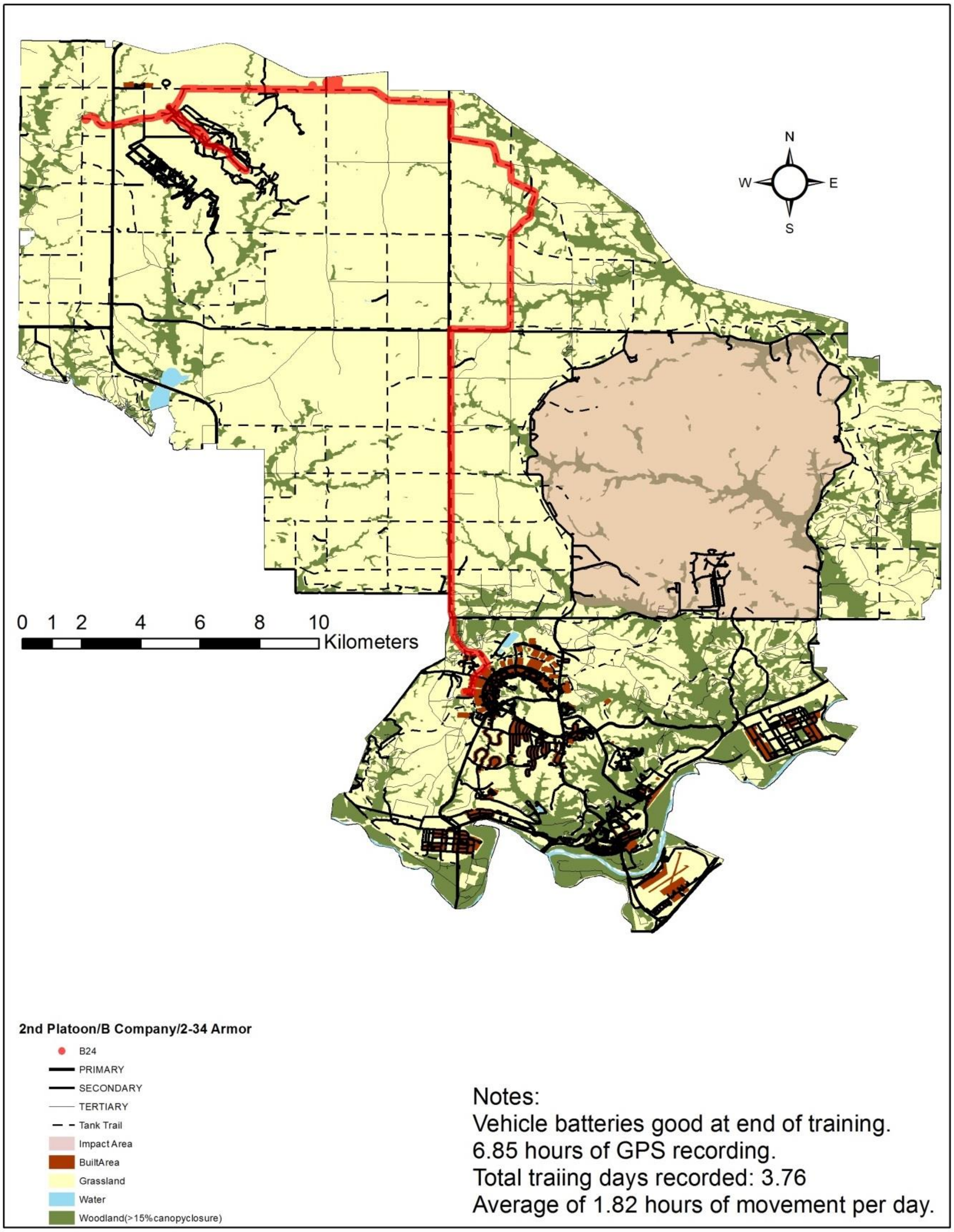


Figure B-55 GPS Points B30 2-34 Armor Battalion

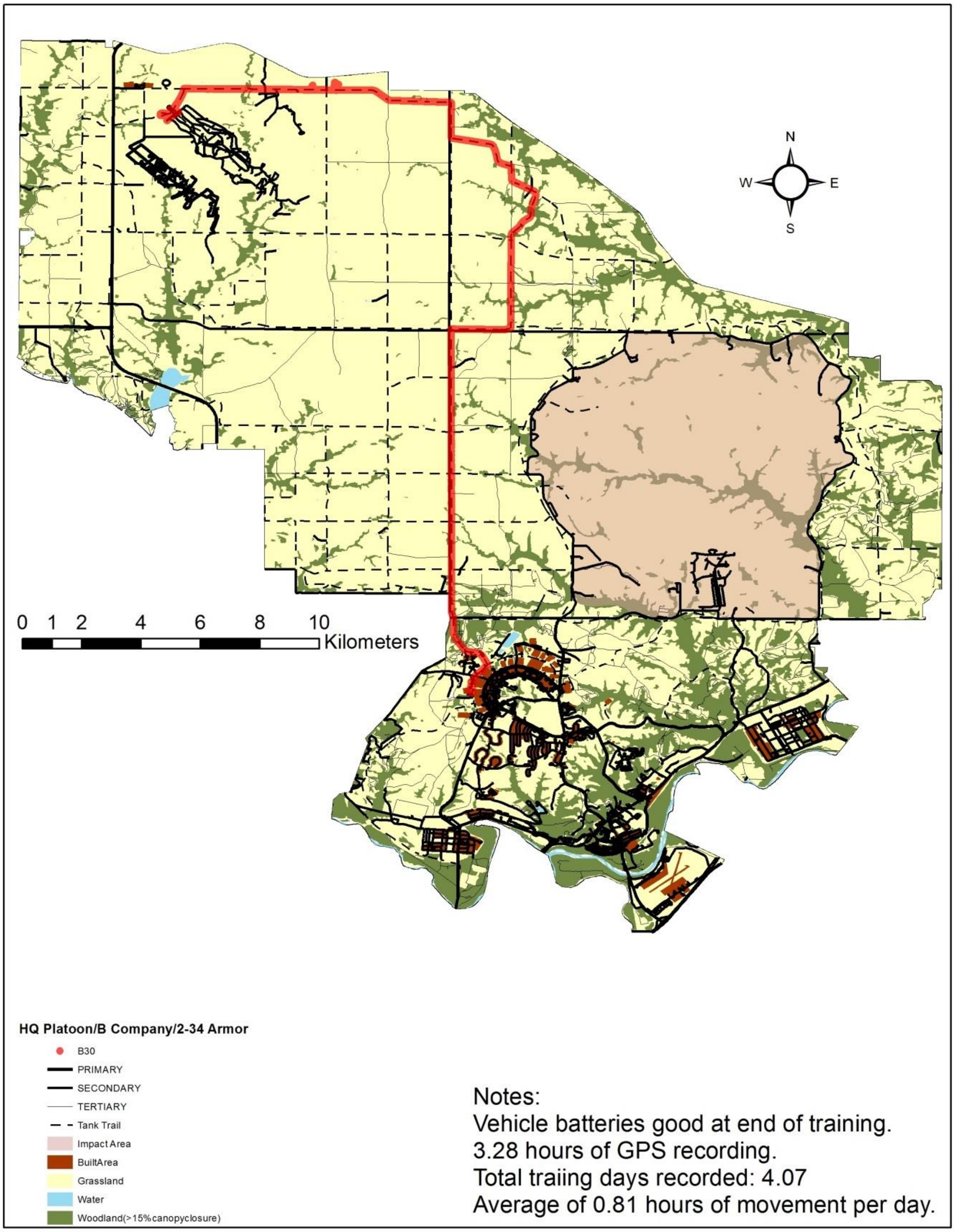


Figure B-56 GPS Points B31 2-34 Armor Battalion

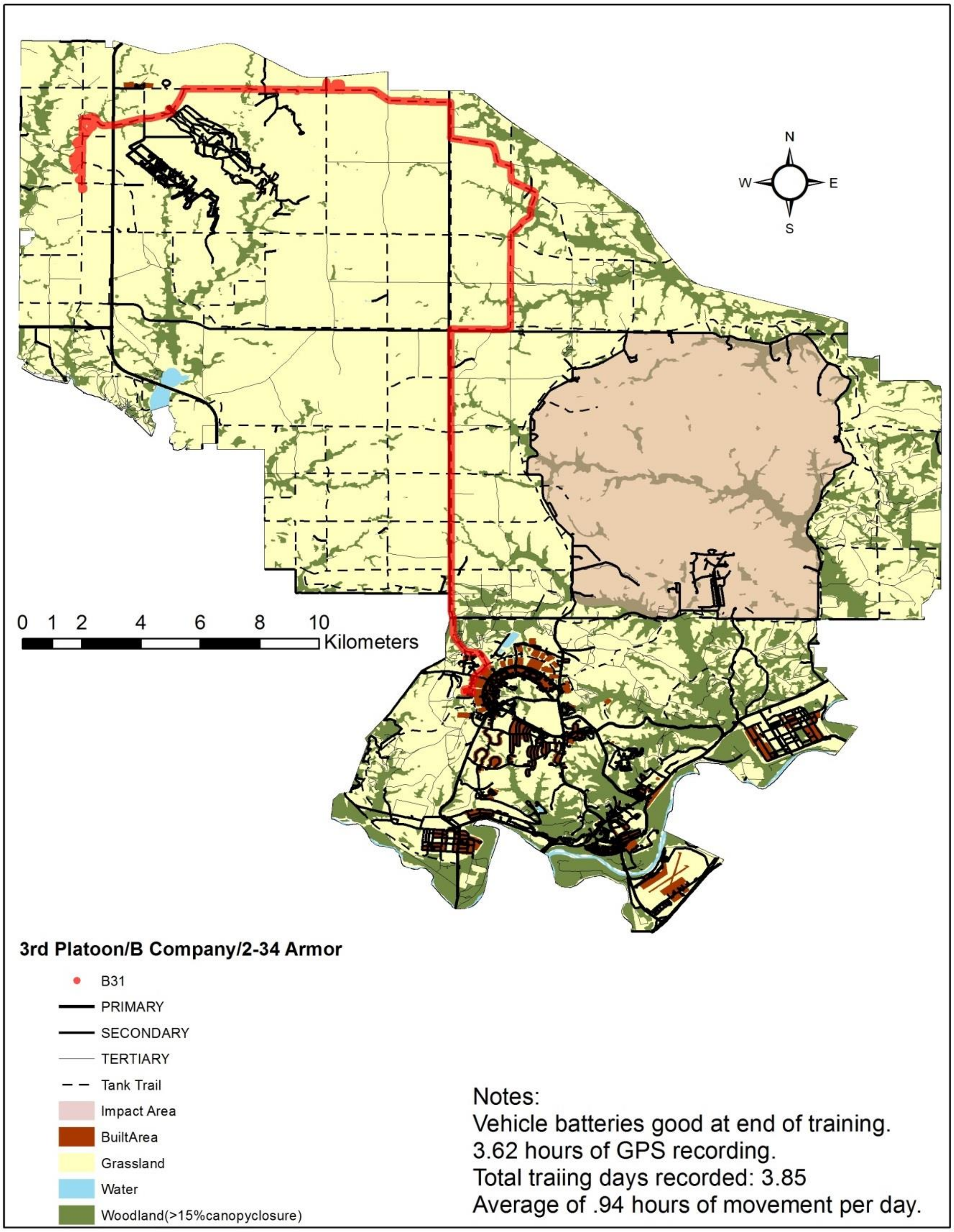


Figure B-57 GPS Points B32 2-34 Armor Battalion

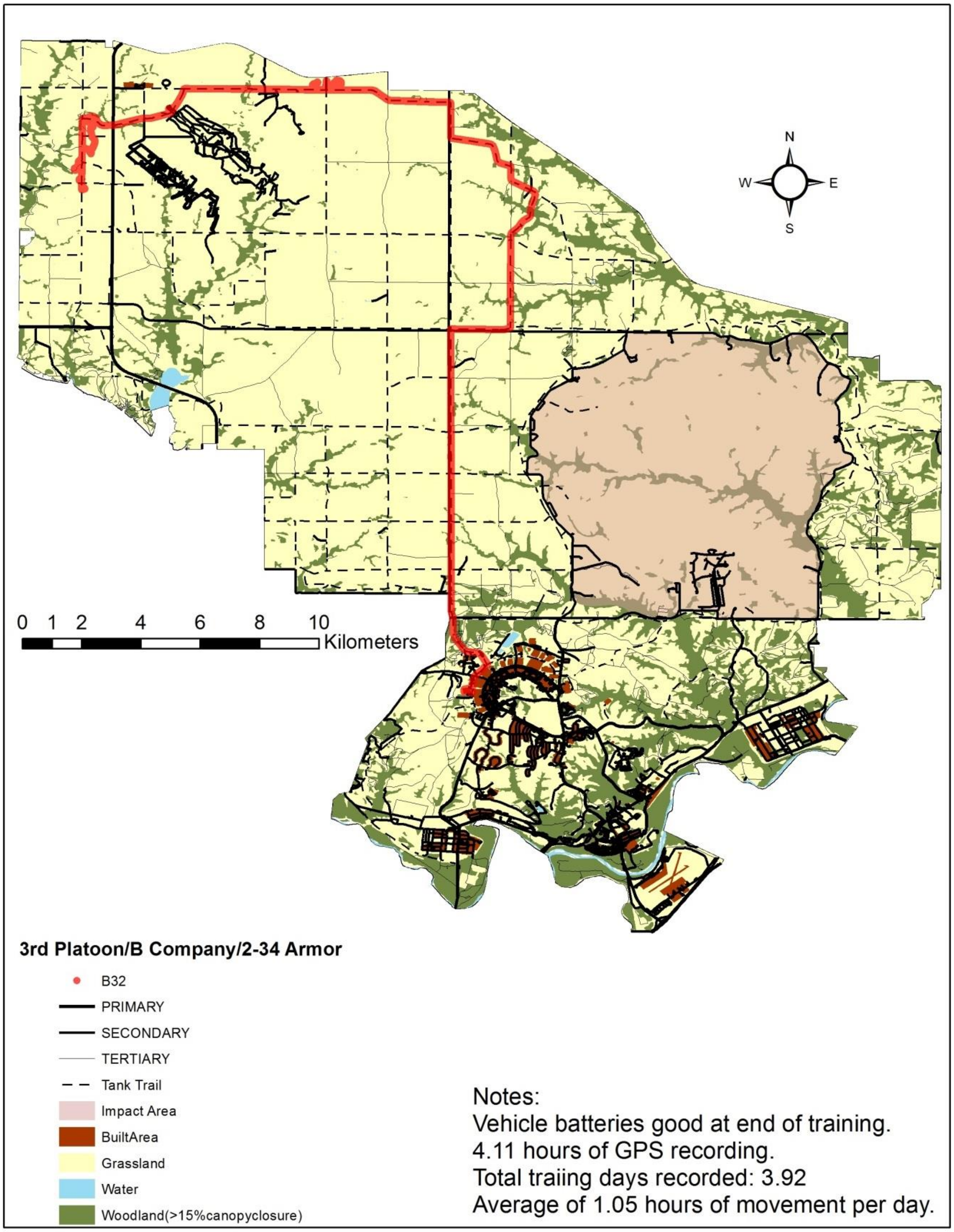


Figure B-58 GPS Points B33 2-34 Armor Battalion

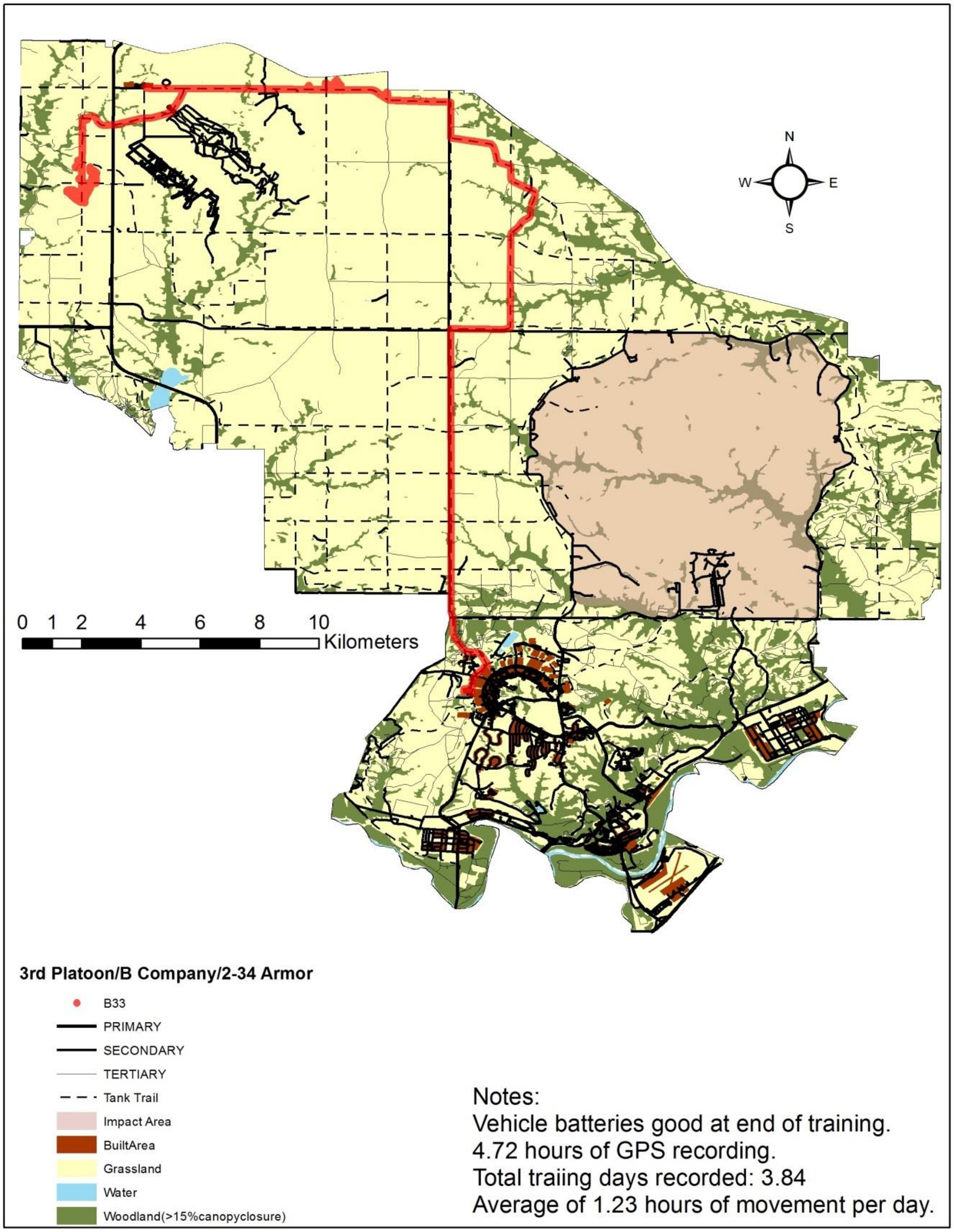


Figure B-59 GPS Points B34 2-34 Armor Battalion

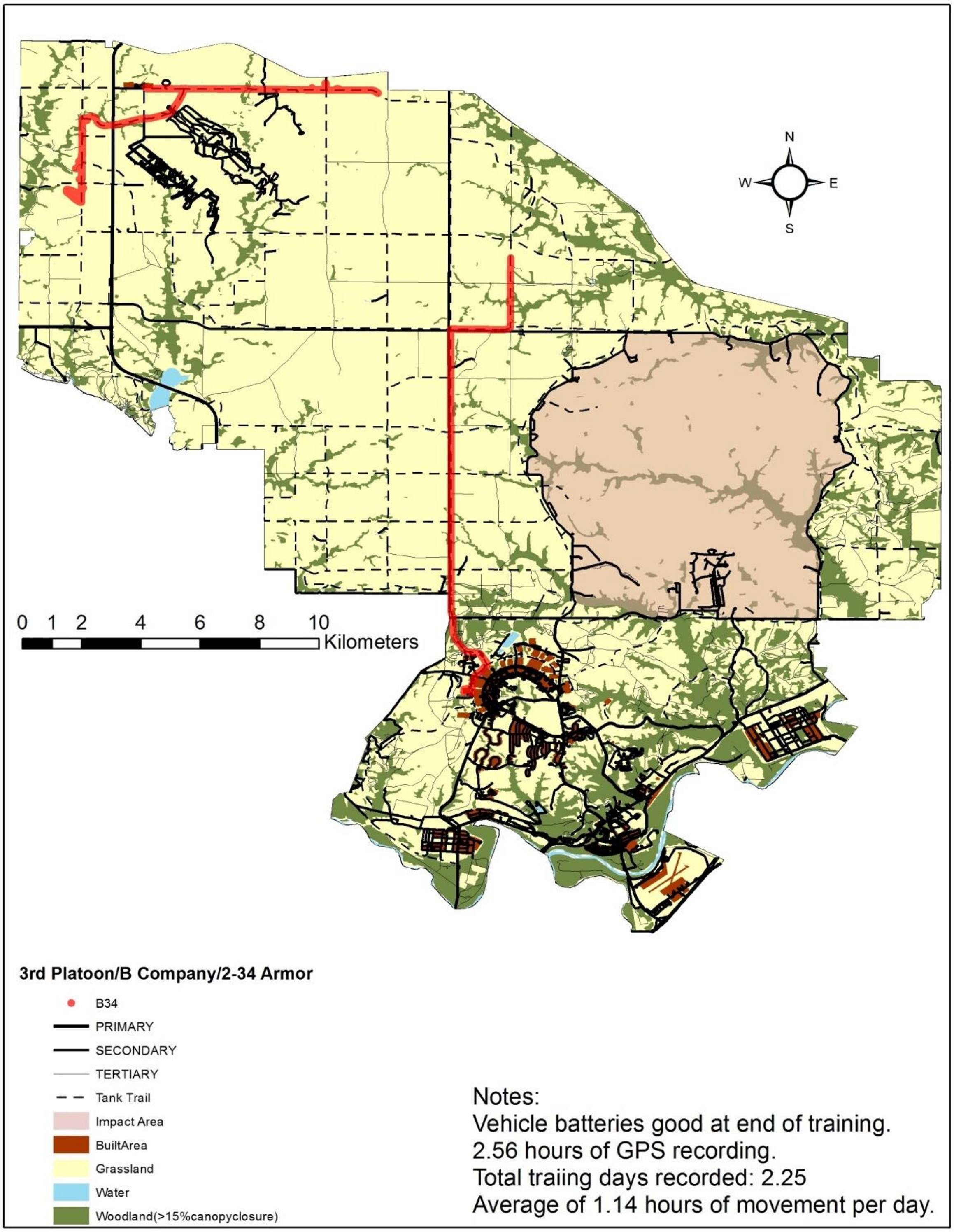


Figure B-60 GPS Points C11 2-34 Armor Battalion

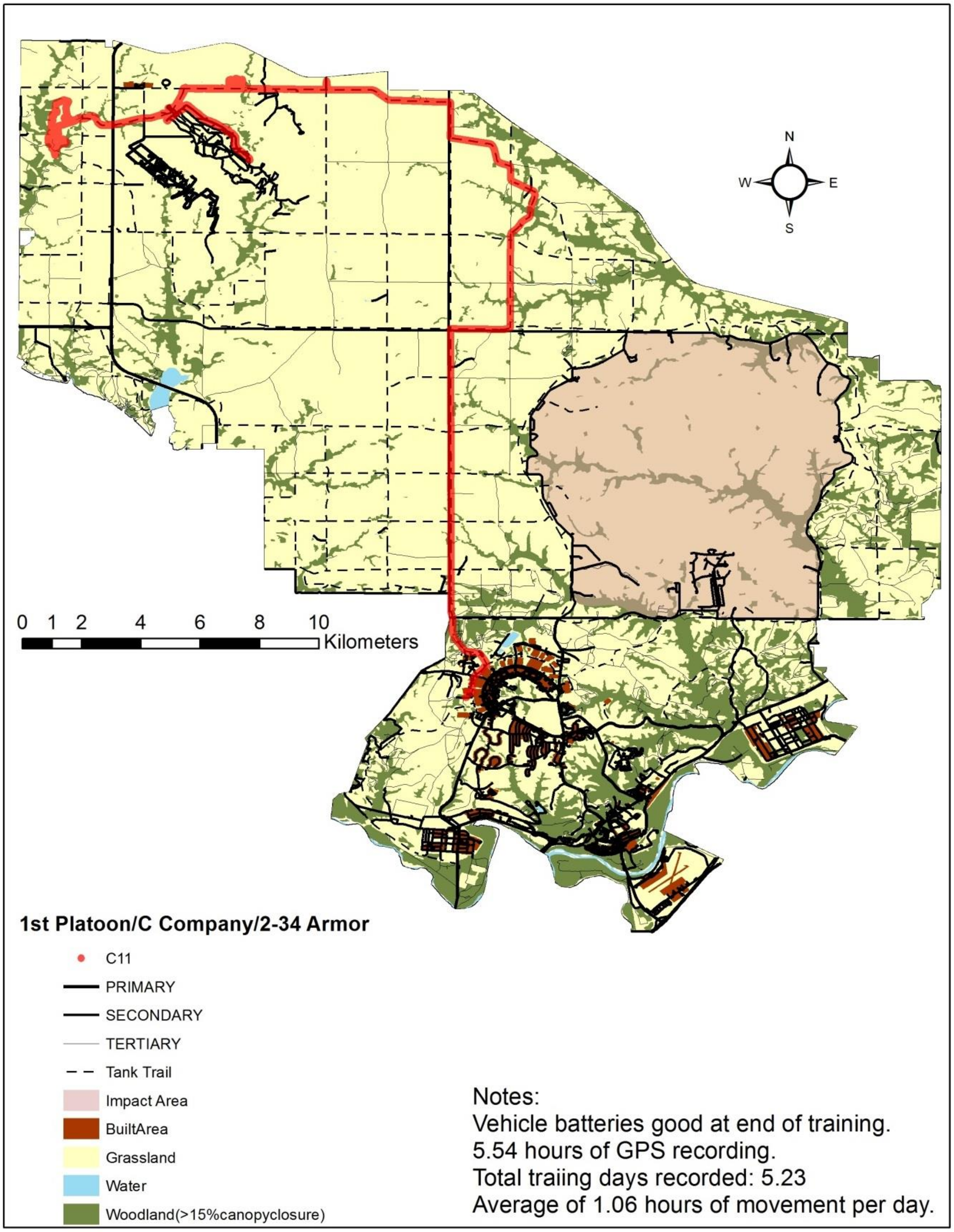


Figure B-61 GPS Points C13 2-34 Armor Battalion

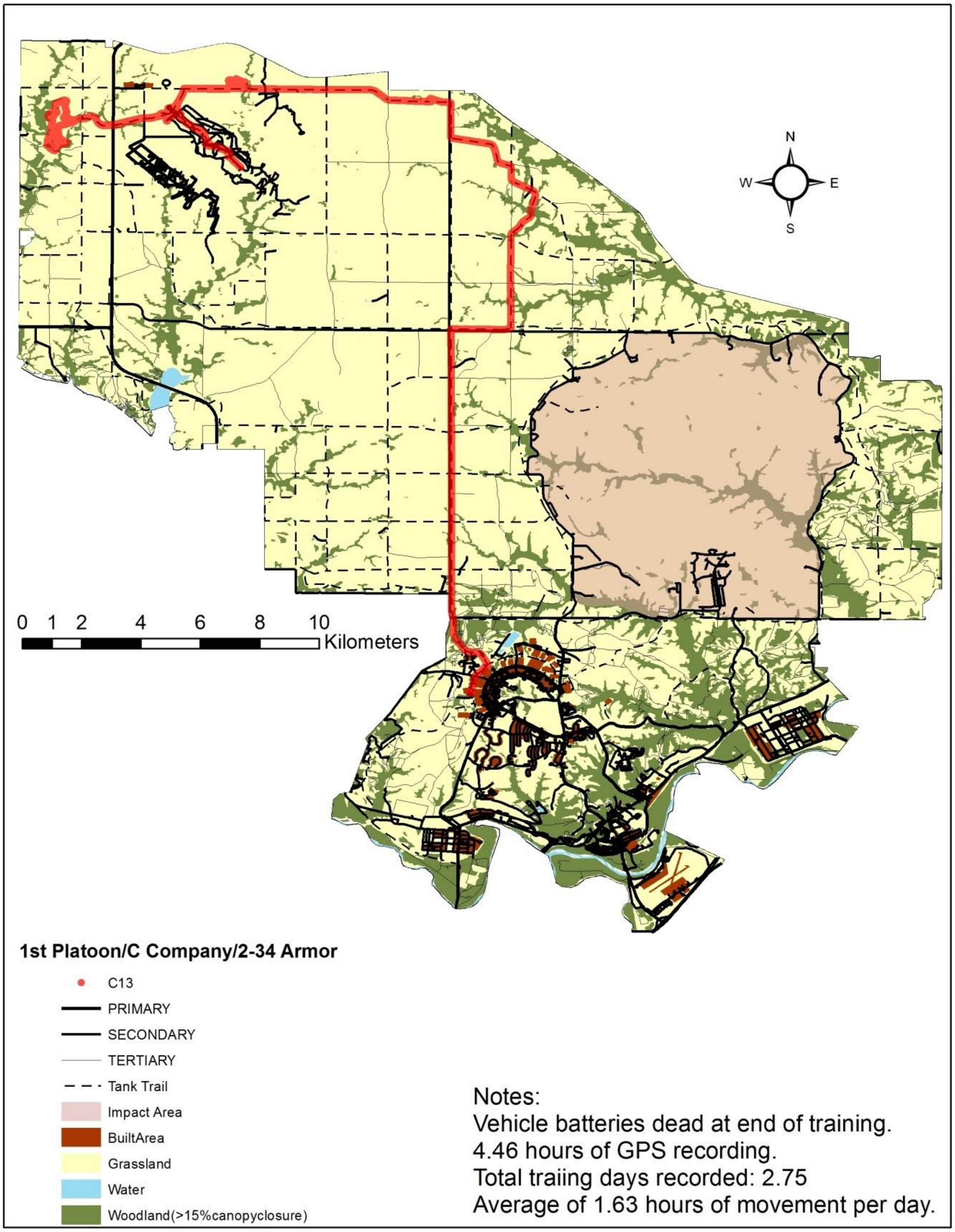


Figure B-62 GPS Points C14 2-34 Armor Battalion

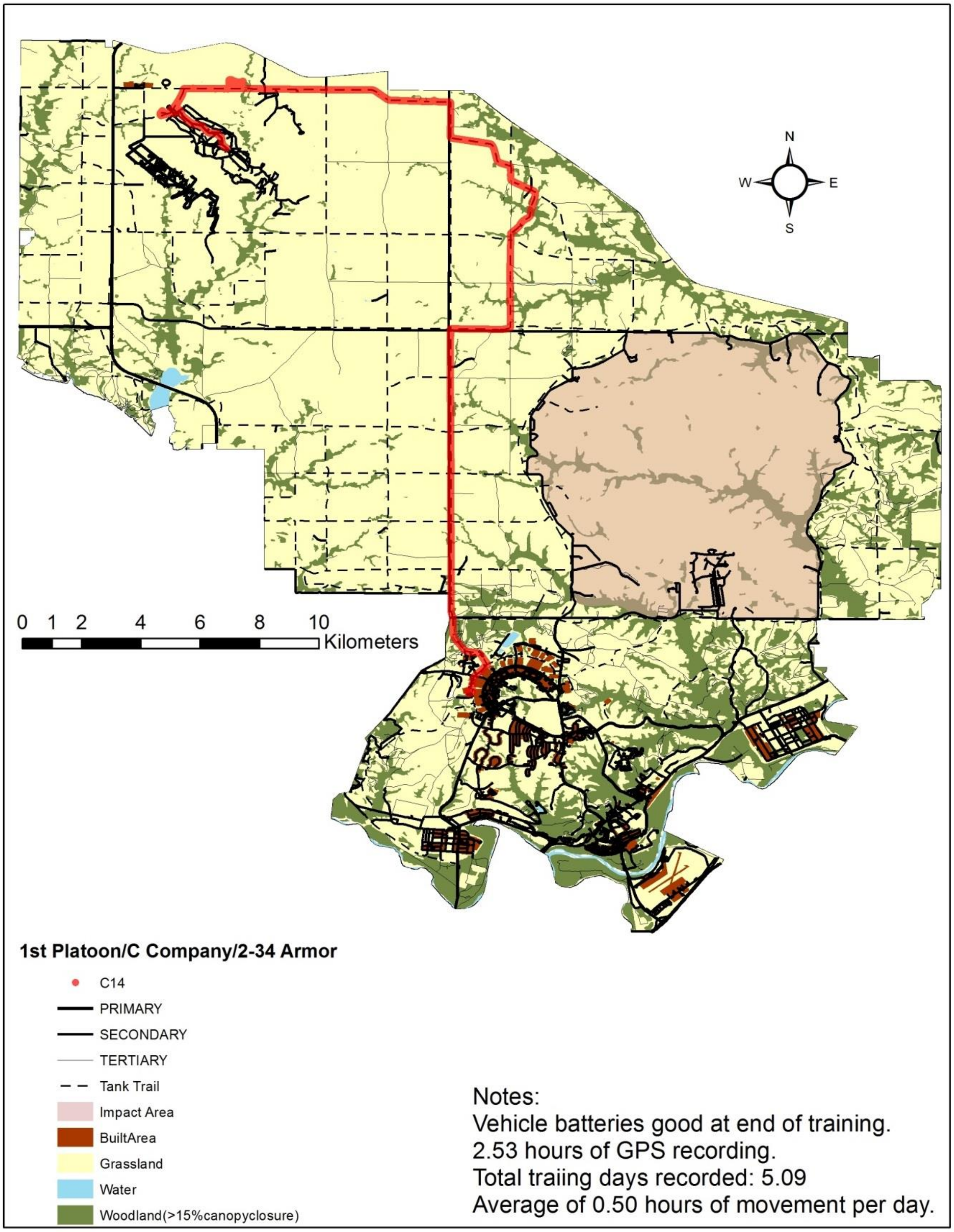


Figure B-63 GPS Points C21 2-34 Armor Battalion

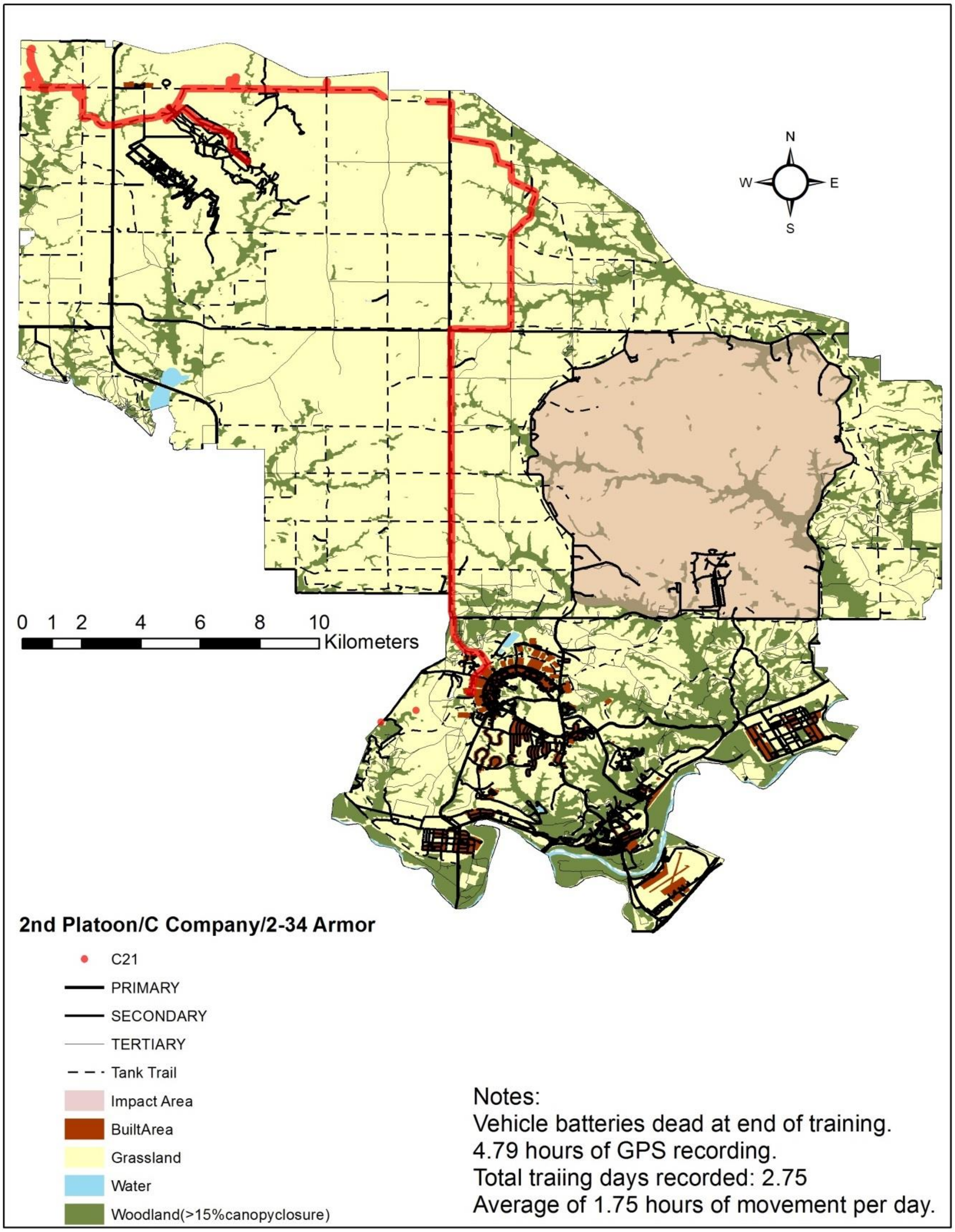


Figure B-64 GPS Points C22 2-34 Armor Battalion

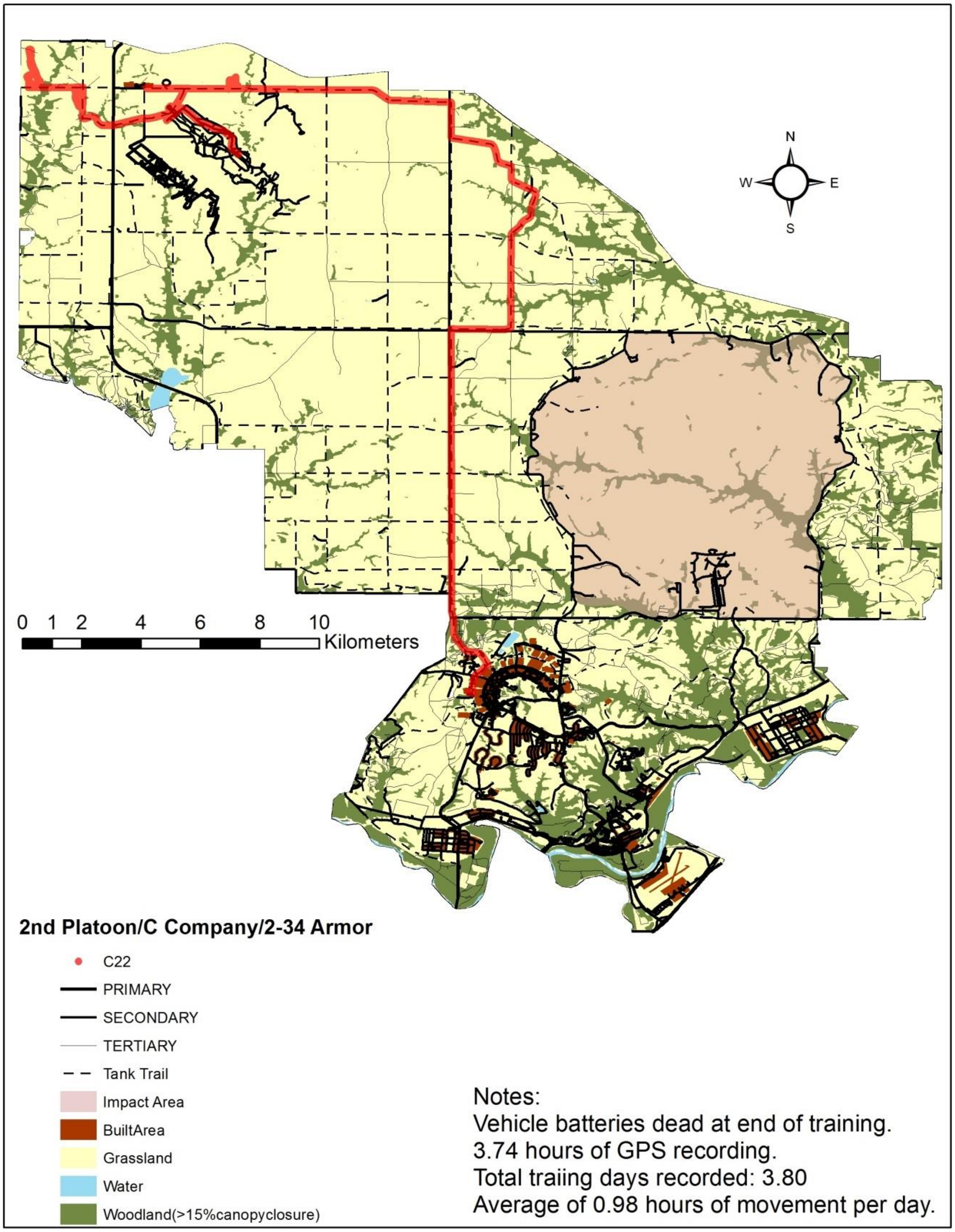


Figure B-65 GPS Points C23 2-34 Armor Battalion

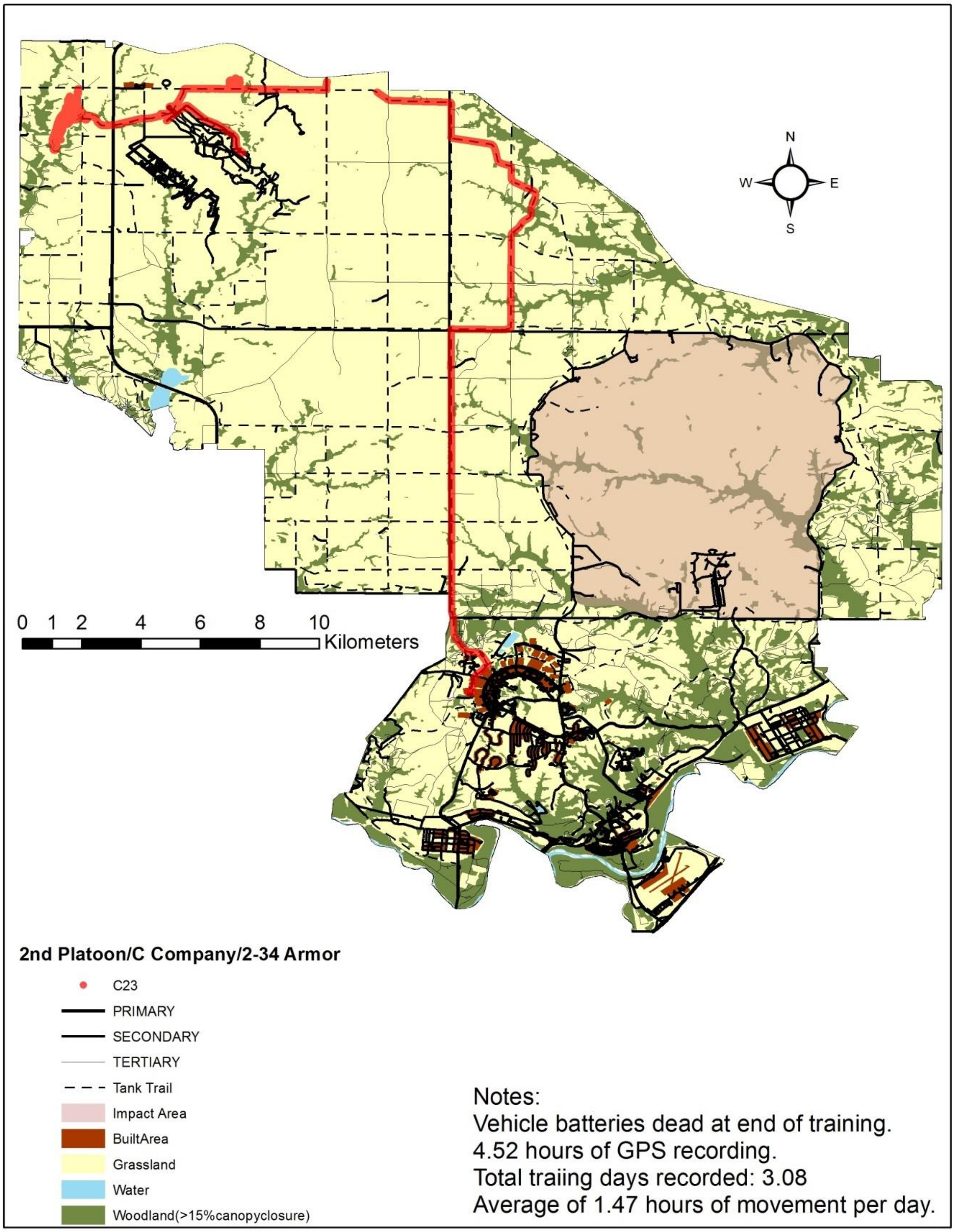


Figure B-66 GPS Points C24 2-34 Armor Battalion

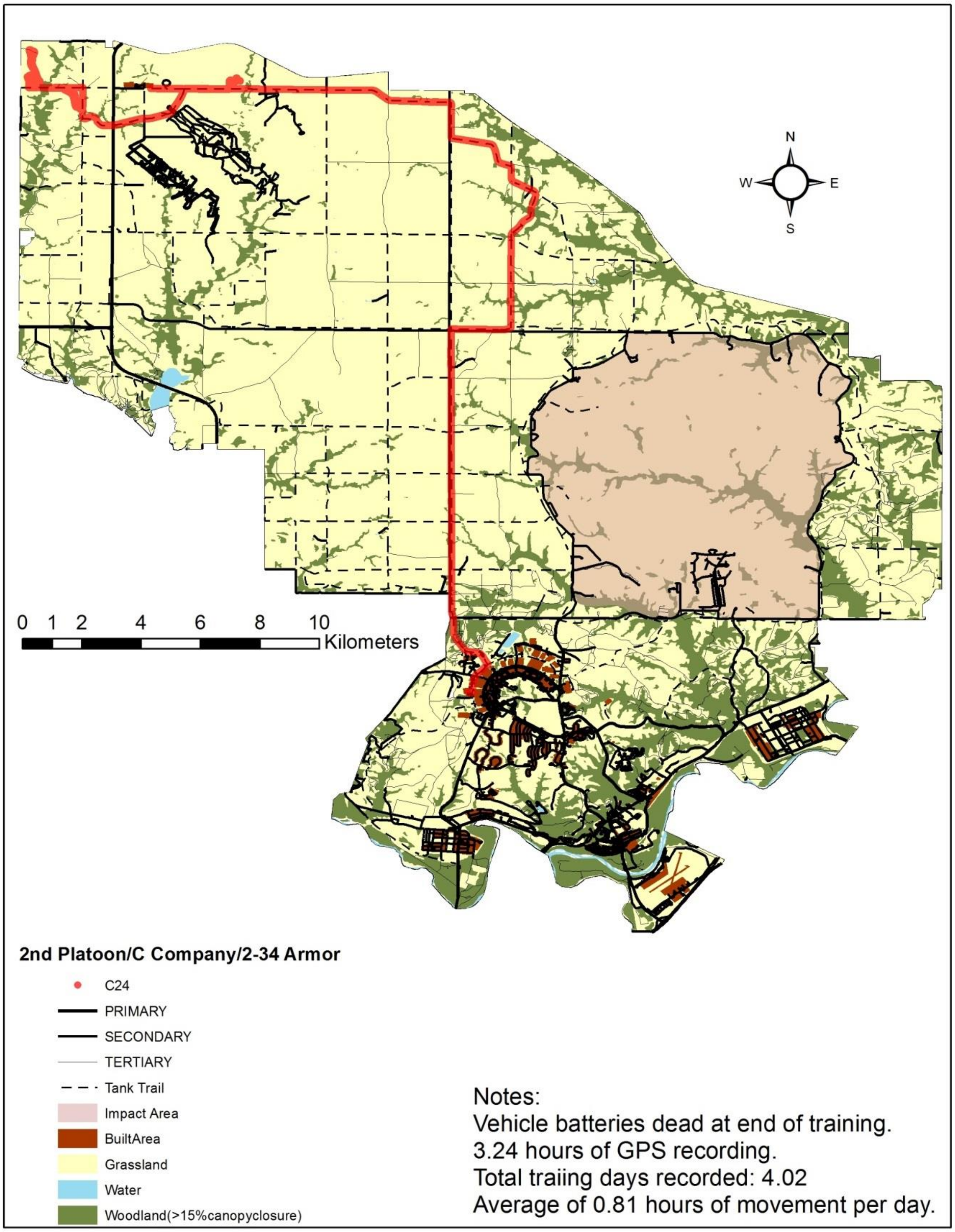


Figure B-67 GPS Points C30 2-34 Armor Battalion

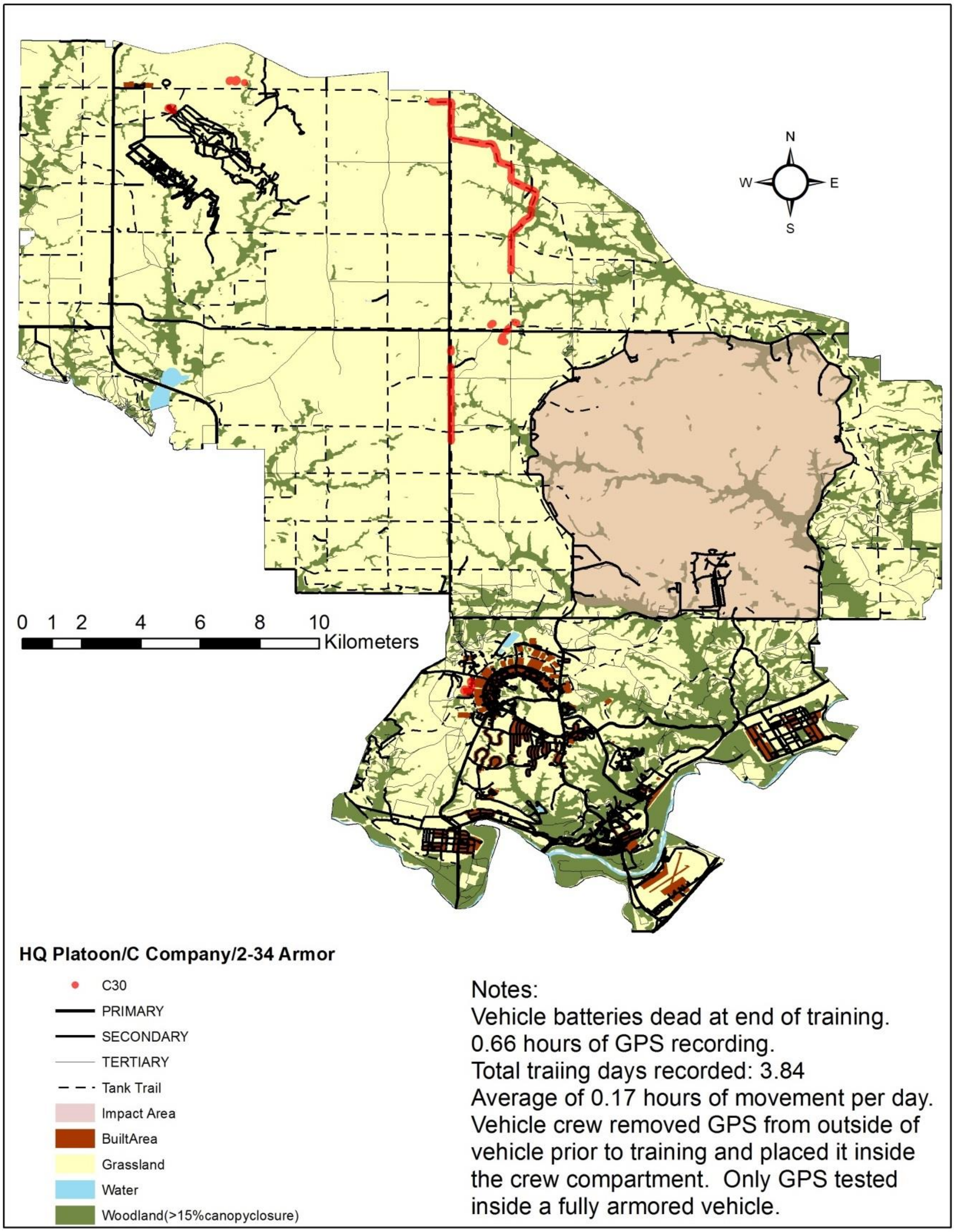


Figure B-68 GPS Points C31 2-34 Armor Battalion

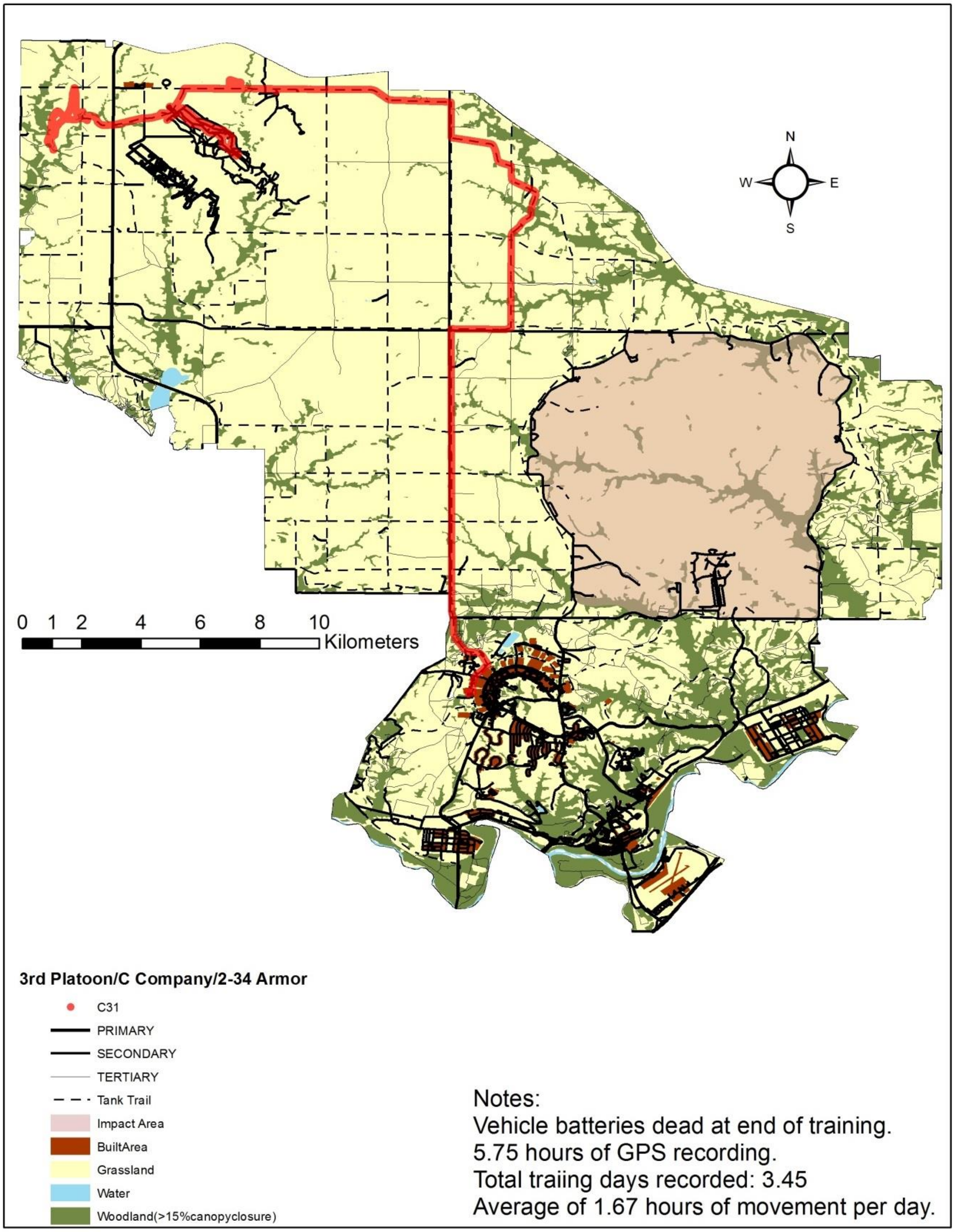


Figure B-69 GPS Points C32 2-34 Armor Battalion

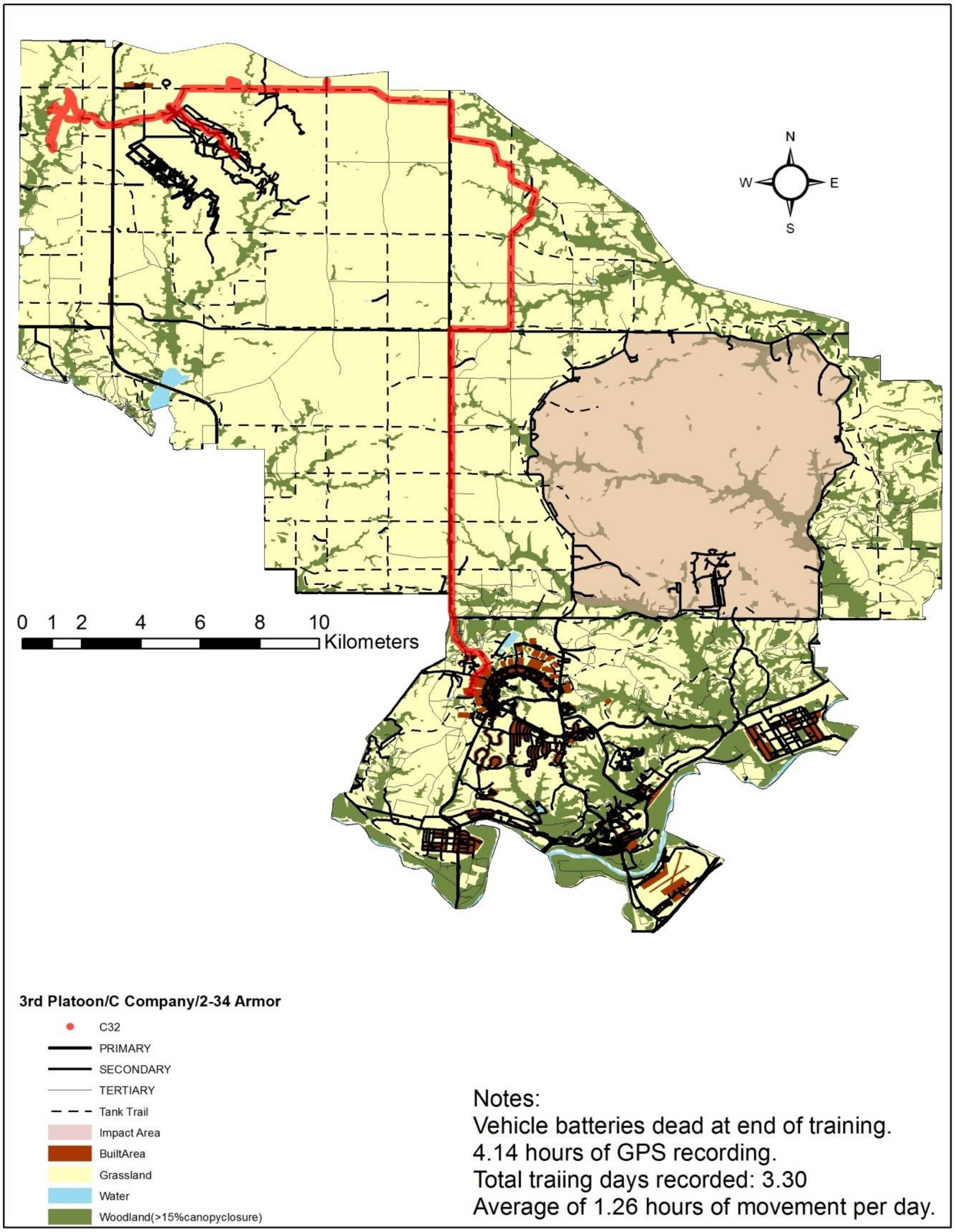


Figure B-70 GPS Points C33 2-34 Armor Battalion

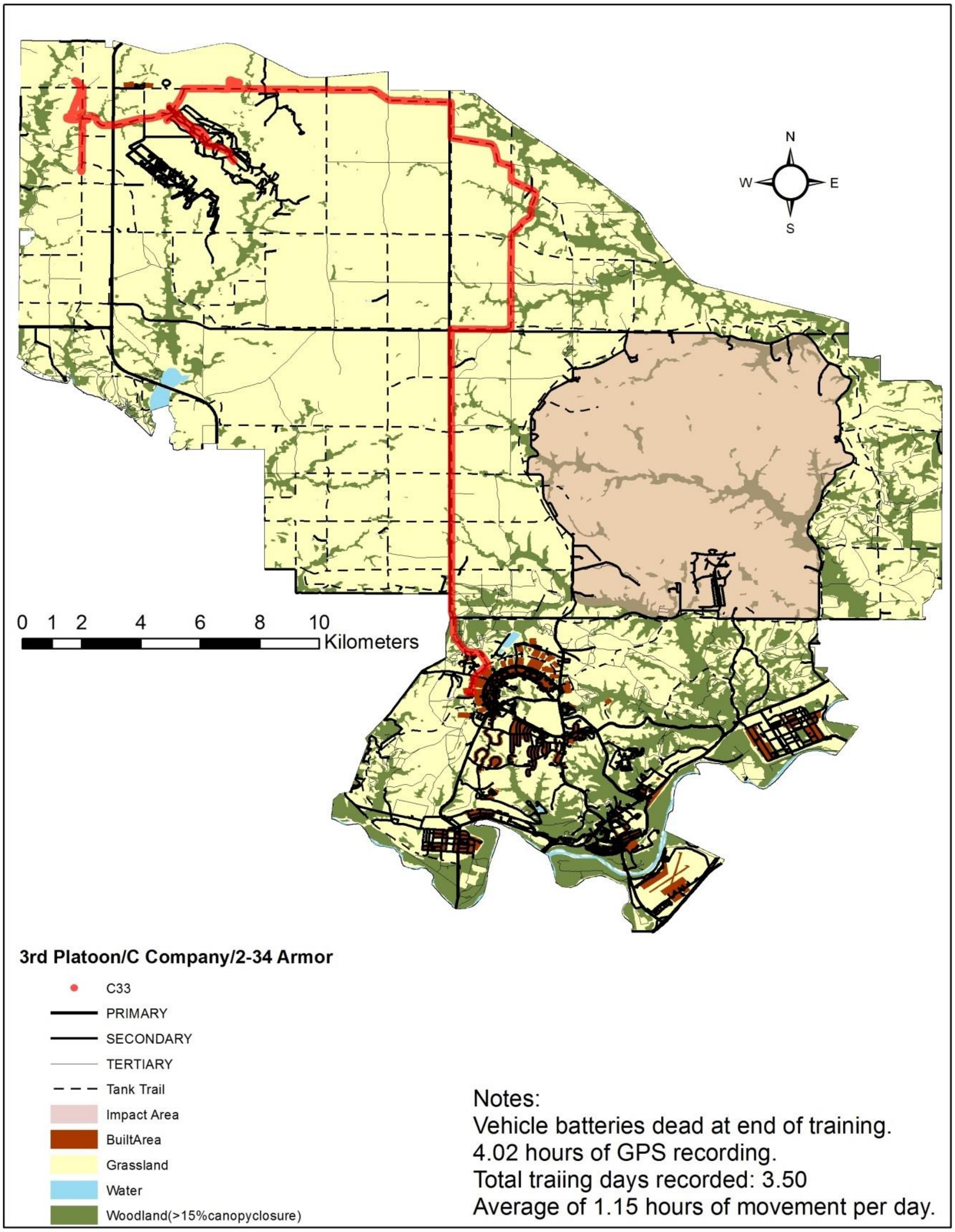


Figure B-71 GPS Points C34 2-34 Armor Battalion

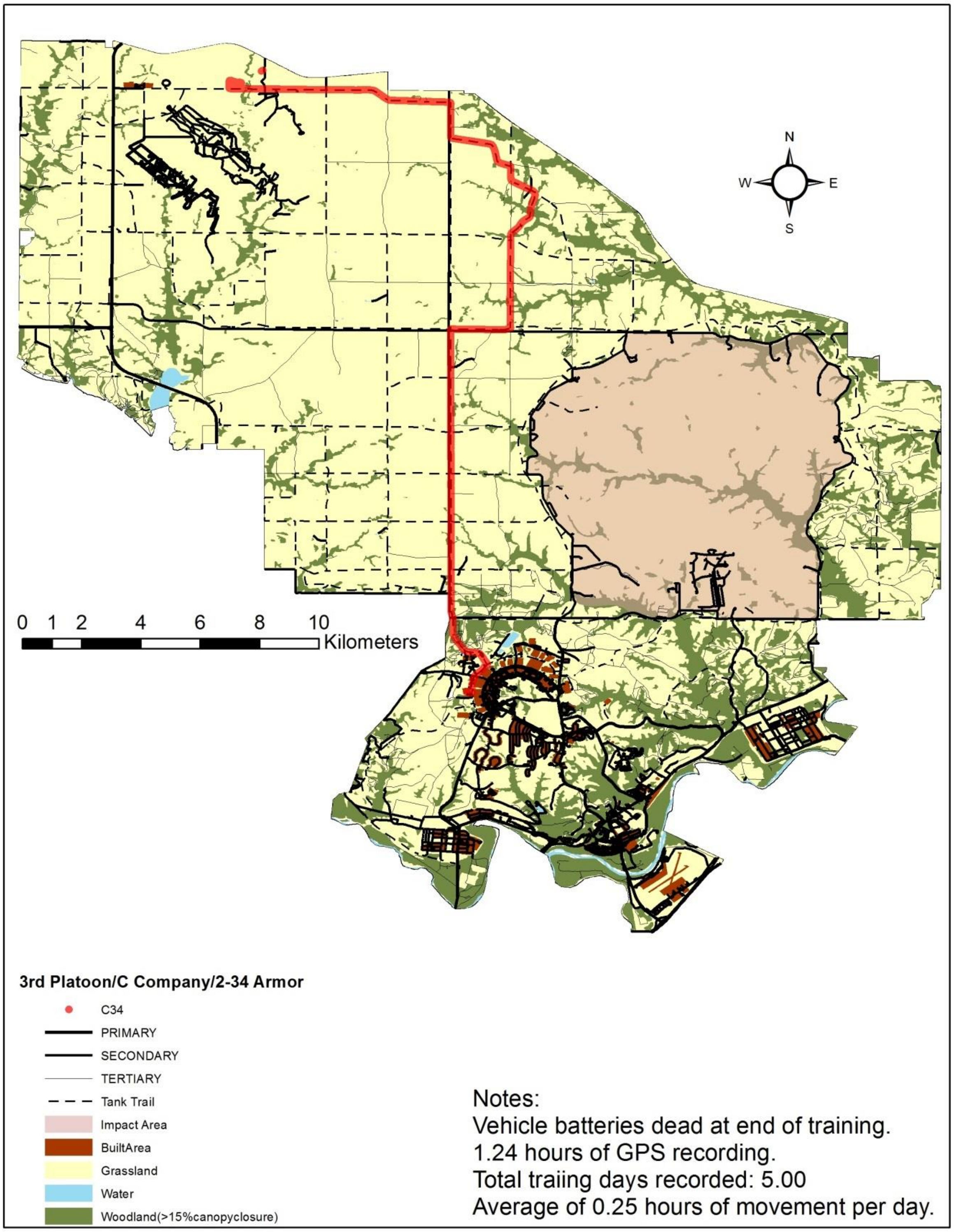


Figure B-72 GPS Points C66 2-34 Armor Battalion

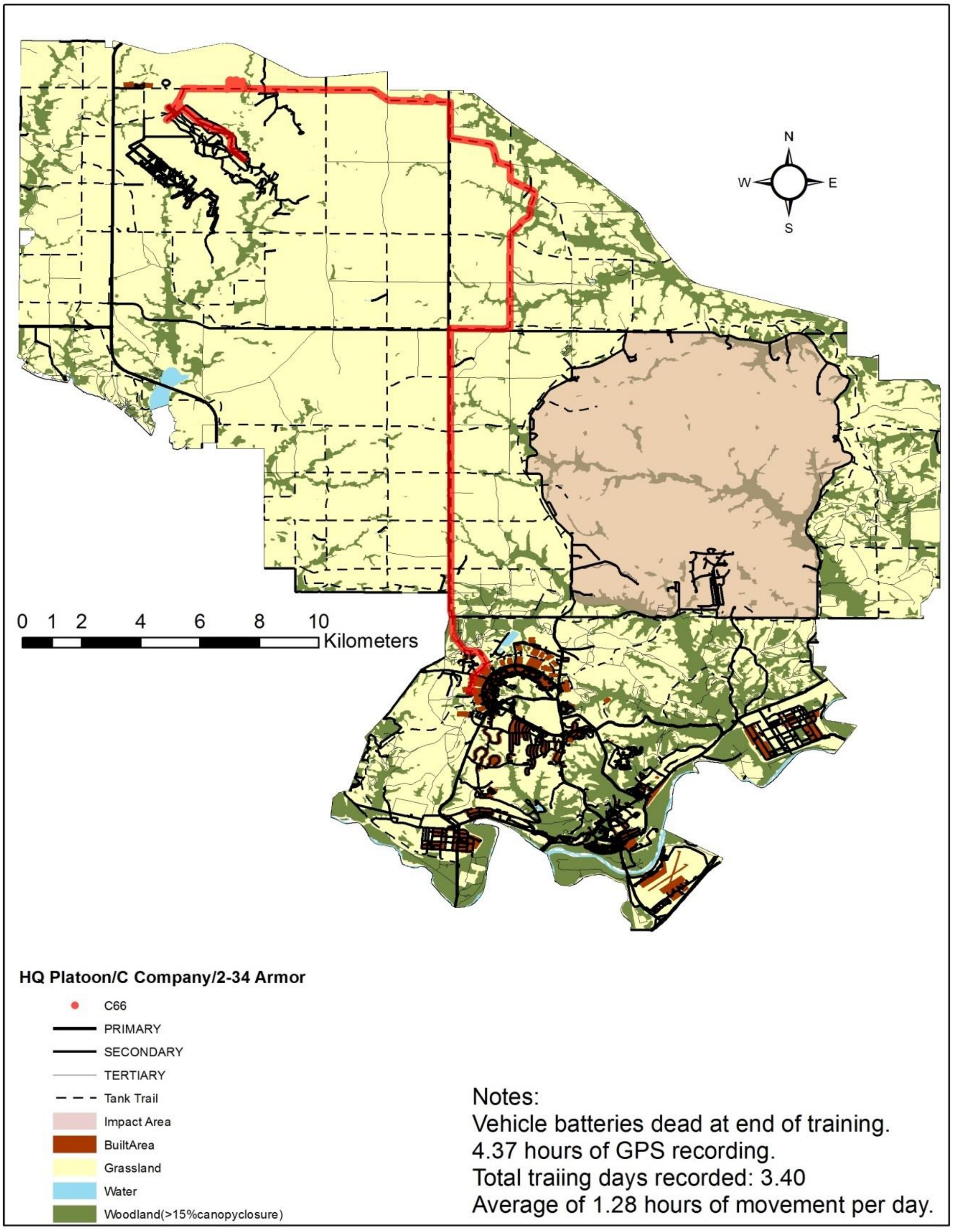


Figure B-73 GPS Points D6 2-34 Armor Battalion

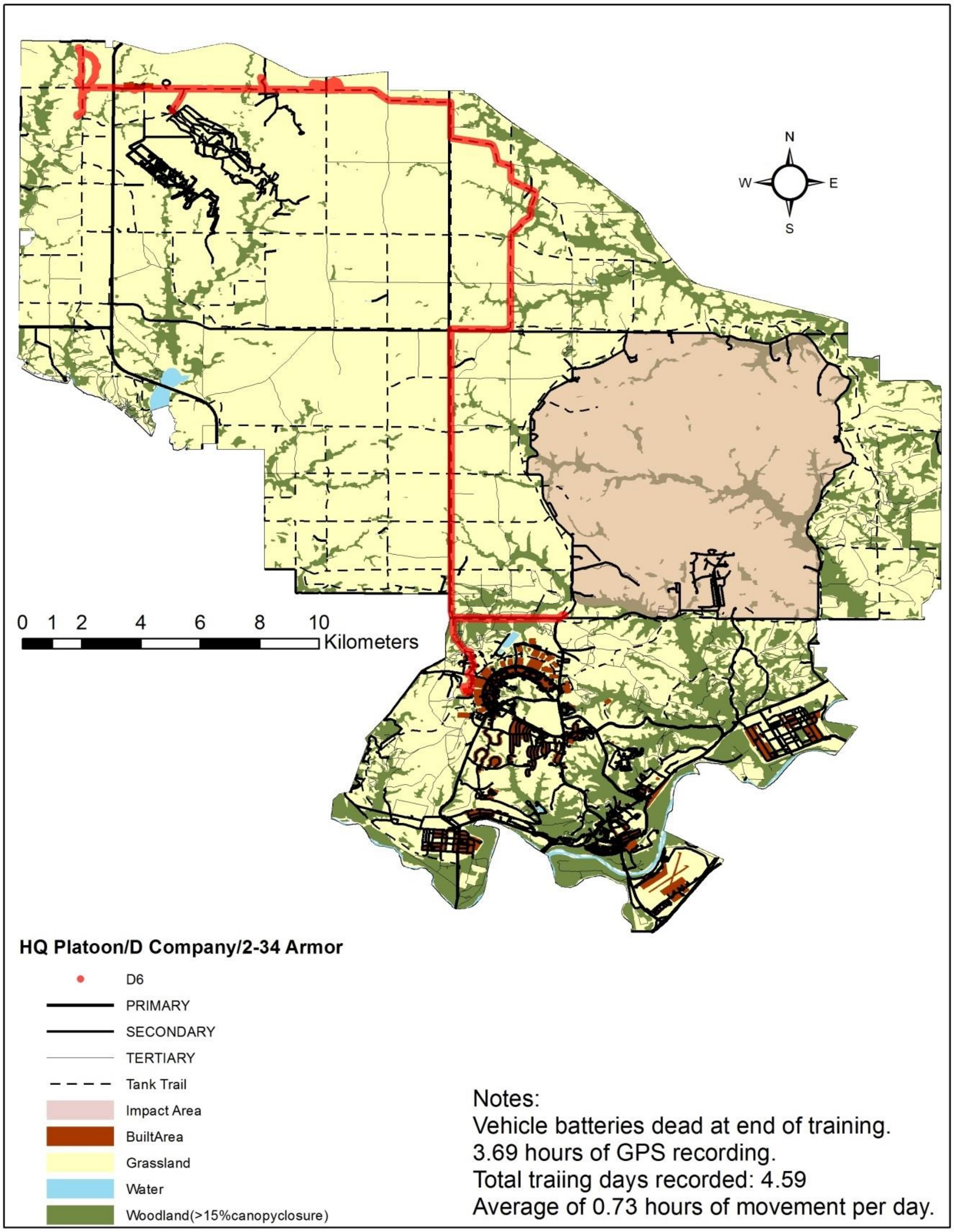


Figure B-74 GPS Points D11 2-34 Armor Battalion

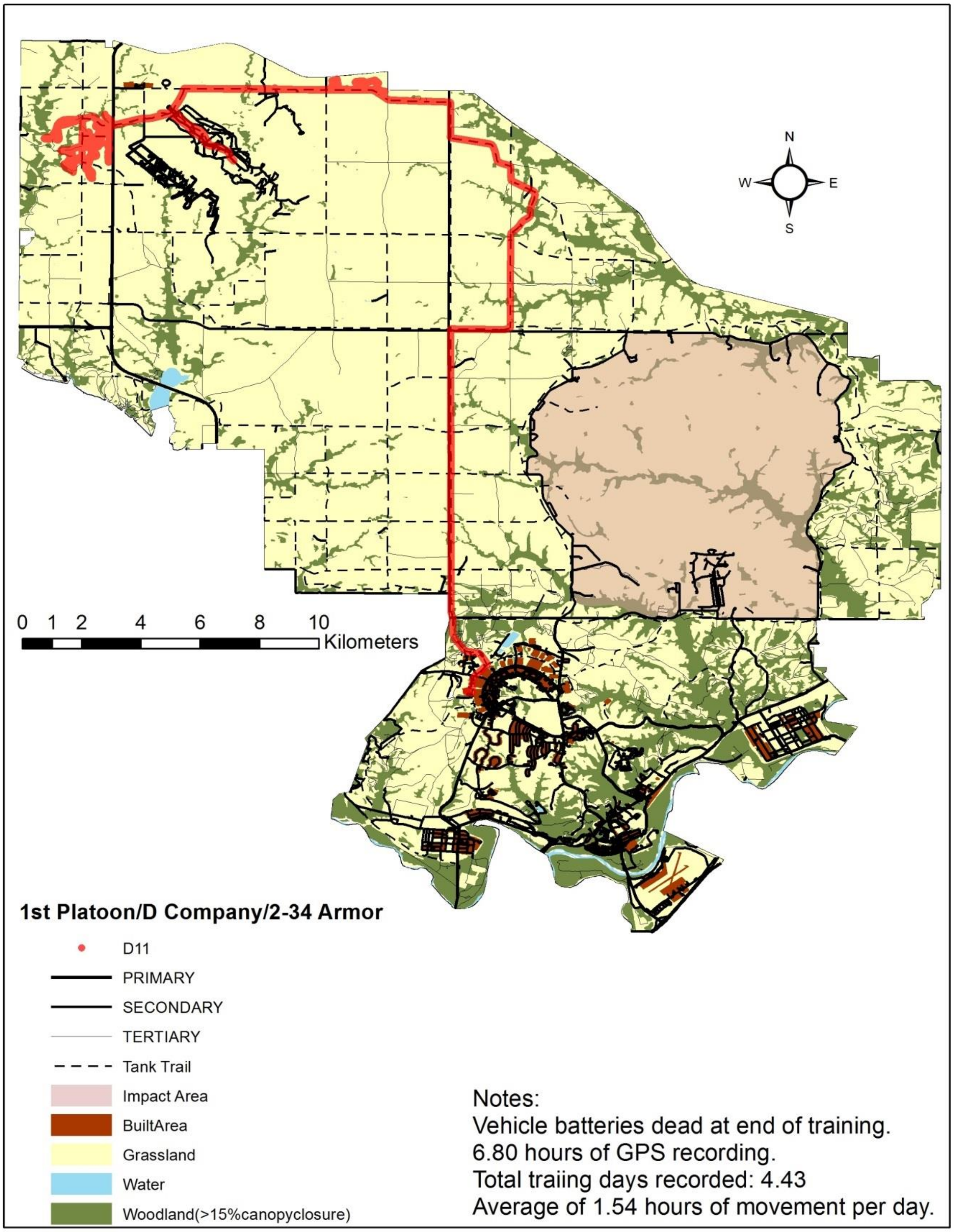


Figure B-75 GPS Points D12 2-34 Armor Battalion

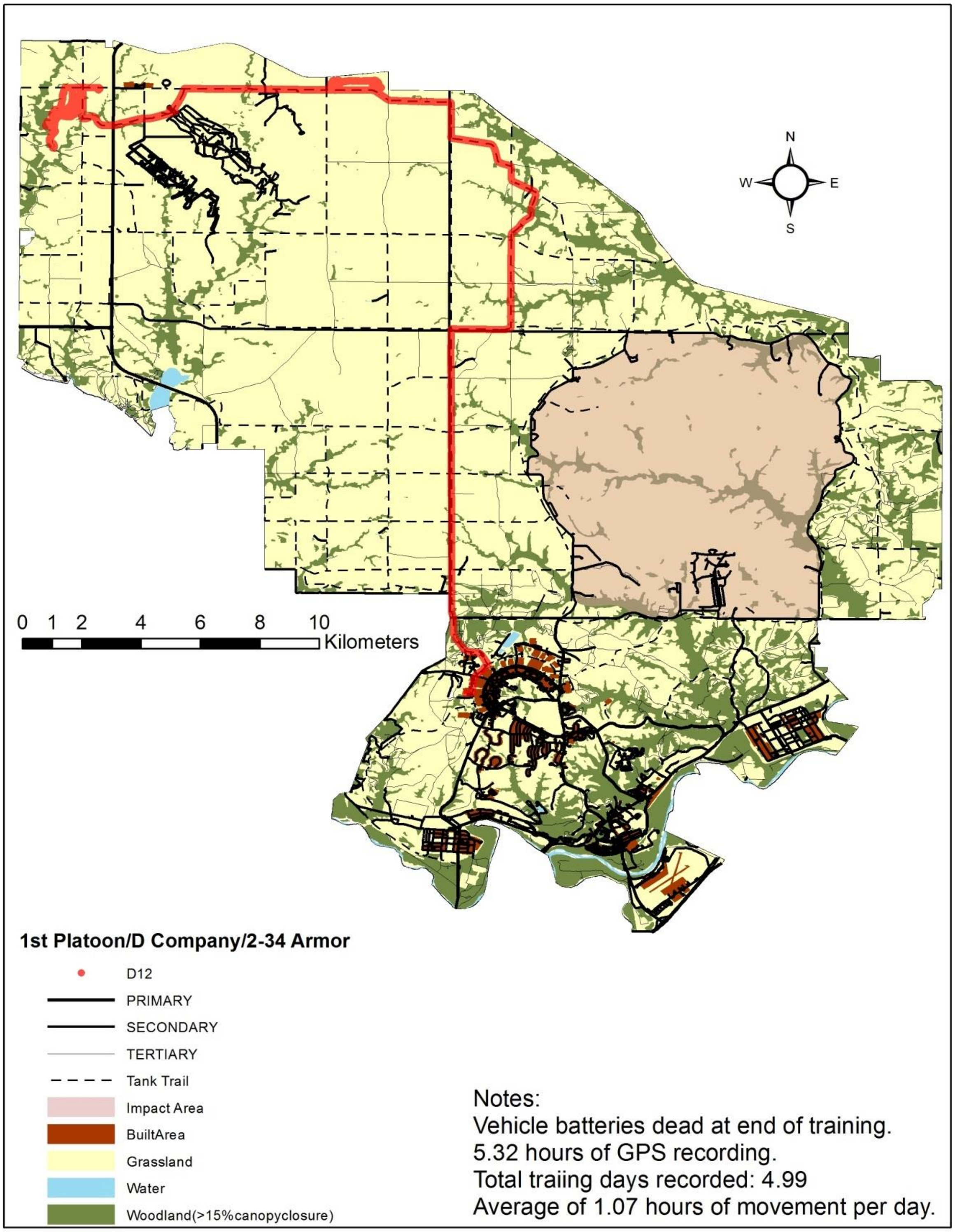


Figure B-76 GPS Points D14 2-34 Armor Battalion

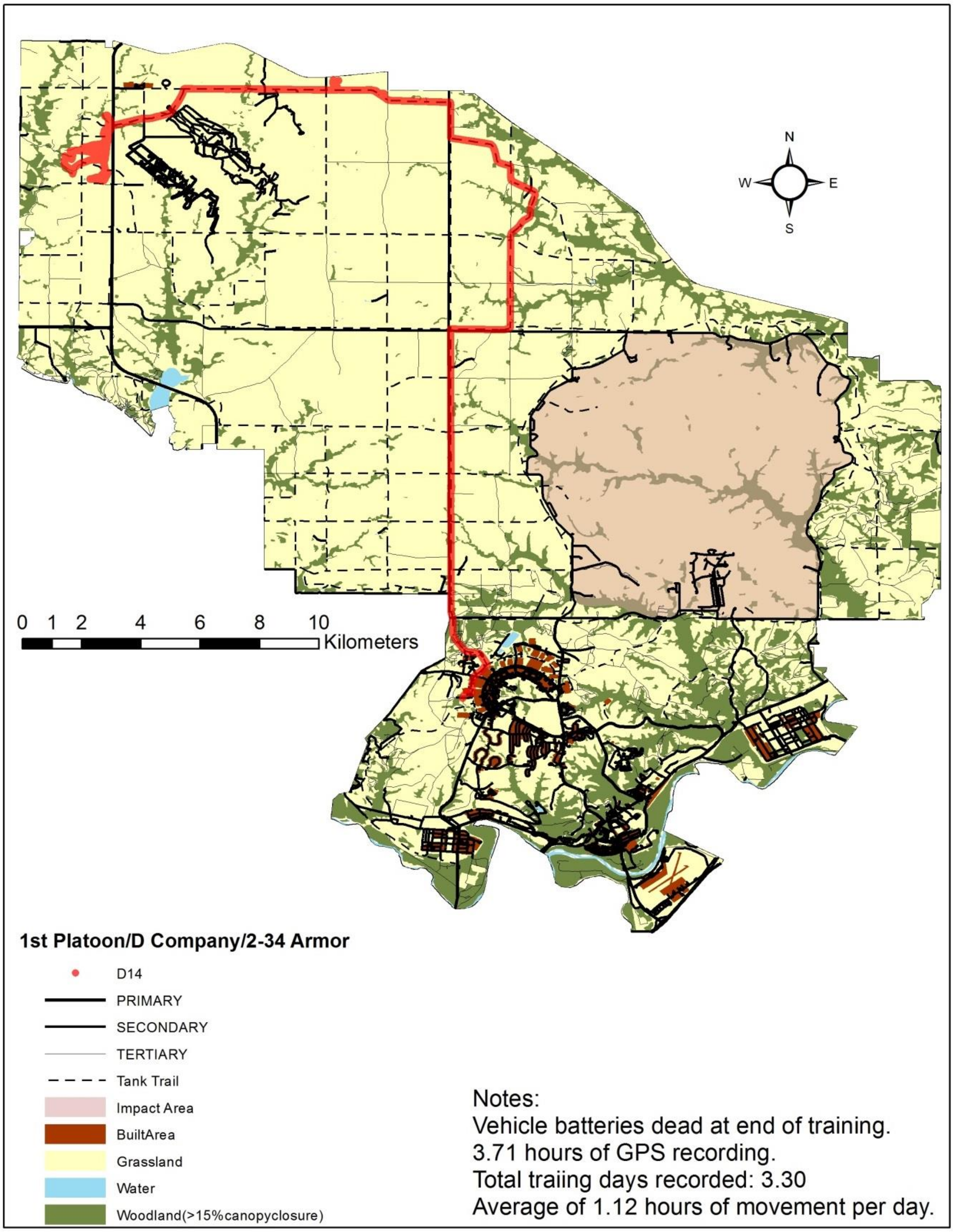


Figure B-77 GPS Points D21 2-34 Armor Battalion

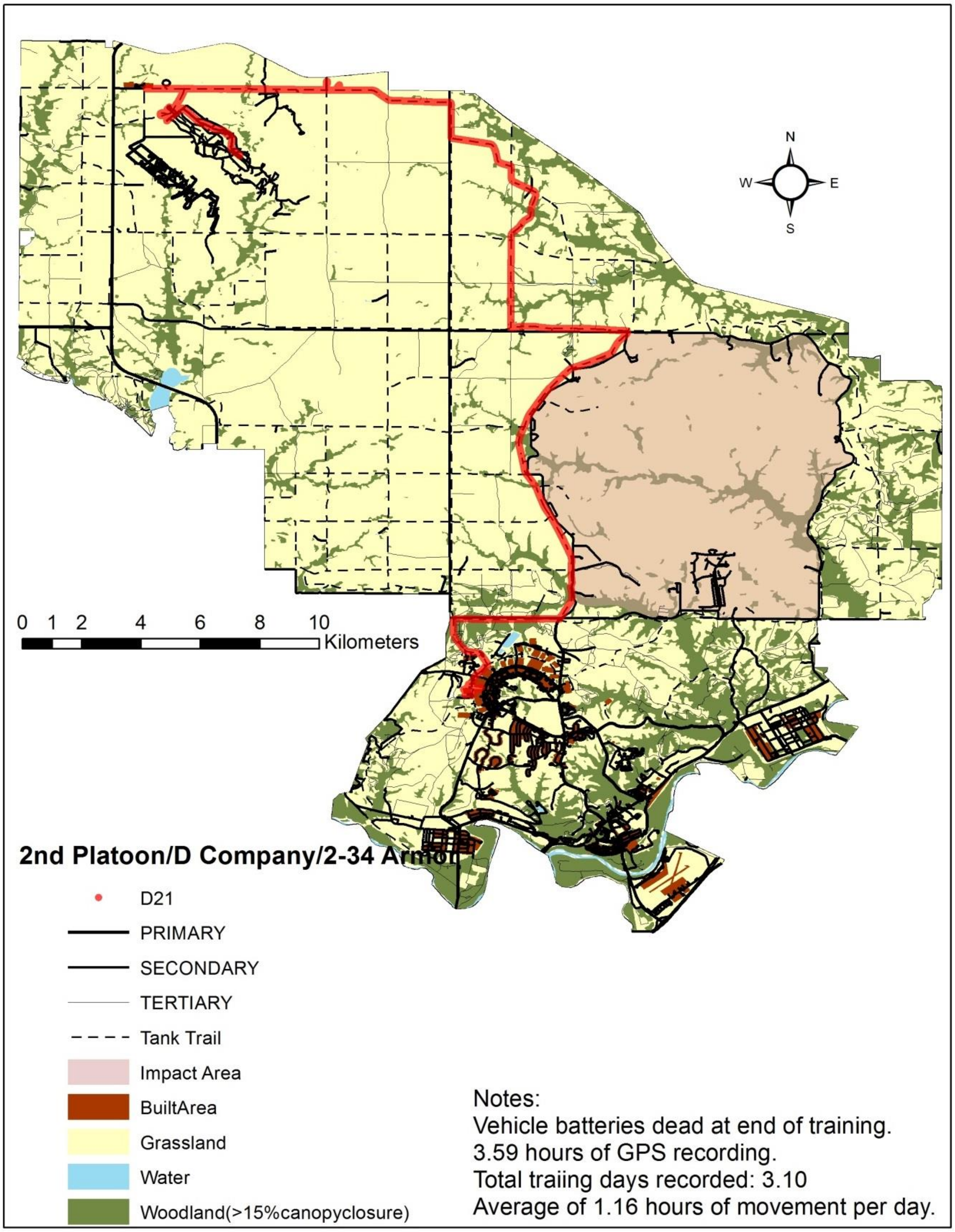


Figure B-78 GPS Points D22 2-34 Armor Battalion

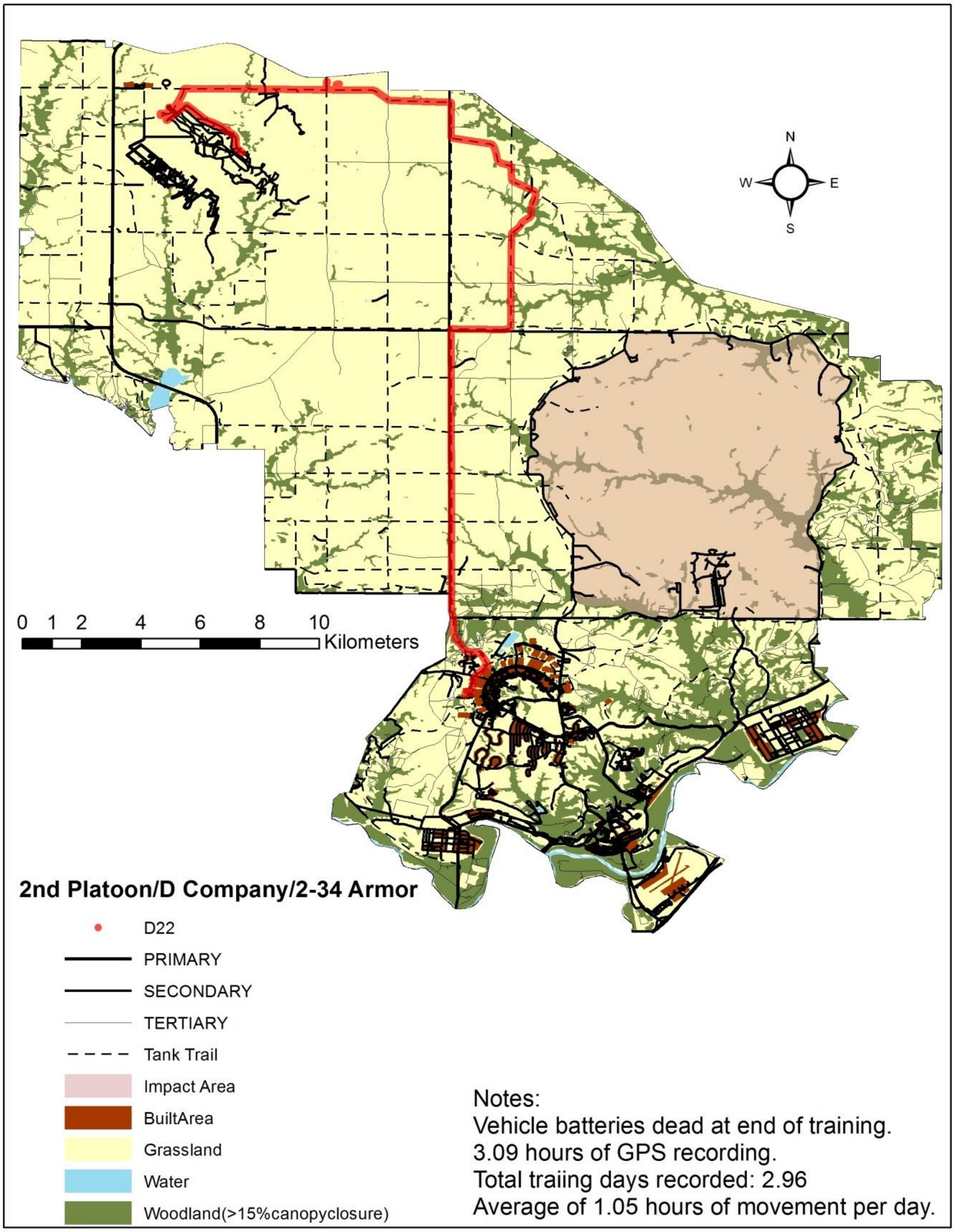


Figure B-79 GPS Points D23 2-34 Armor Battalion

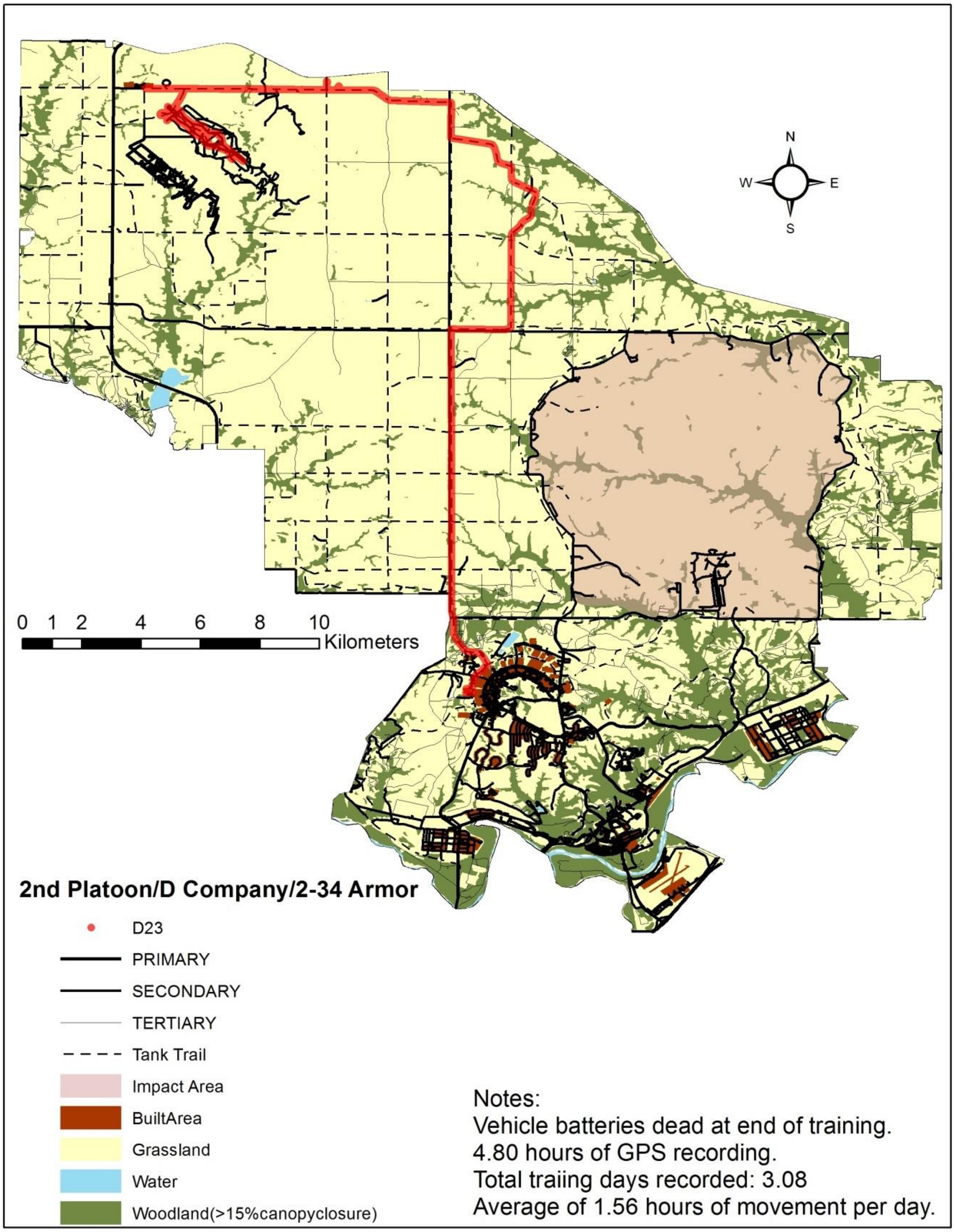


Figure B-80 GPS Points D24 2-34 Armor Battalion

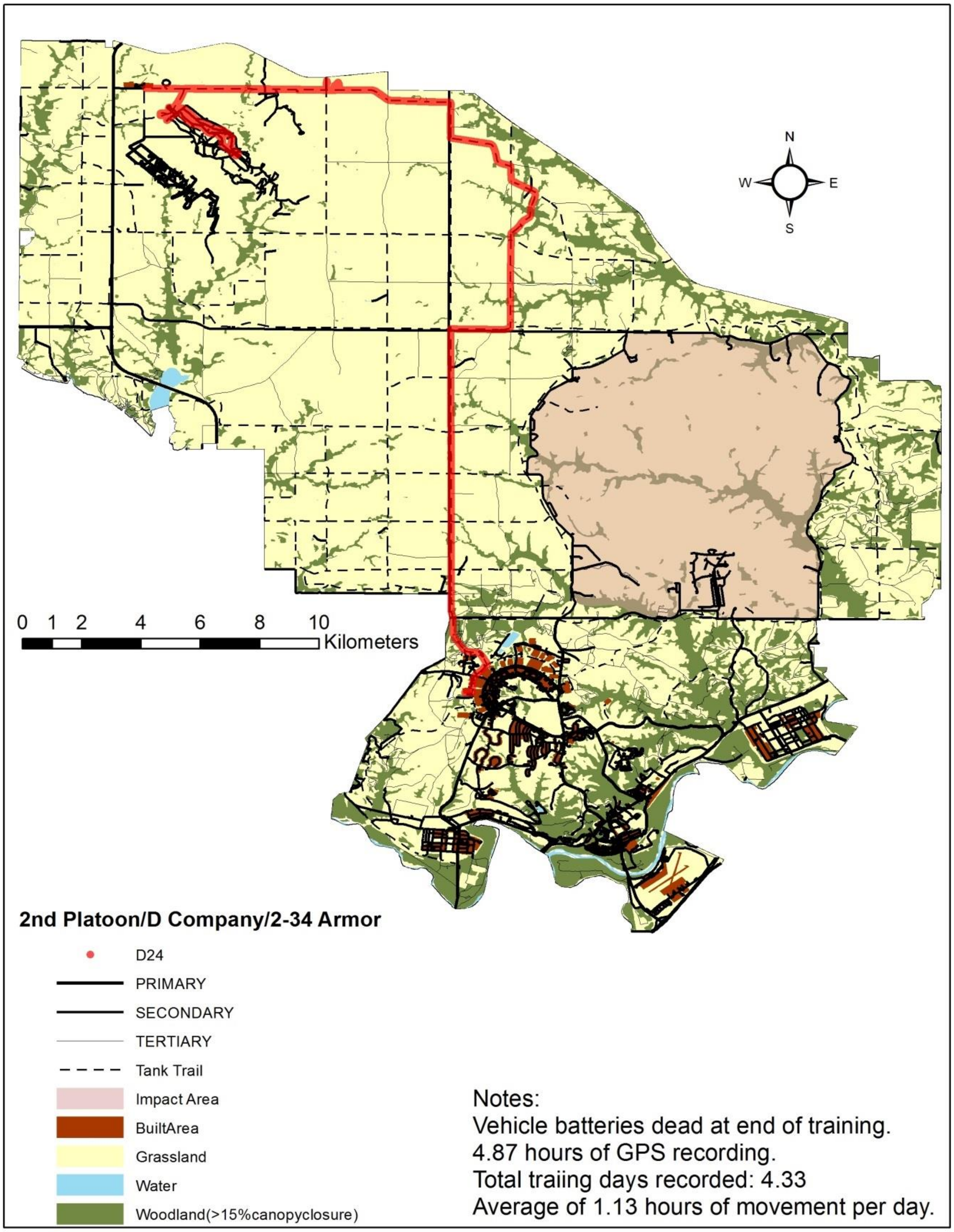


Figure B-81 GPS Points D30 2-34 Armor Battalion

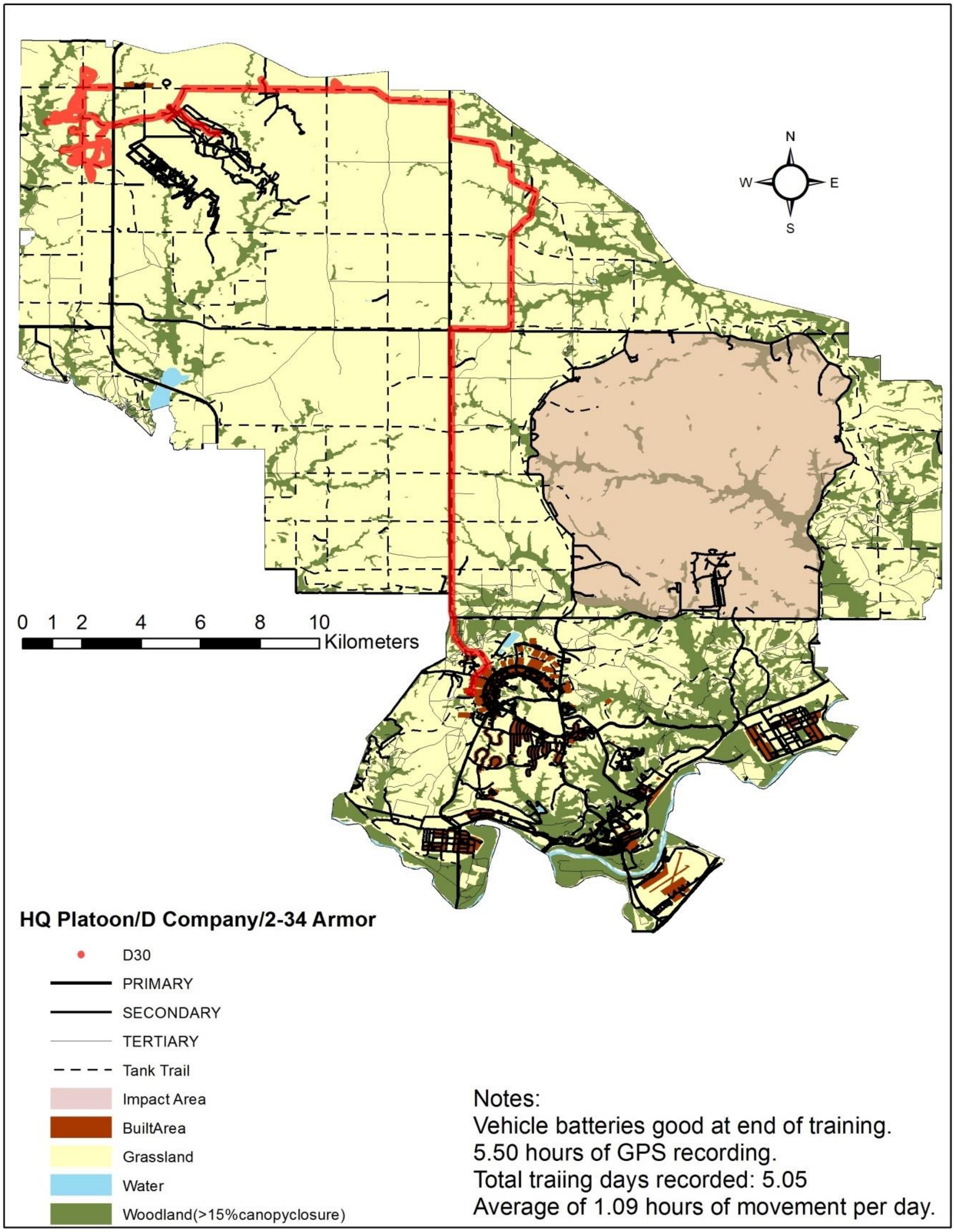


Figure B-82 GPS Points D31 2-34 Armor Battalion

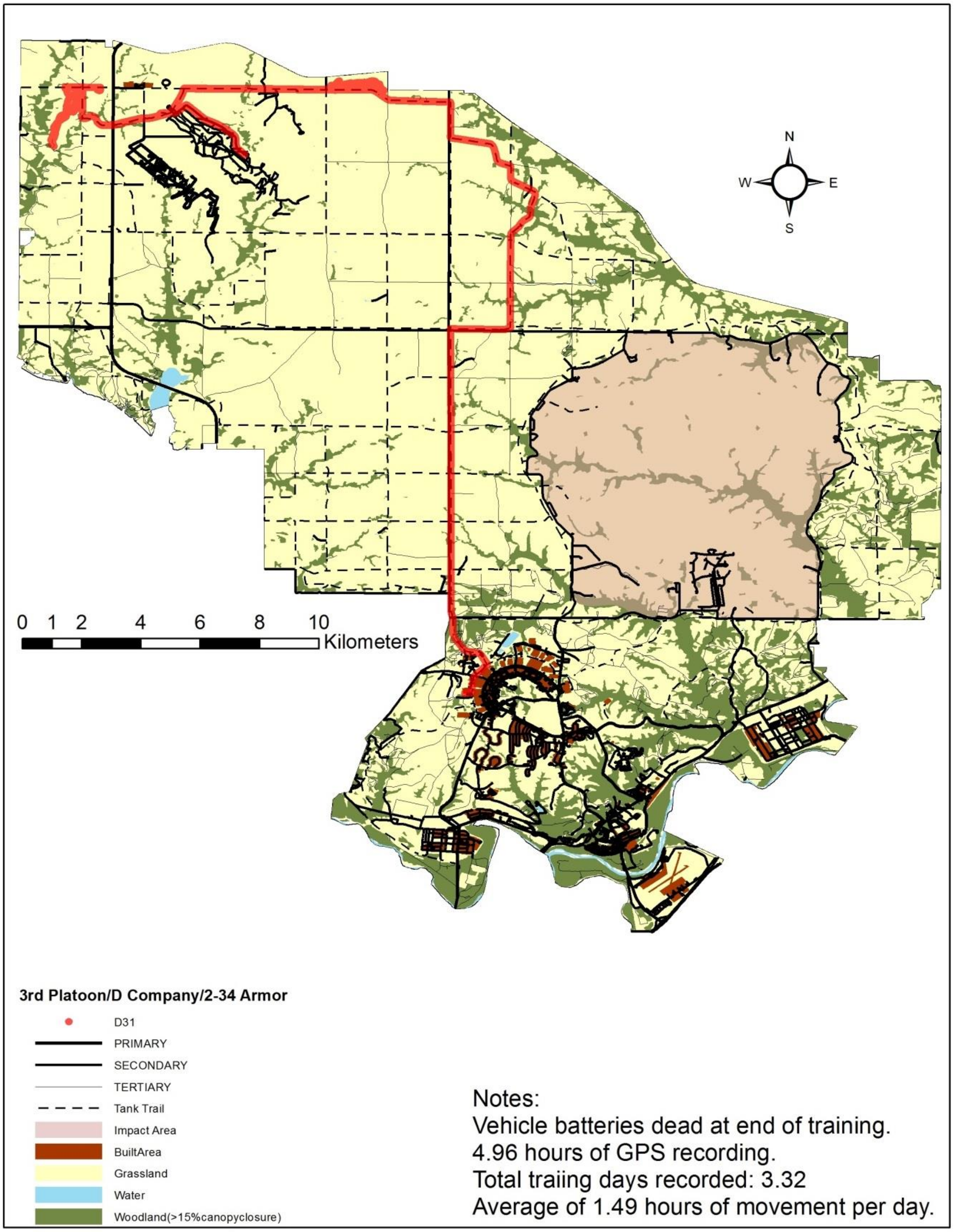


Figure B-83 GPS Points D32 2-34 Armor Battalion

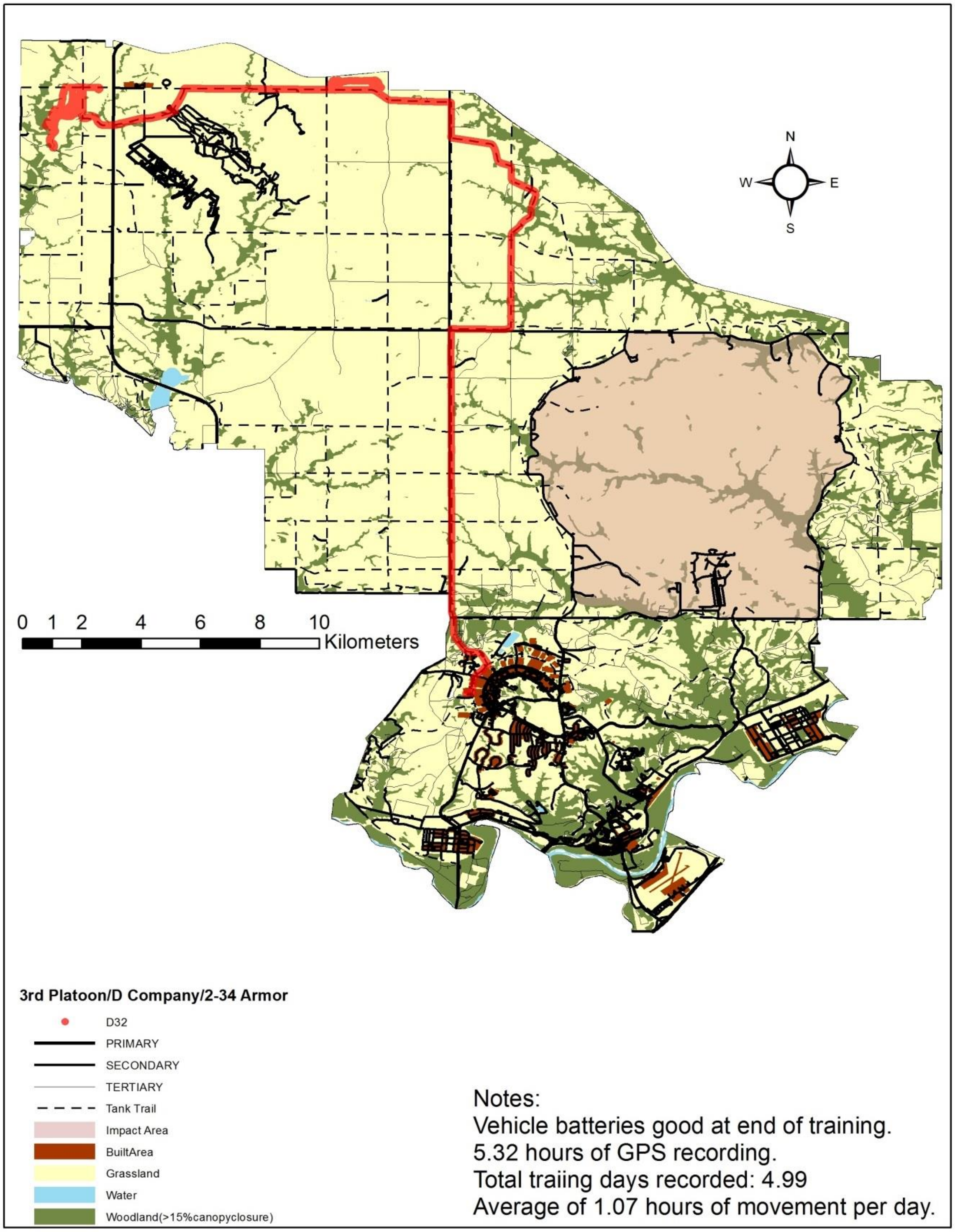


Figure B-84 GPS Points D33 2-34 Armor Battalion

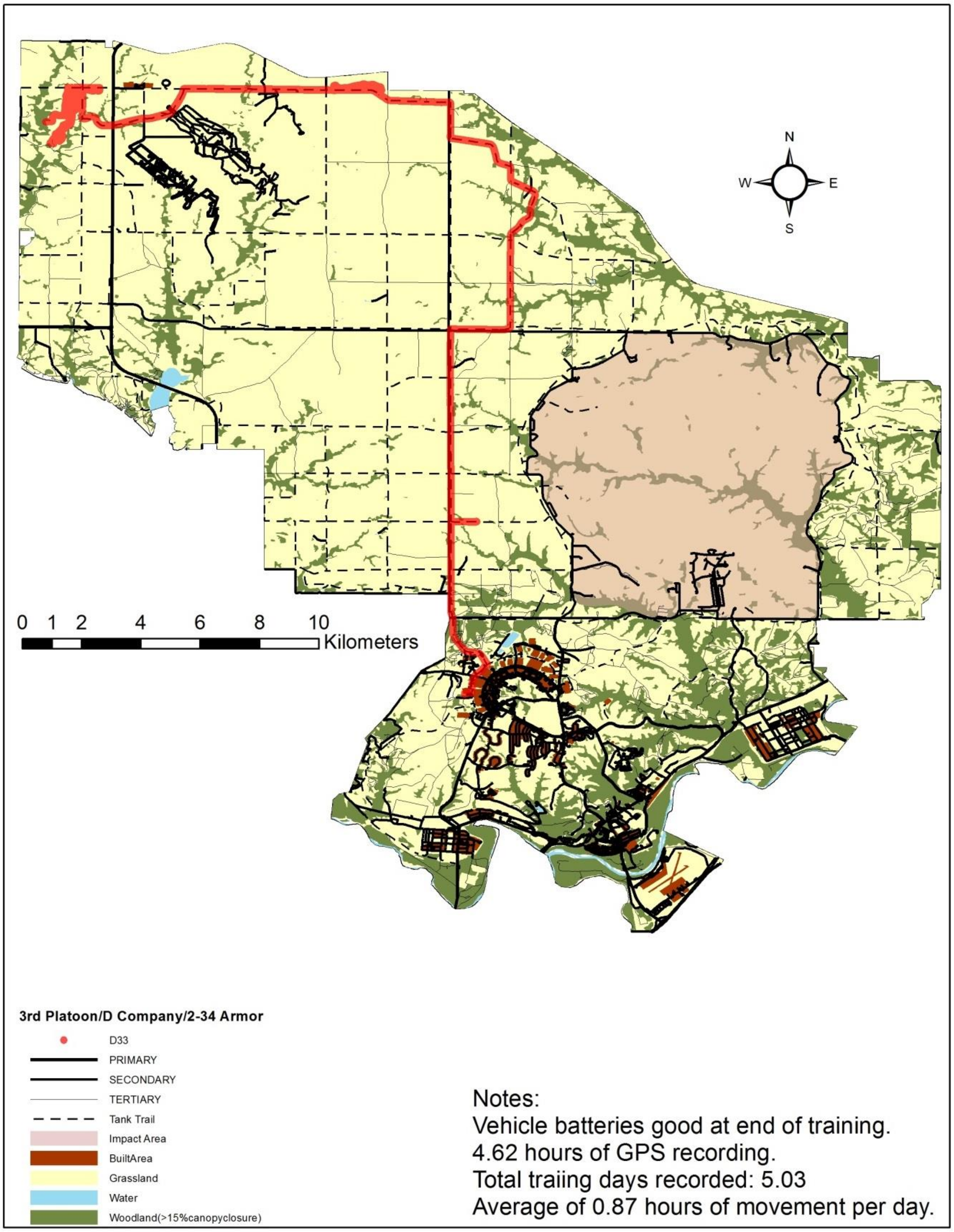


Figure B-85 GPS Points D34 2-34 Armor Battalion

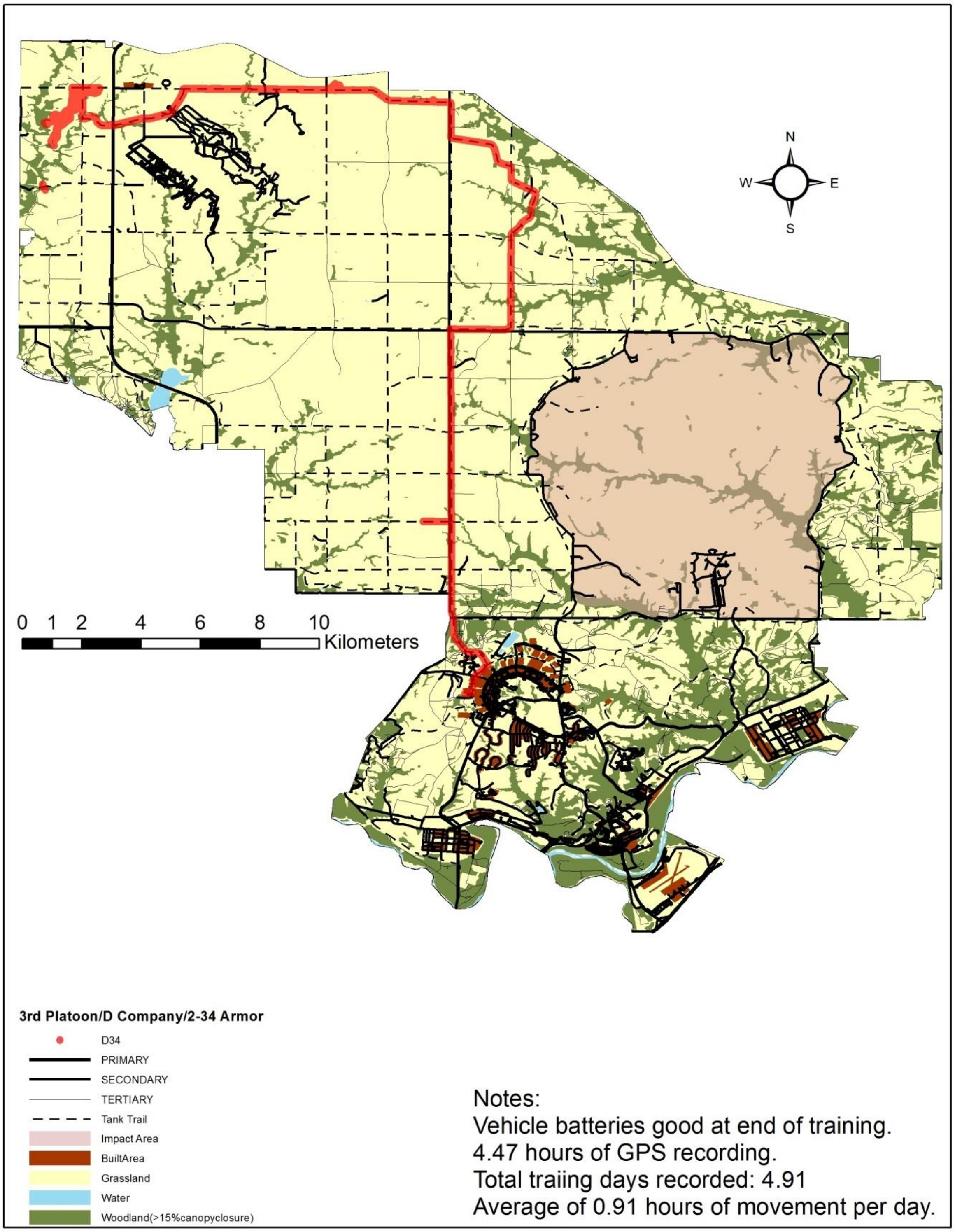


Figure B-86 GPS Points D65 2-34 Armor Battalion

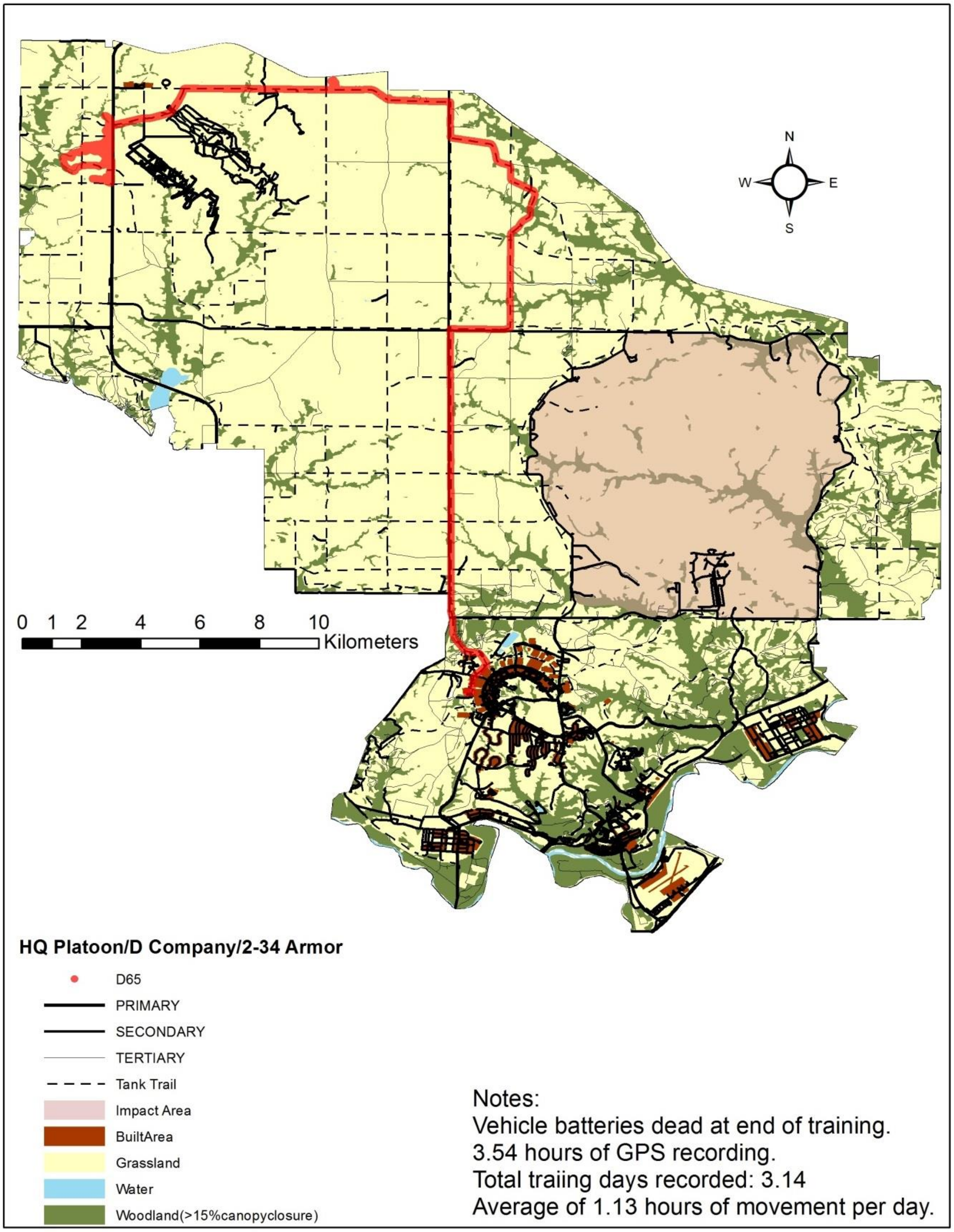


Figure B-87 GPS Points D77 2-34 Armor Battalion

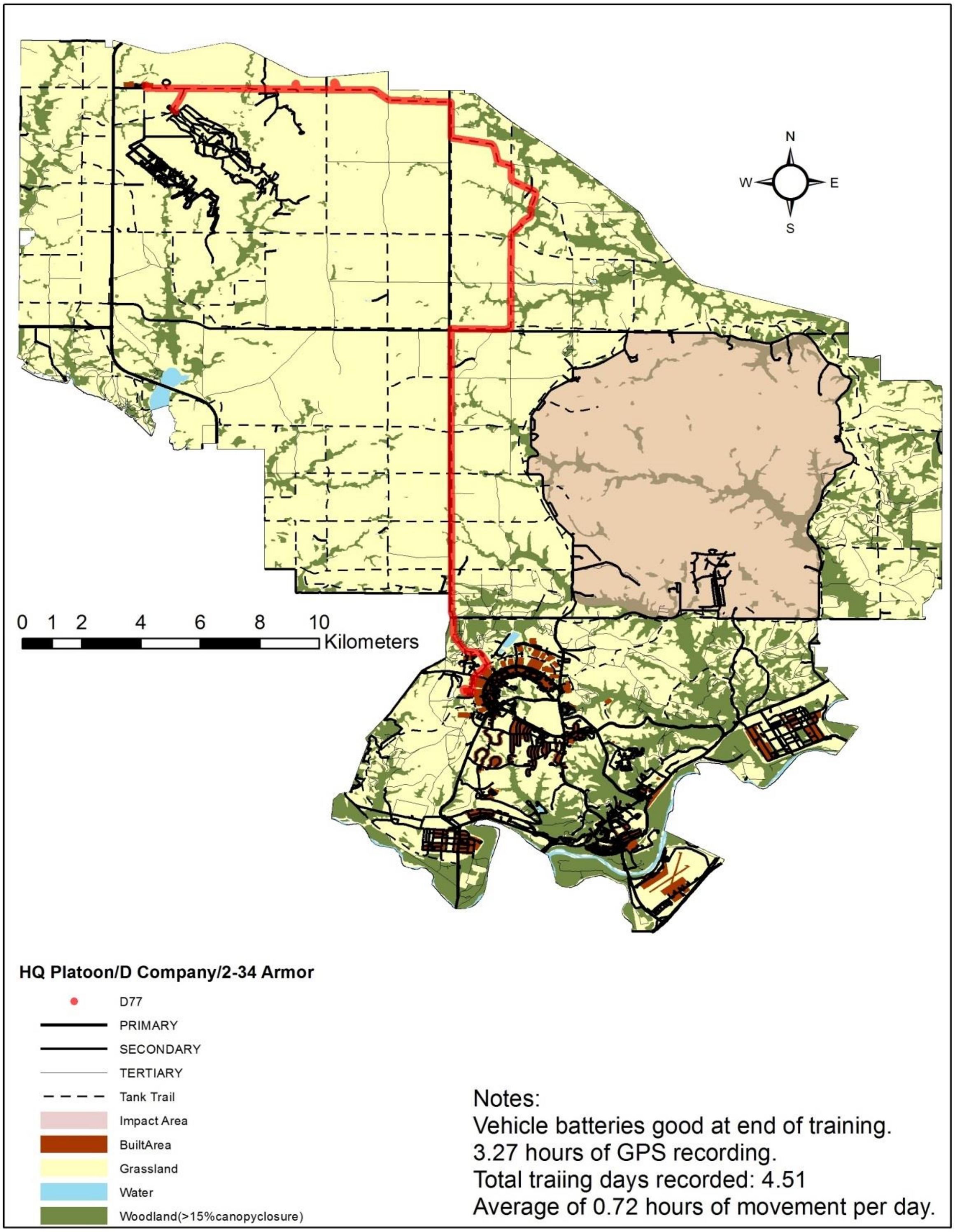


Figure B-88 GPS Points A11 4-4 Cavalry Squadron

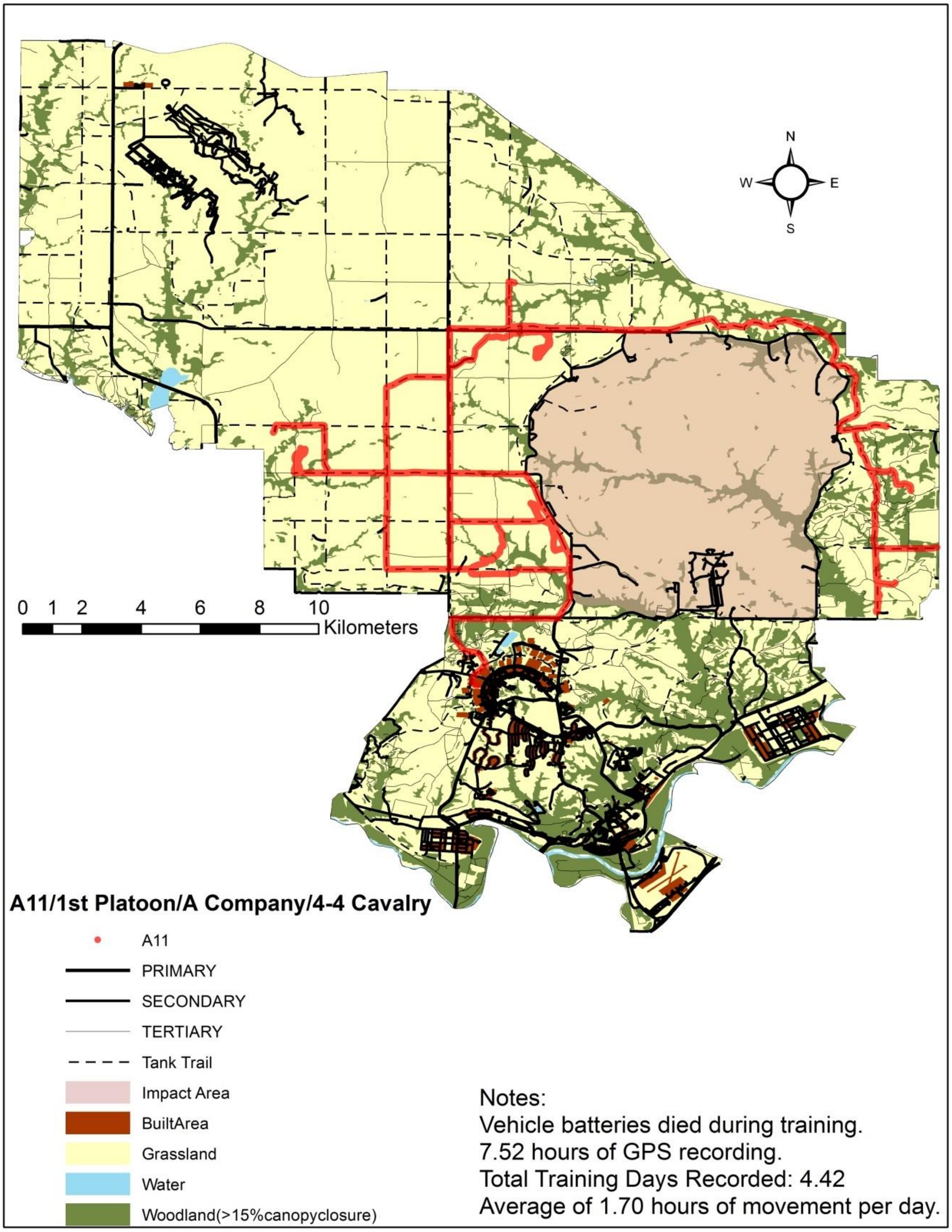


Figure B-89 GPS Points A12 4-4 Cavalry Squadron

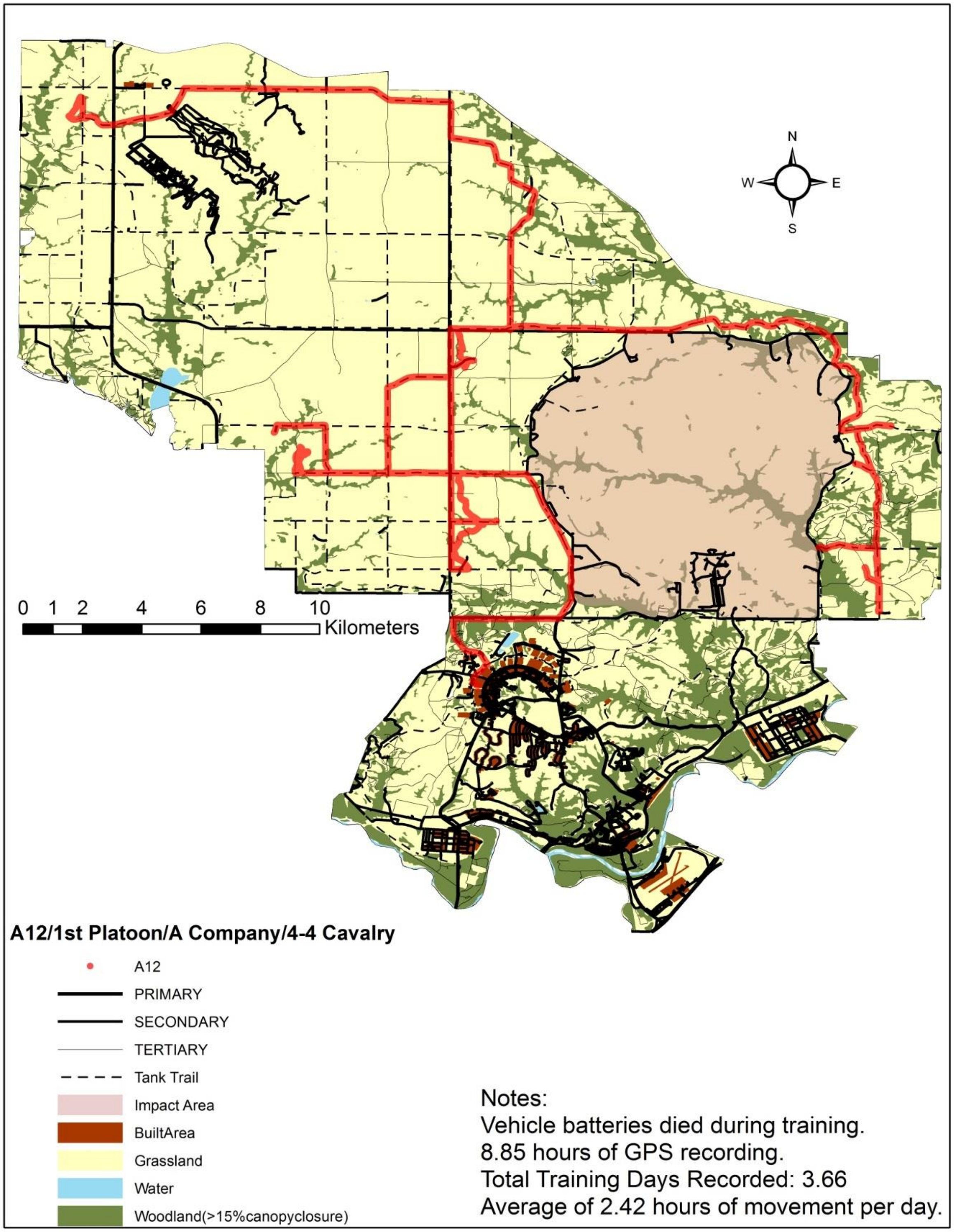


Figure B-90 GPS Points A14 4-4 Cavalry Squadron

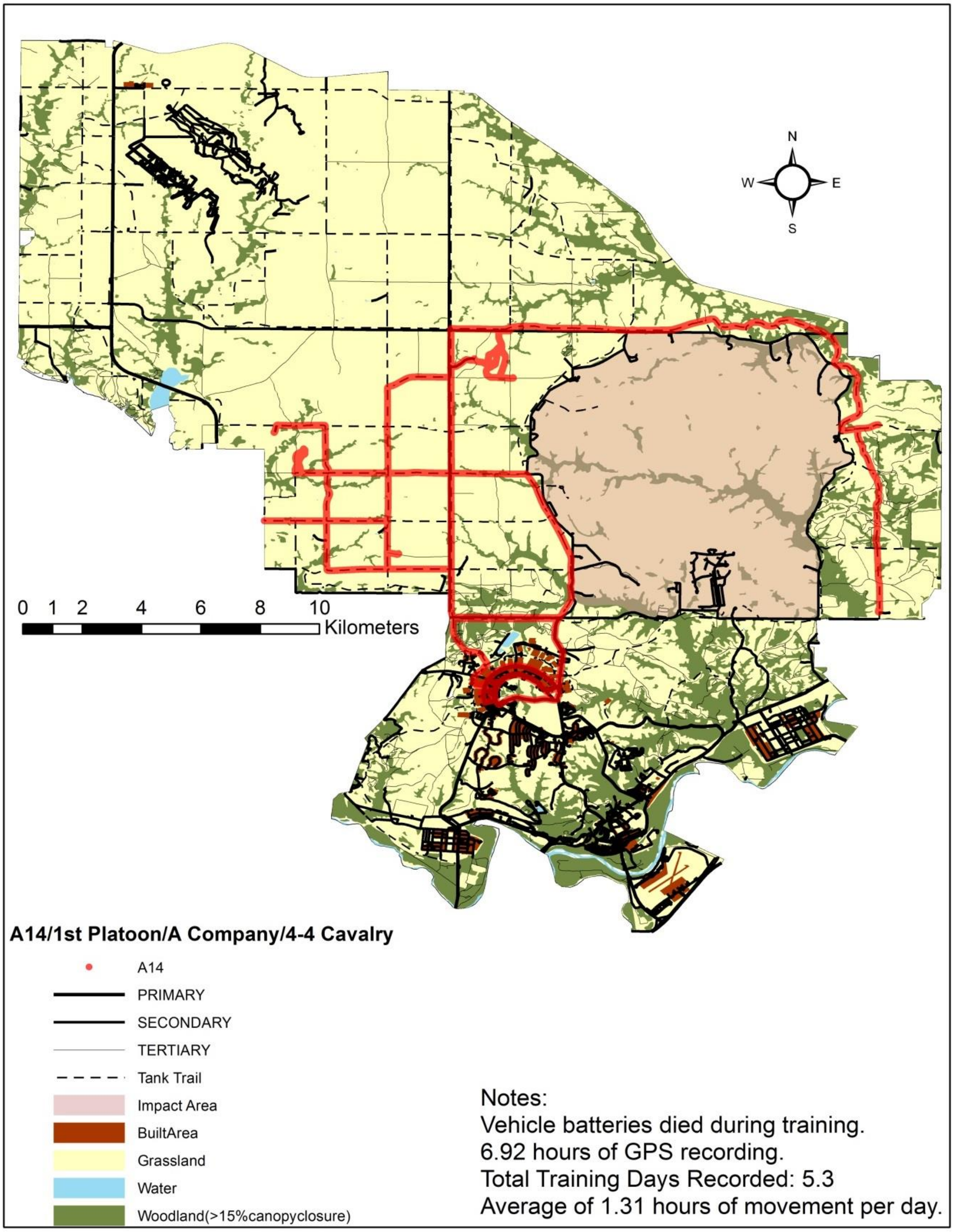


Figure B-91 GPS Points A15 4-4 Cavalry Squadron

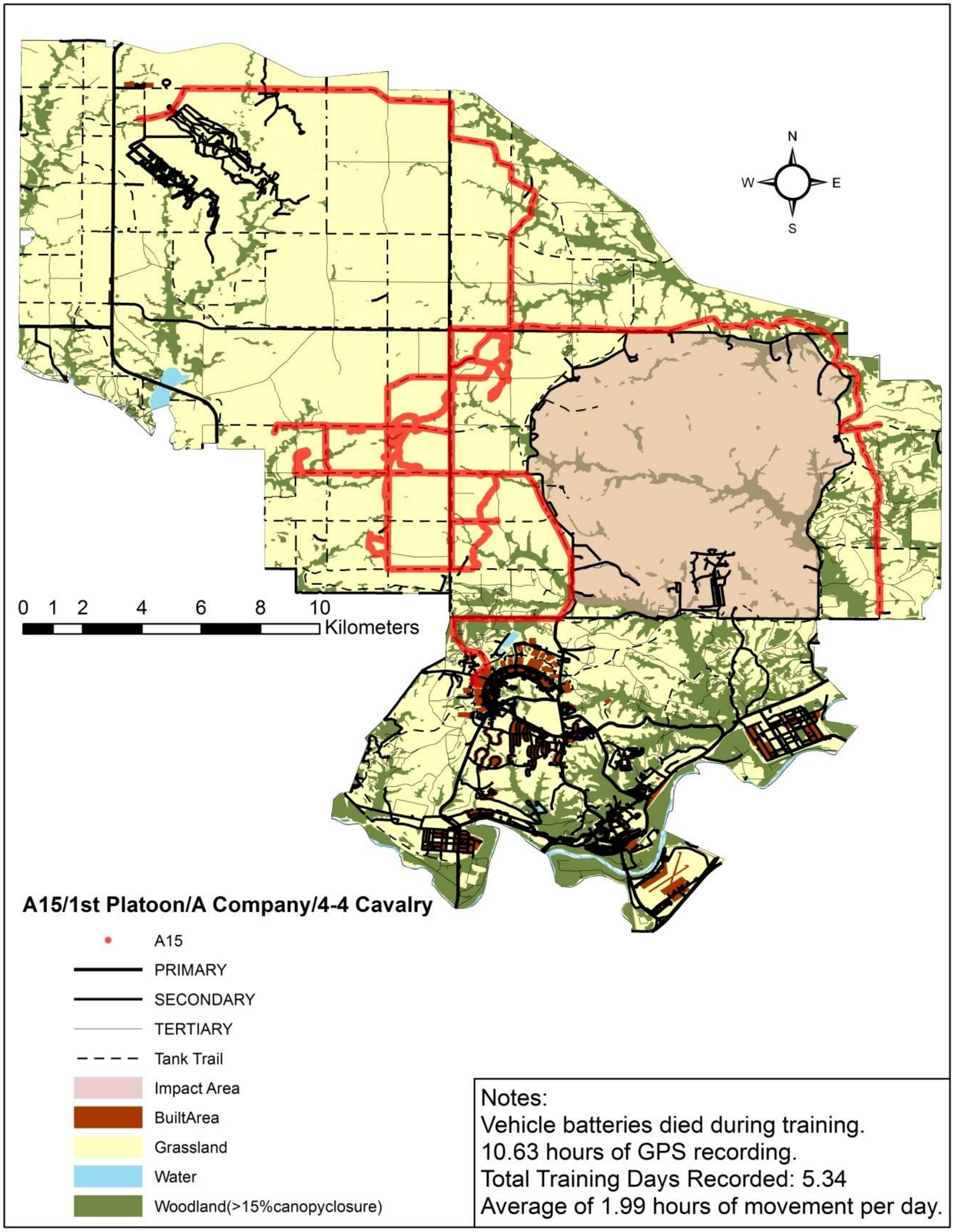


Figure B-92 GPS Points A22 4-4 Cavalry Squadron

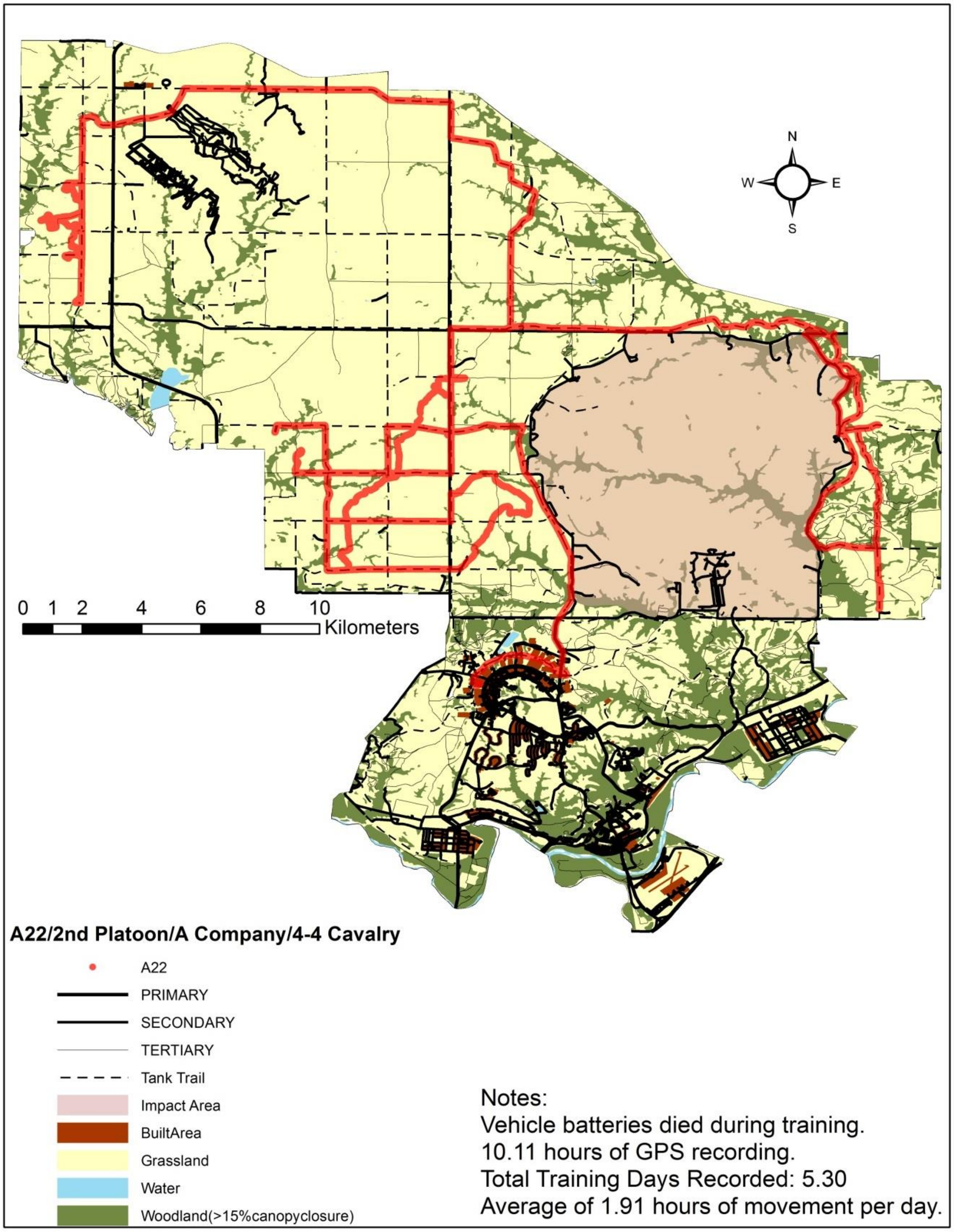


Figure B-93 GPS Points A24 4-4 Cavalry Squadron

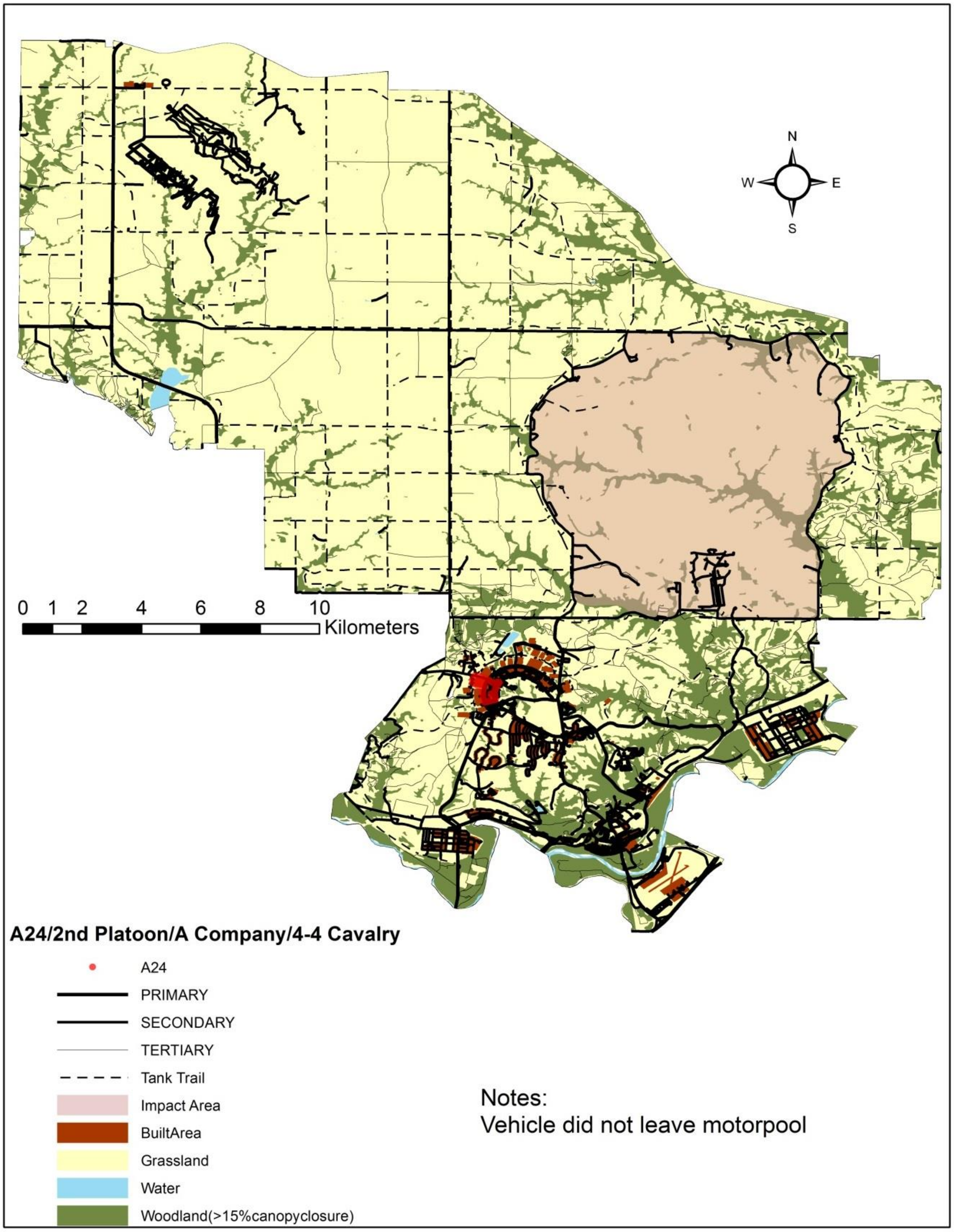


Figure B-94 GPS Points A25 4-4 Cavalry Squadron

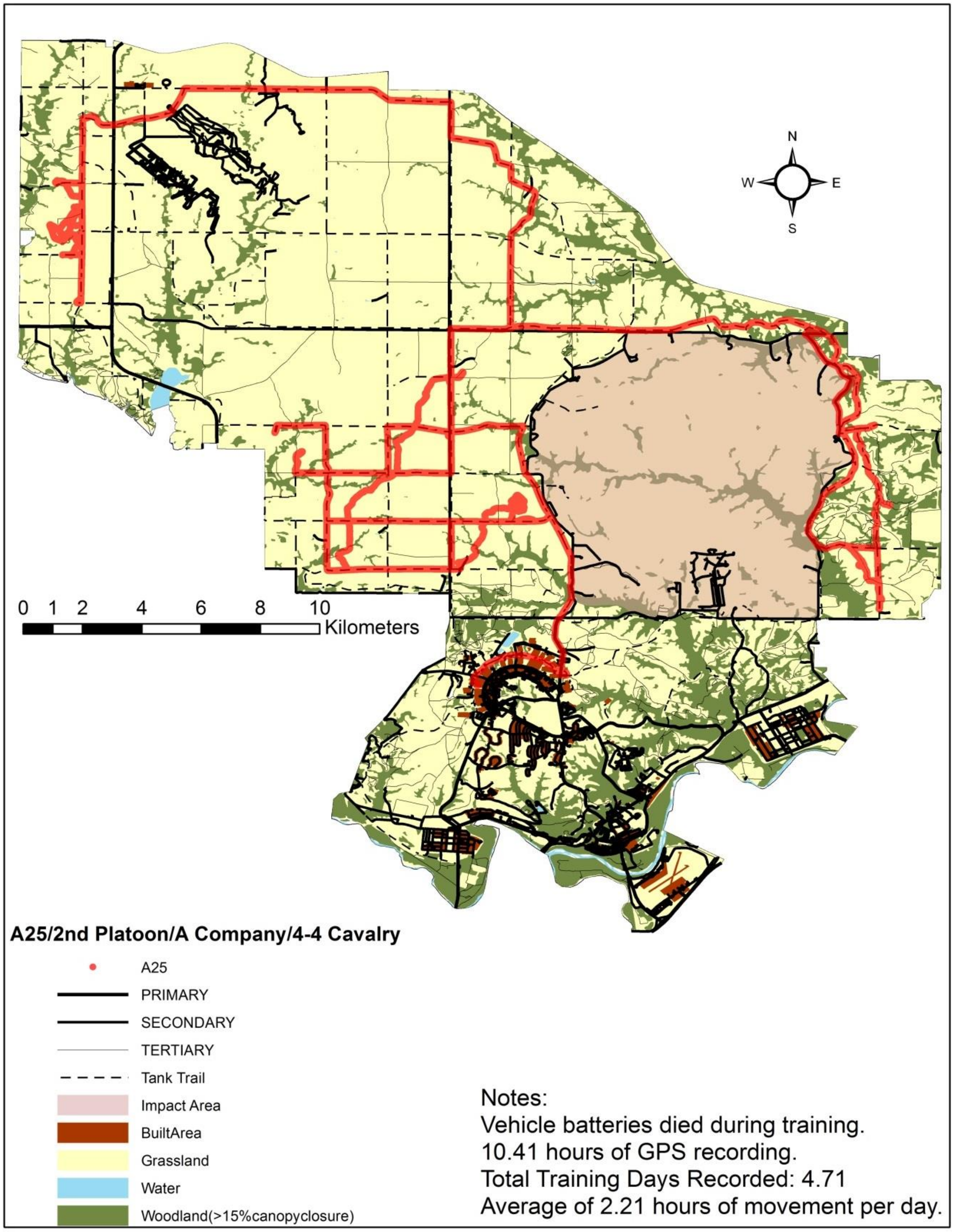


Figure B-95 GPS Points B11 4-4 Cavalry Squadron

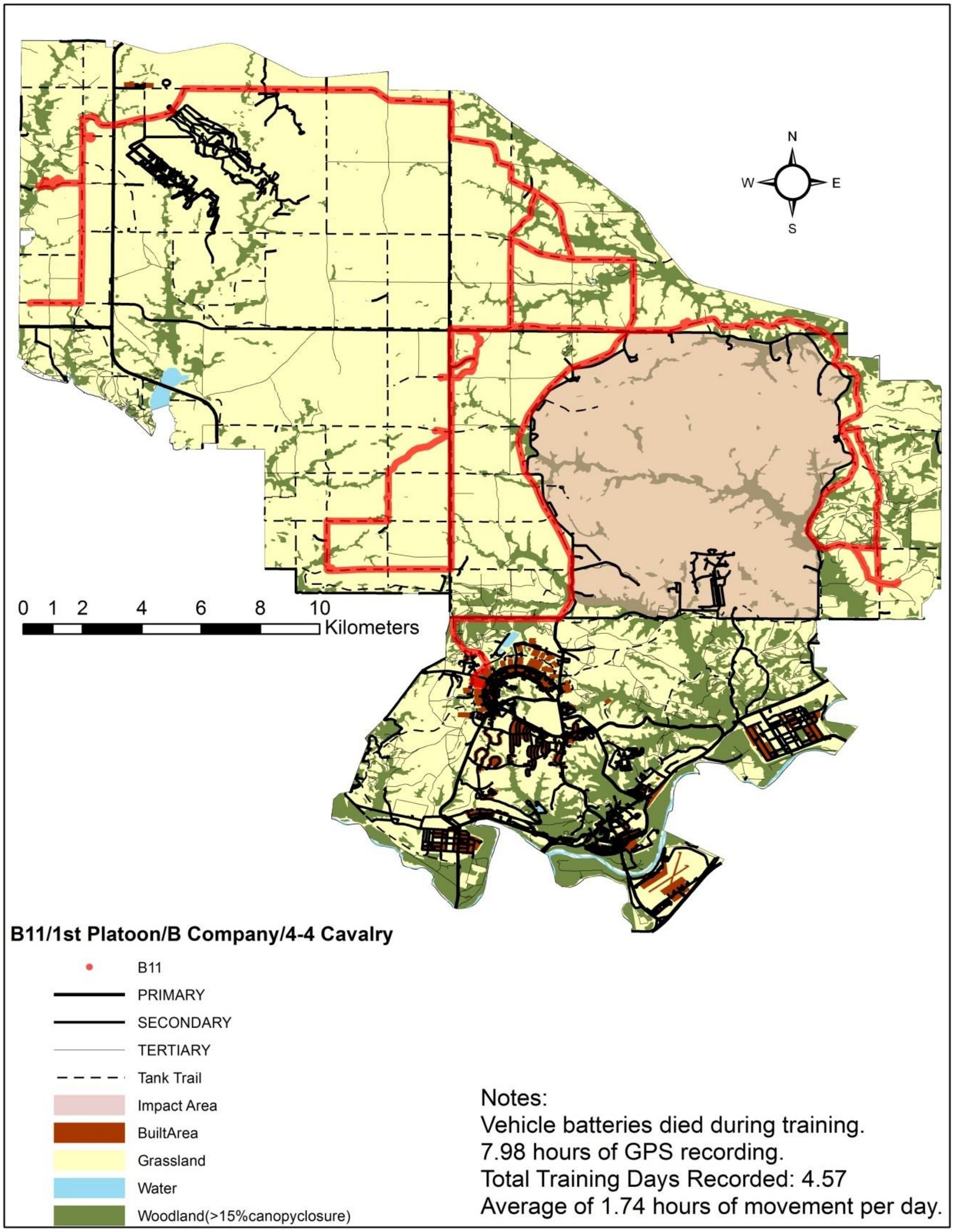


Figure B-96 GPS Points B12 4-4 Cavalry Squadron

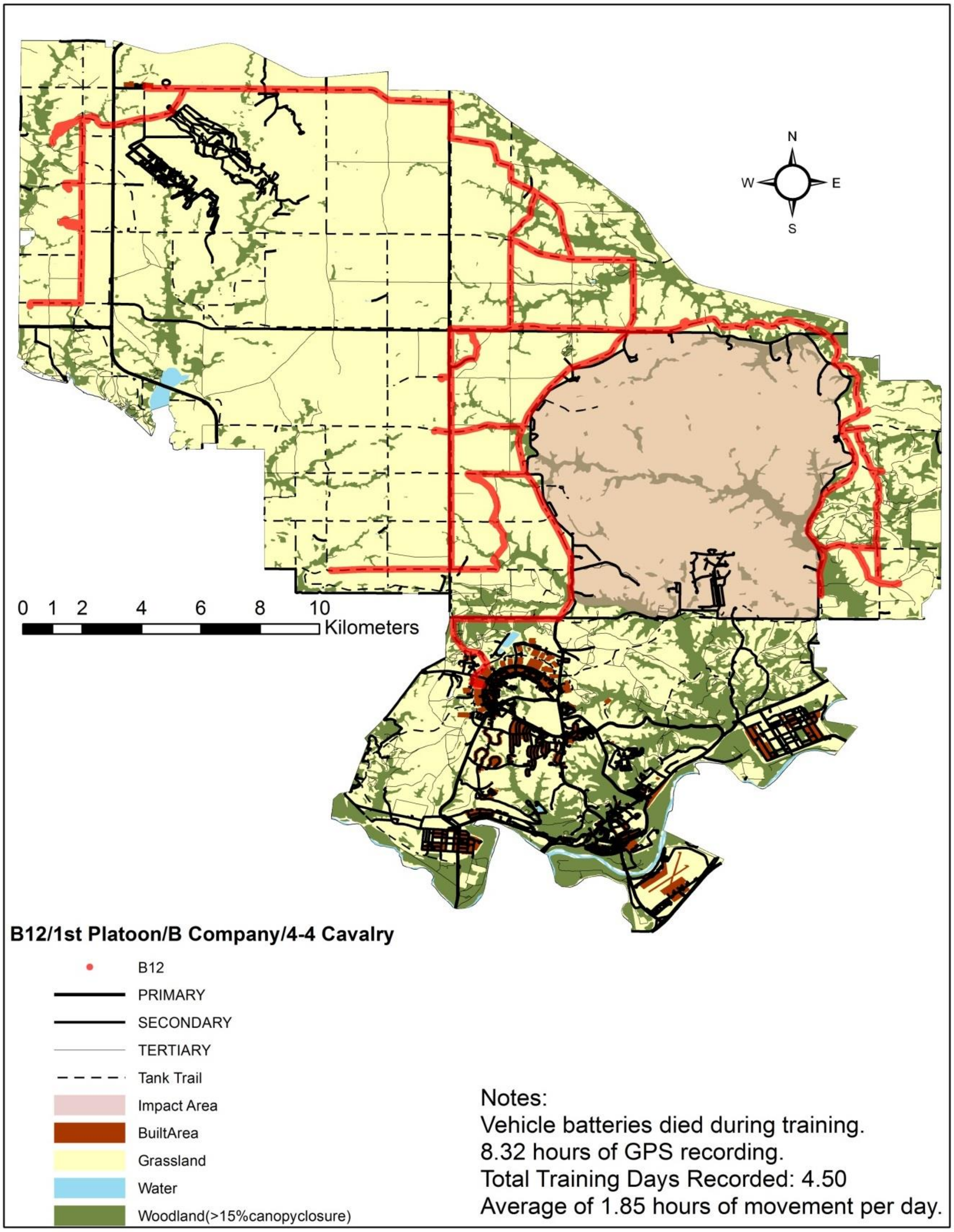


Figure B-97 GPS Points B13 4-4 Cavalry Squadron

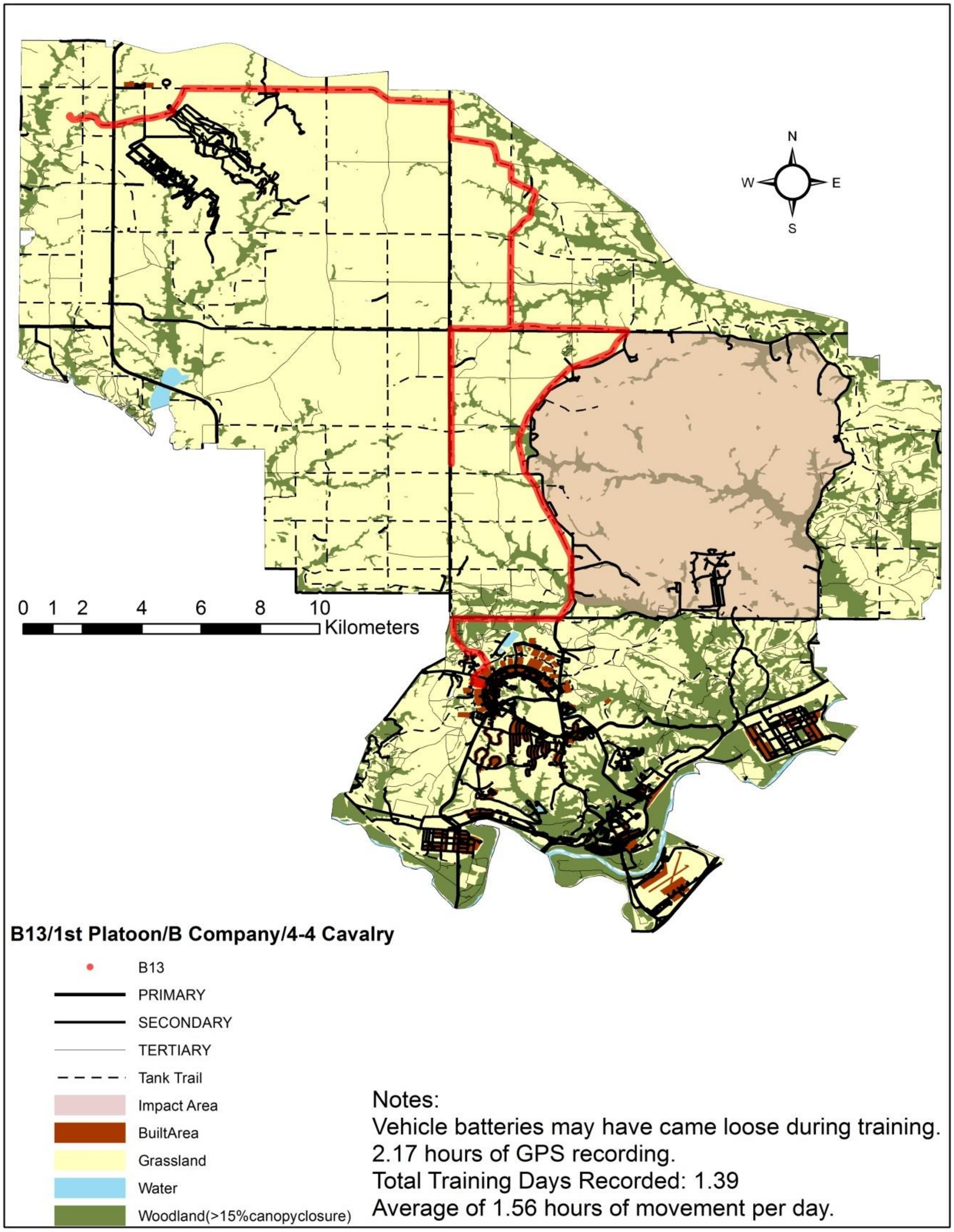


Figure B-98 GPS Points B14 4-4 Cavalry Squadron

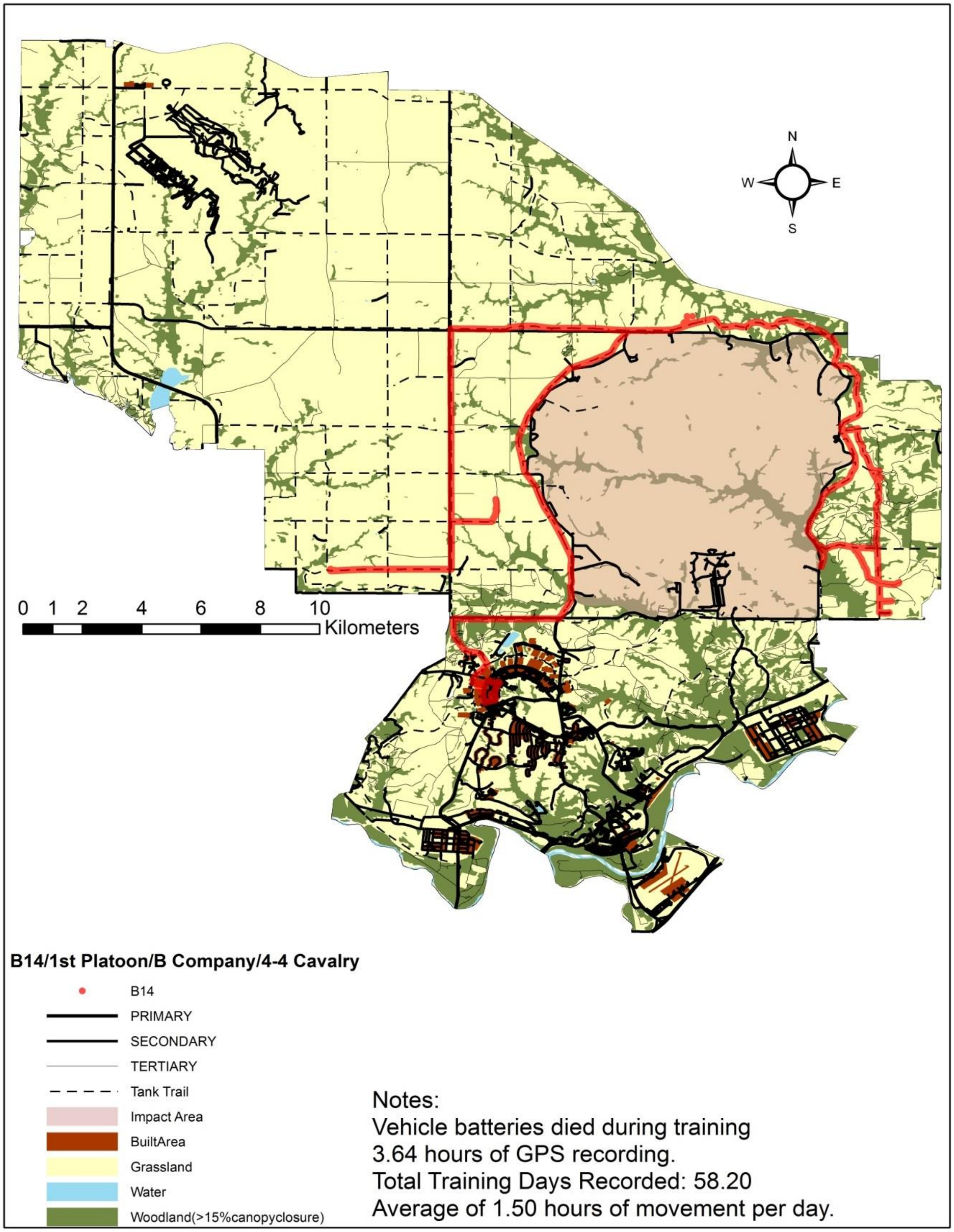


Figure B-99 GPS Points B16 4-4 Cavalry Squadron

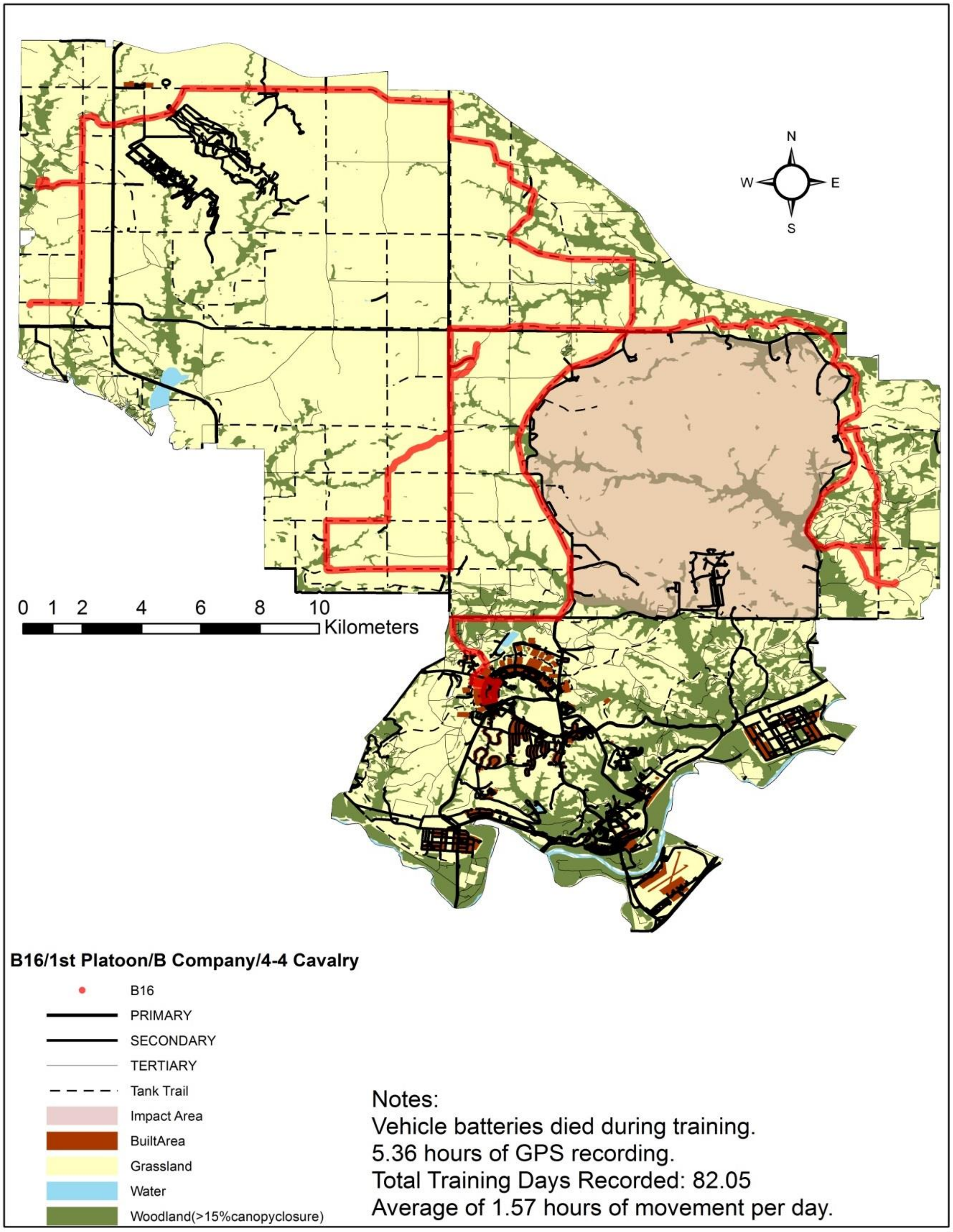


Figure B-100 GPS Points B17 4-4 Cavalry Squadron

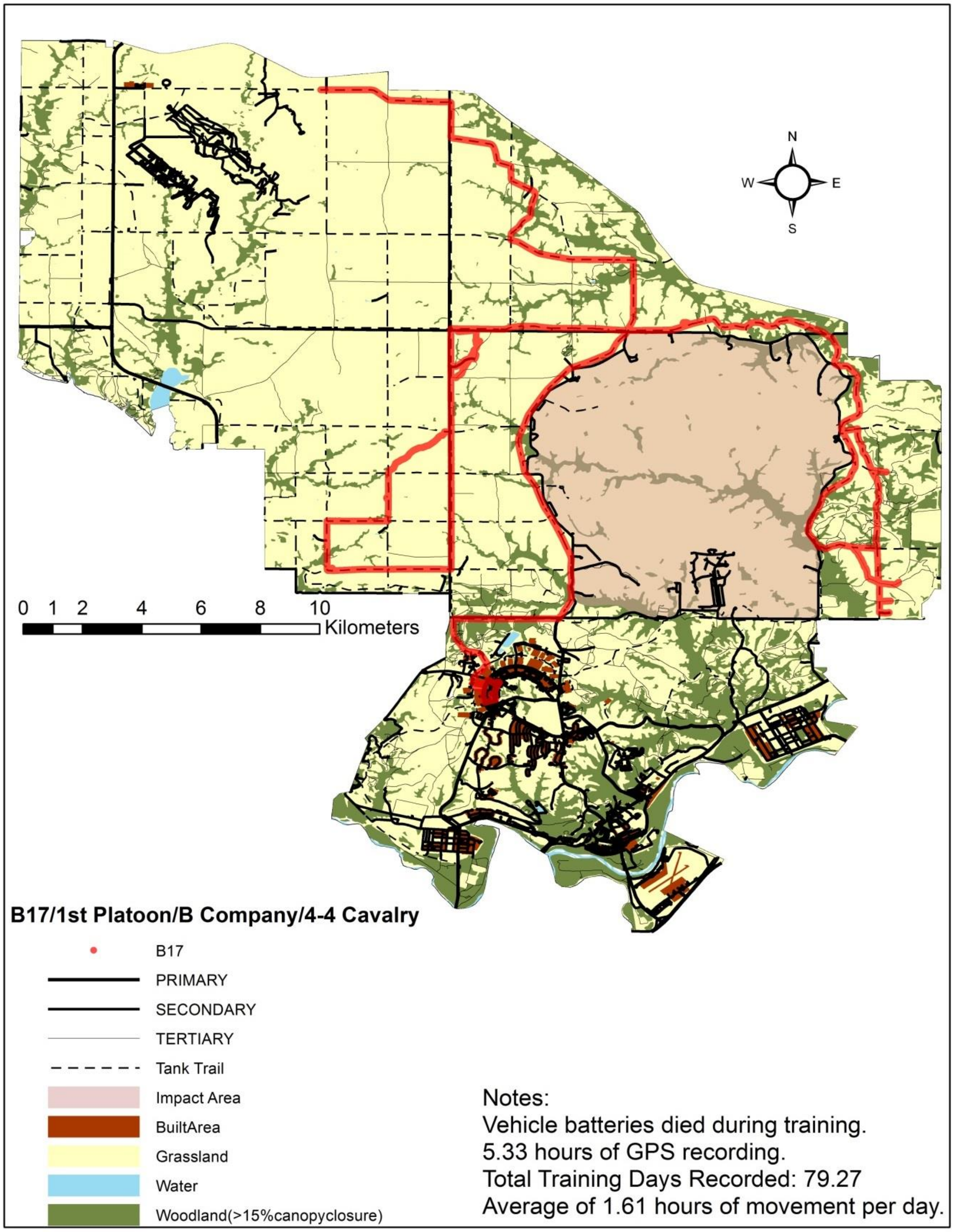


Figure B-101 GPS Points B21 4-4 Cavalry Squadron

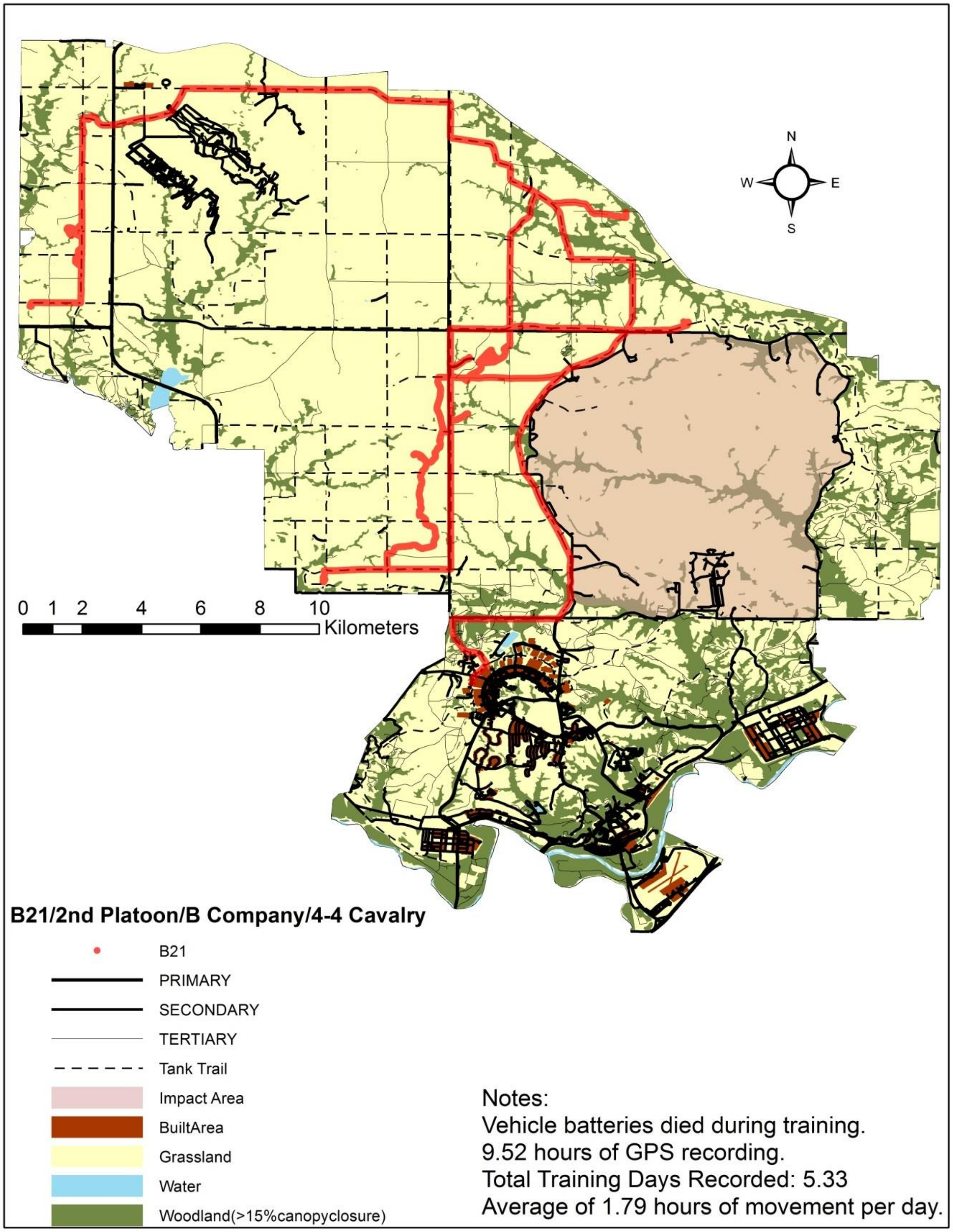


Figure B-102 GPS Points B22 4-4 Cavalry Squadron

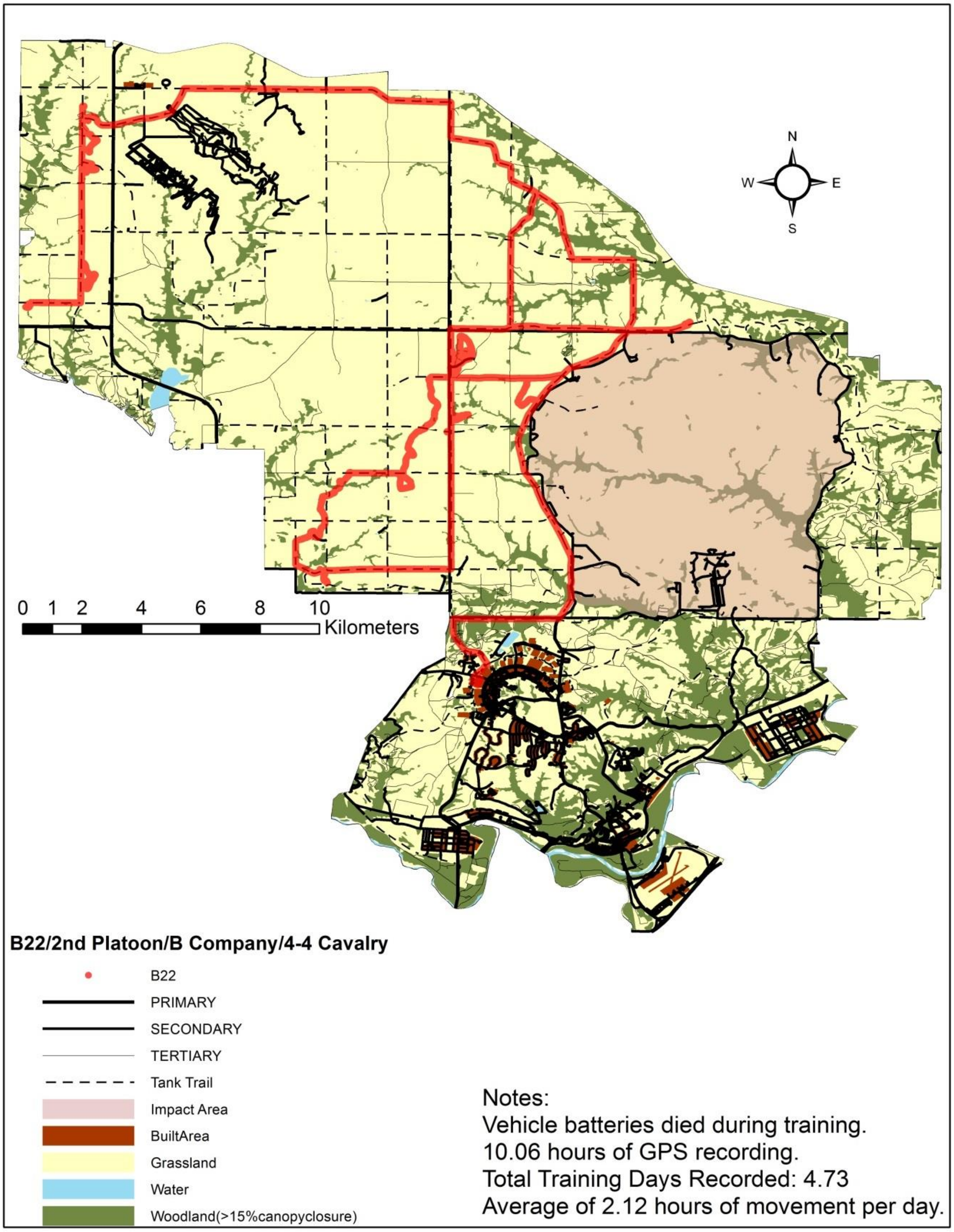


Figure B-103 GPS Points B23 4-4 Cavalry Squadron

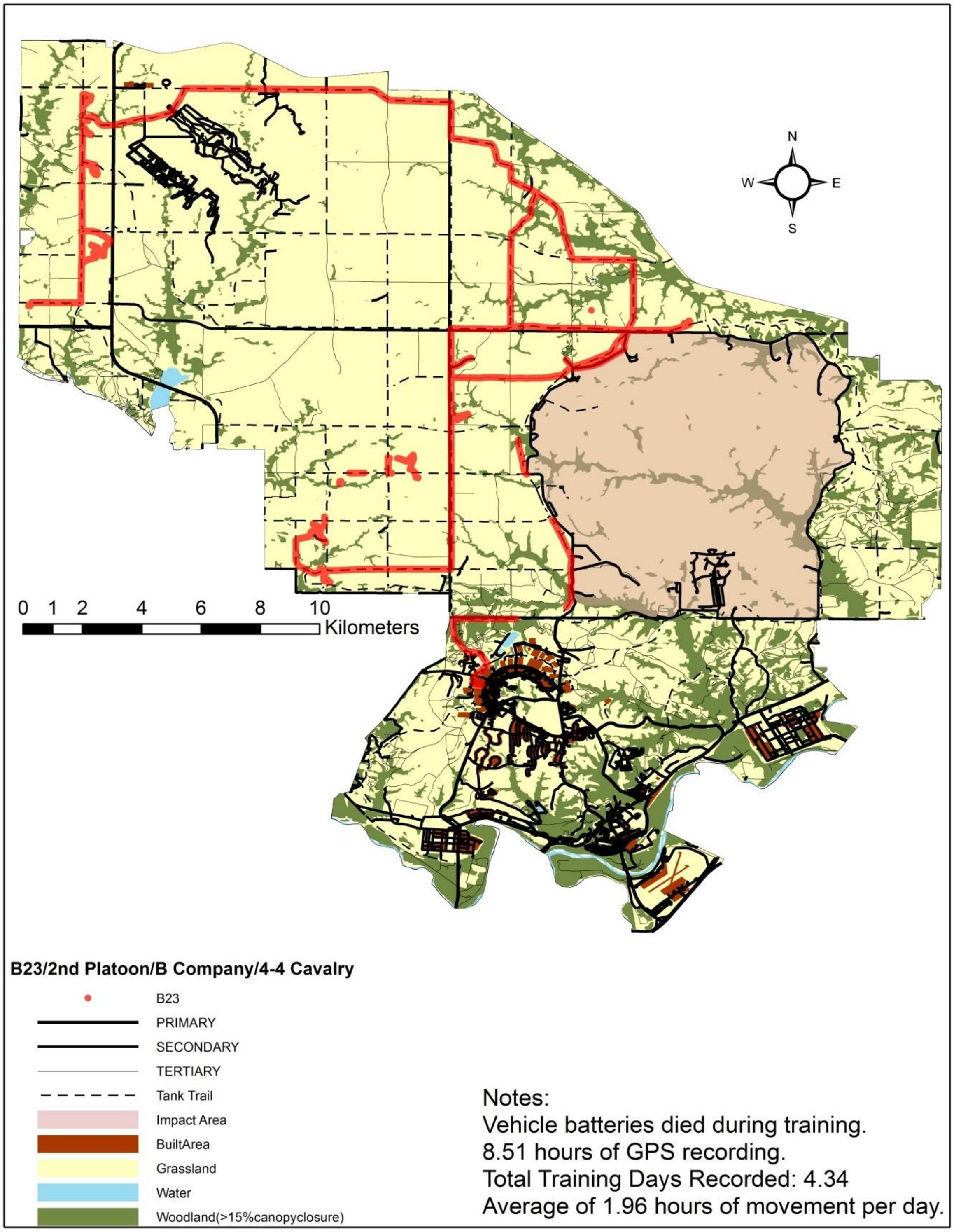


Figure B-104 GPS Points B24 4-4 Cavalry Squadron

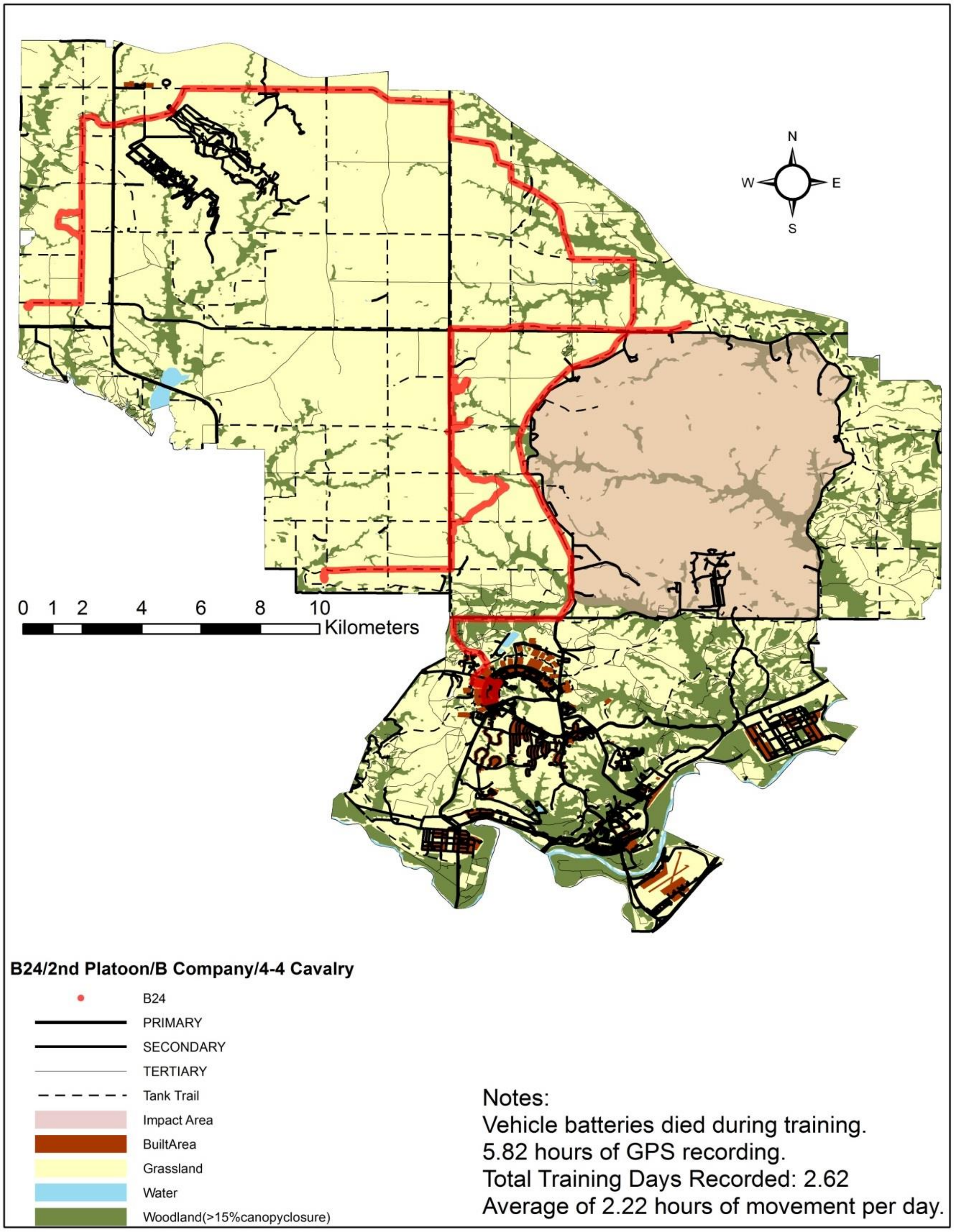


Figure B-105 GPS Points B25 4-4 Cavalry Squadron

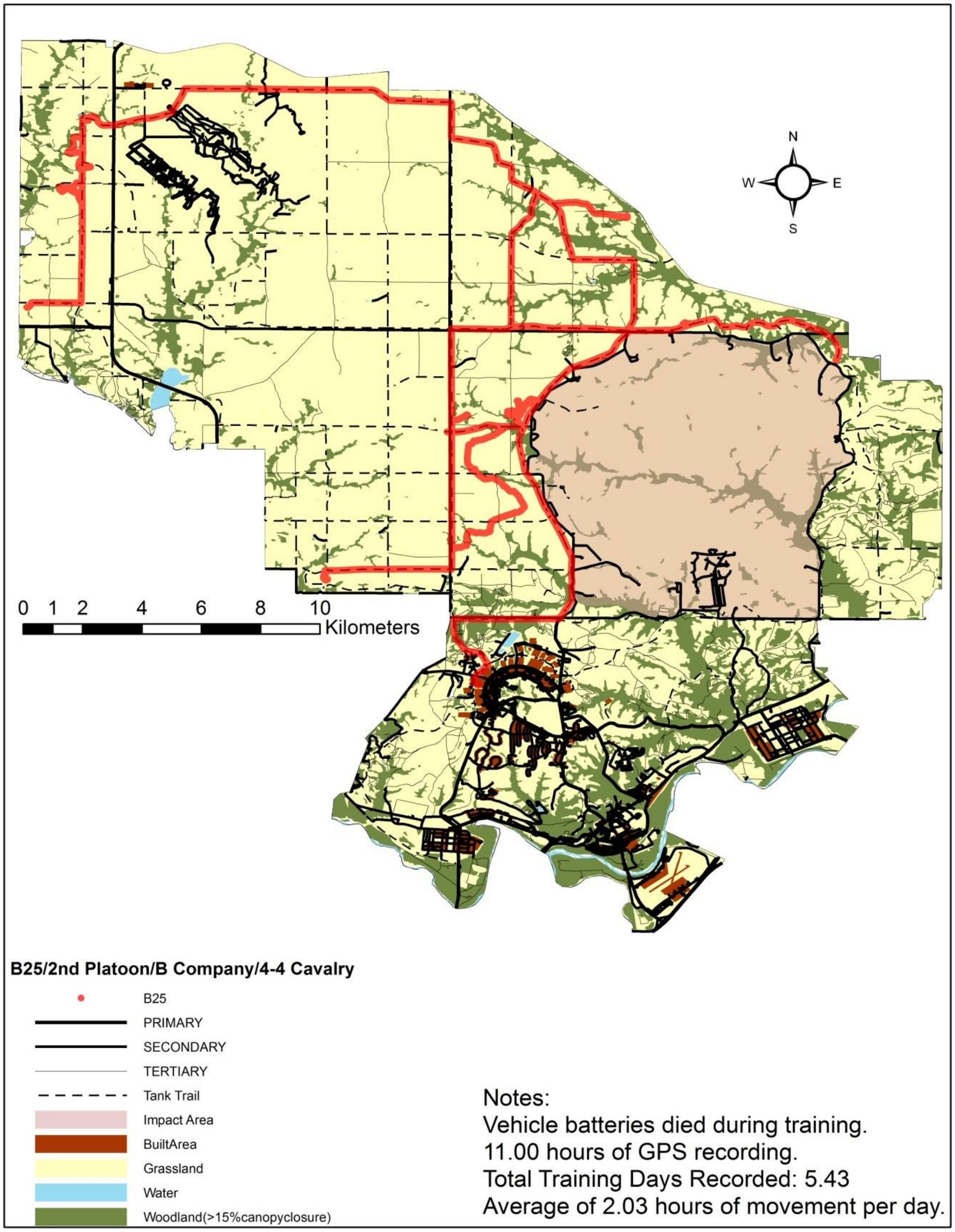


Figure B-106 GPS Points B26 4-4 Cavalry Squadron

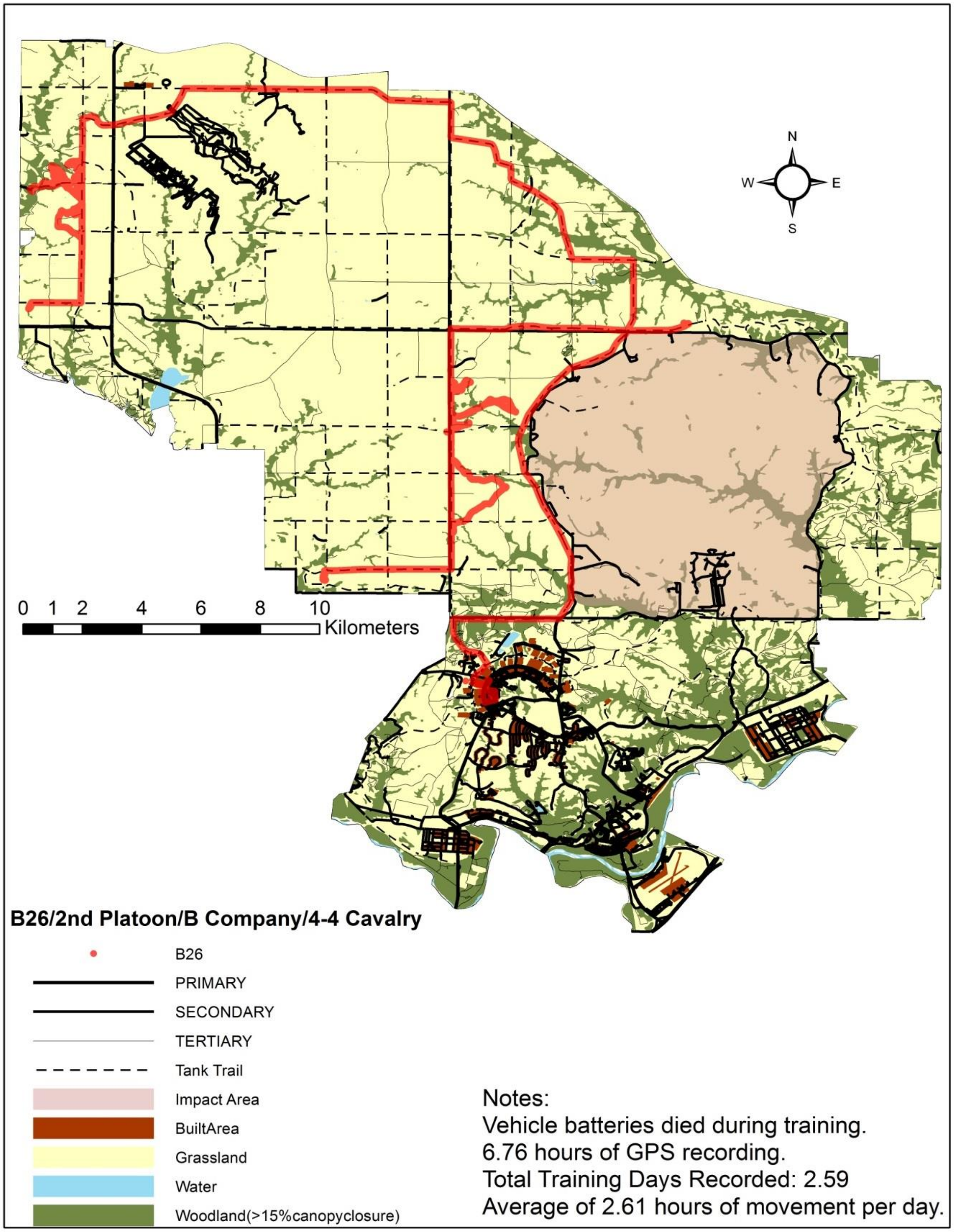


Figure B-107 GPS Points B27 4-4 Cavalry Squadron

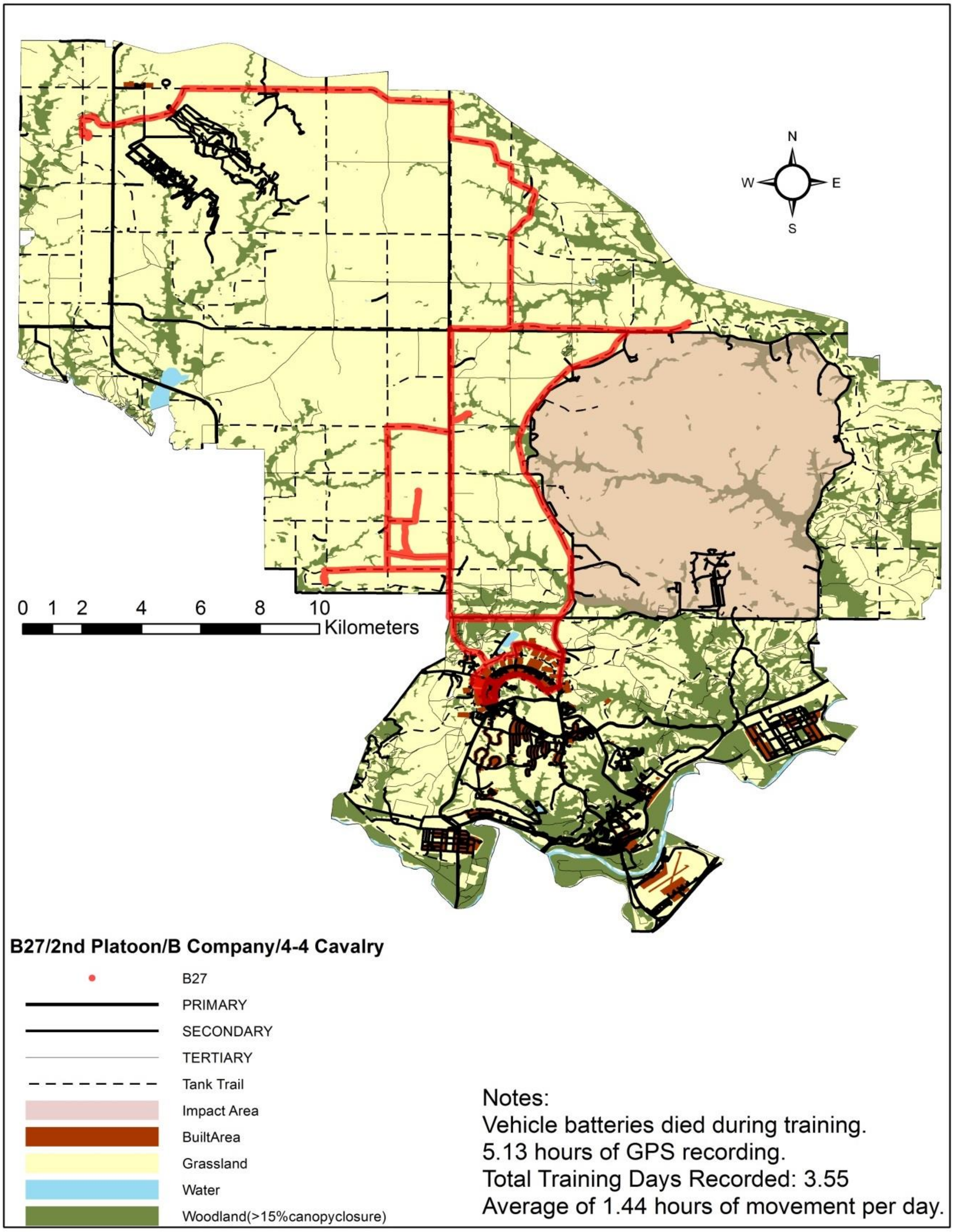


Figure B-108 GPS Points B28 4-4 Cavalry Squadron

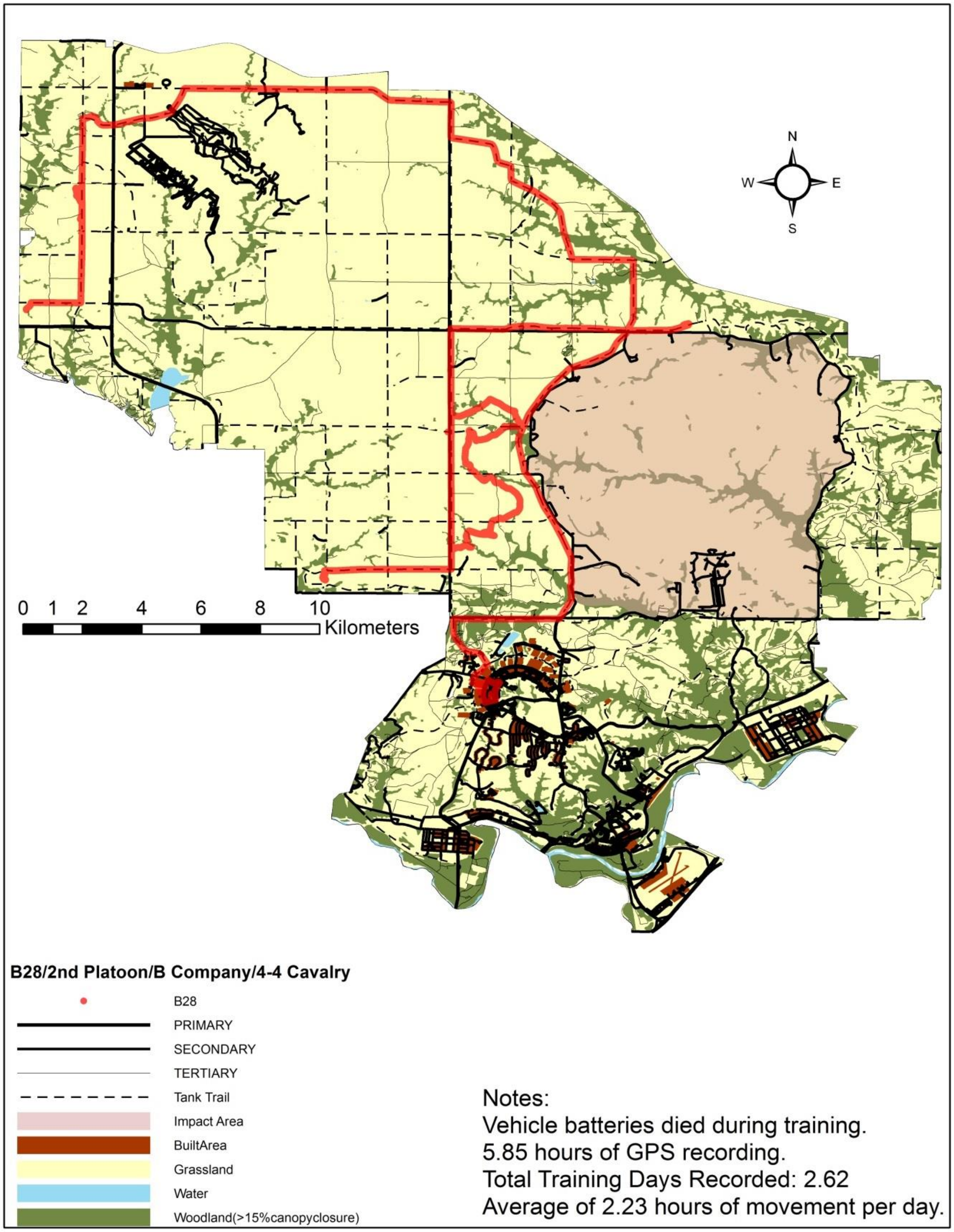


Figure B-109 GPS Points C7 4-4 Cavalry Squadron

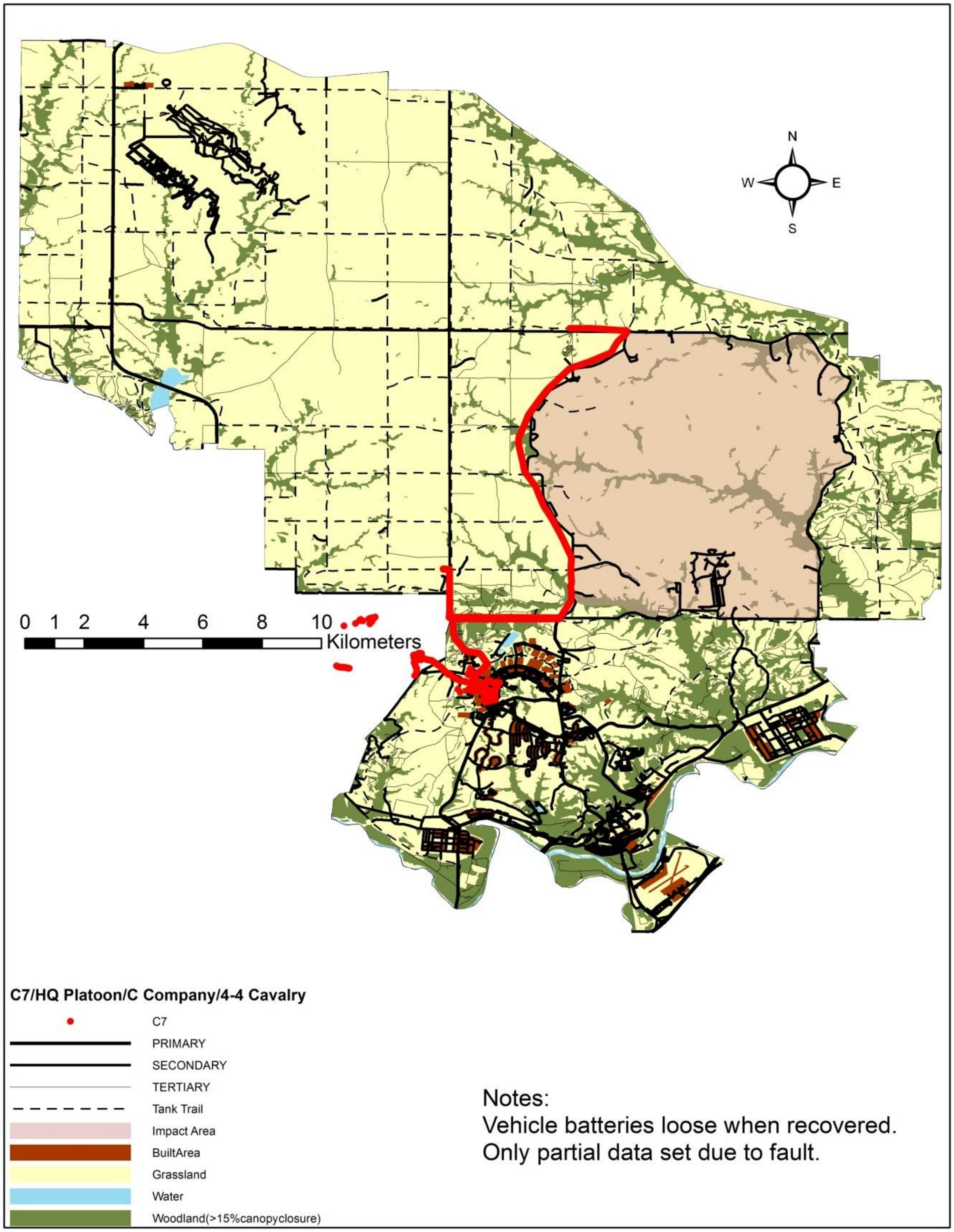


Figure B-110 GPS Points C11 4-4 Cavalry Squadron

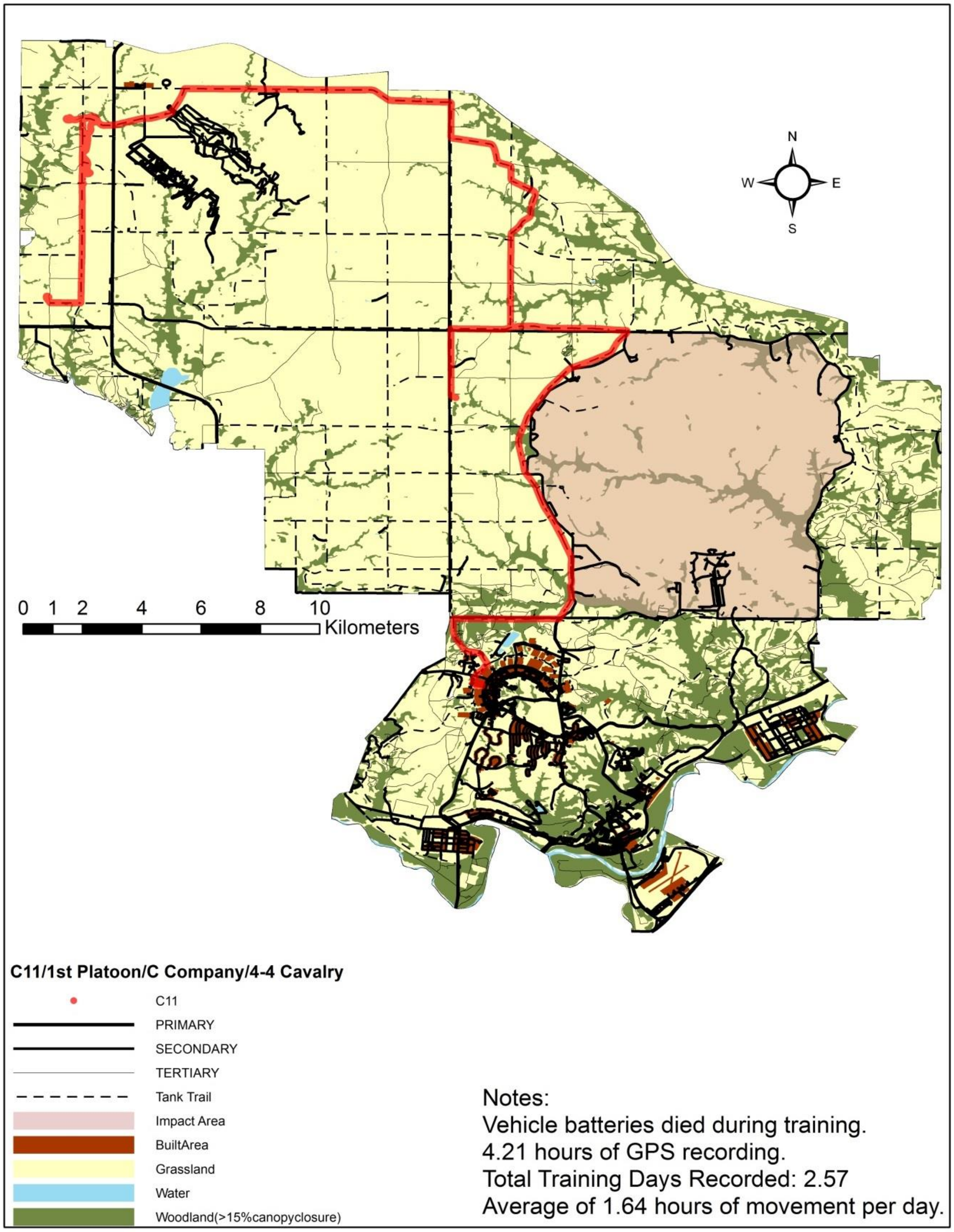


Figure B-111 GPS Points C14 4-4 Cavalry Squadron

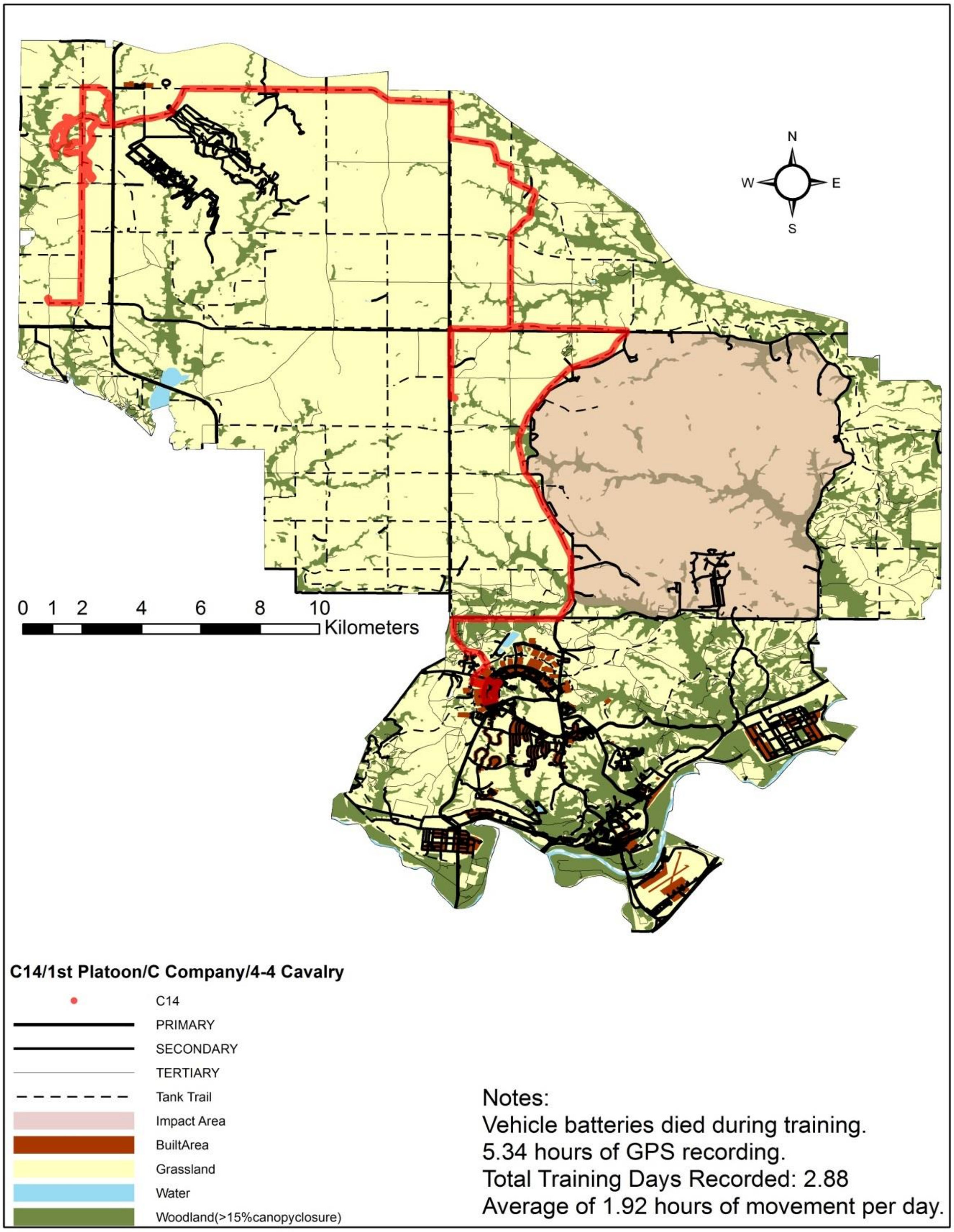


Figure B-112 GPS Points C21 4-4 Cavalry Squadron

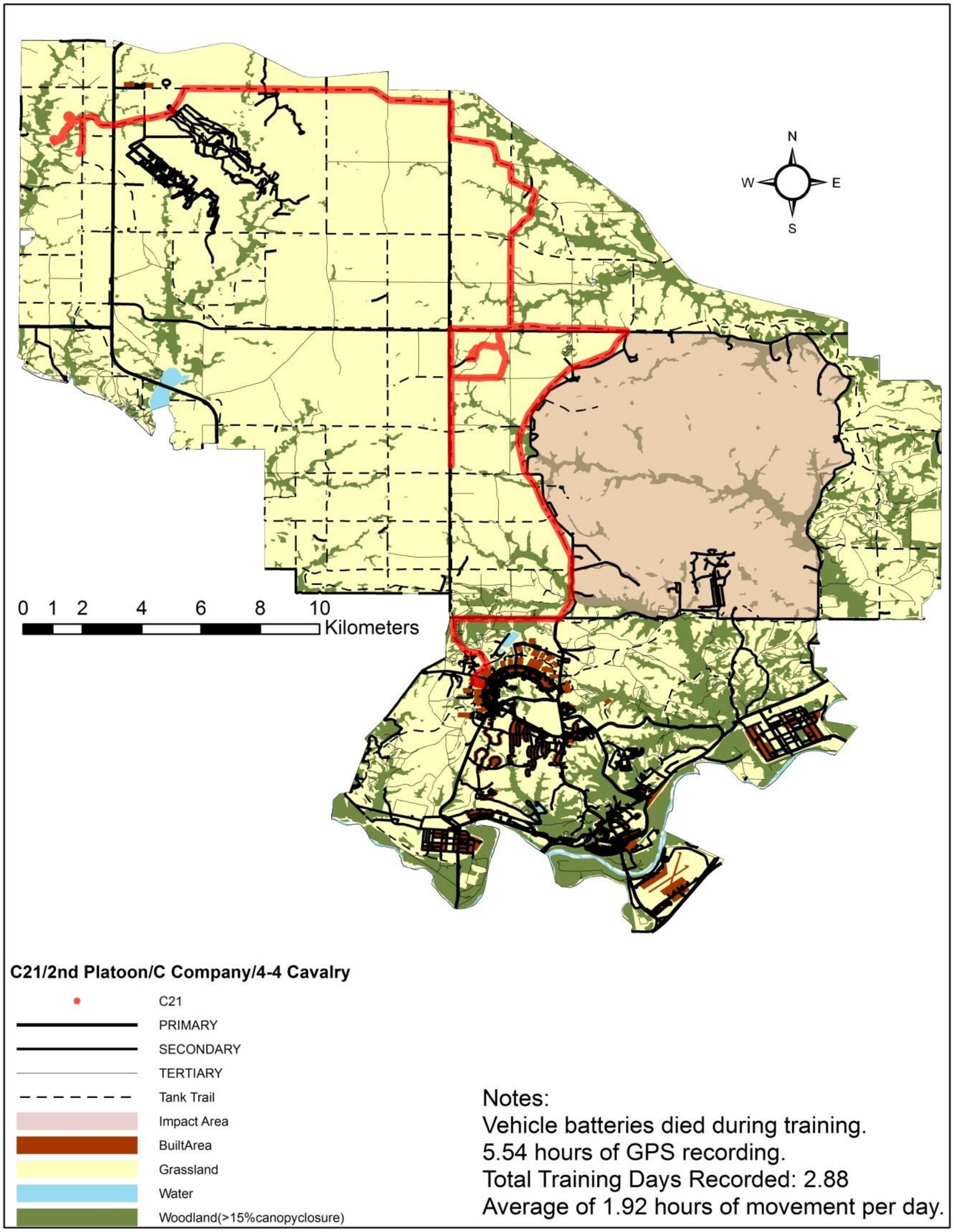


Figure B-113 GPS Points C26 4-4 Cavalry Squadron

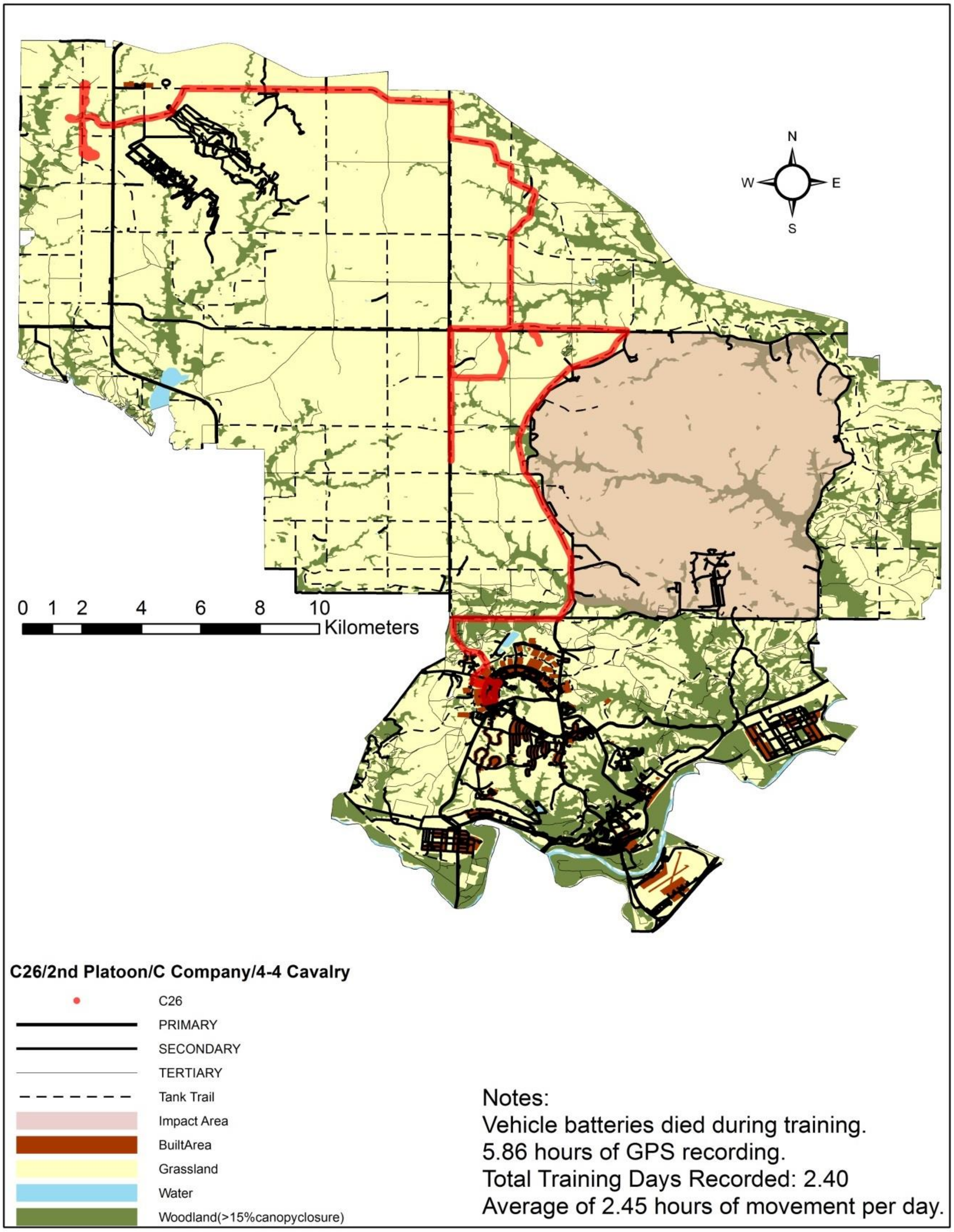


Figure B-114 GPS Points C66 4-4 Cavalry Squadron

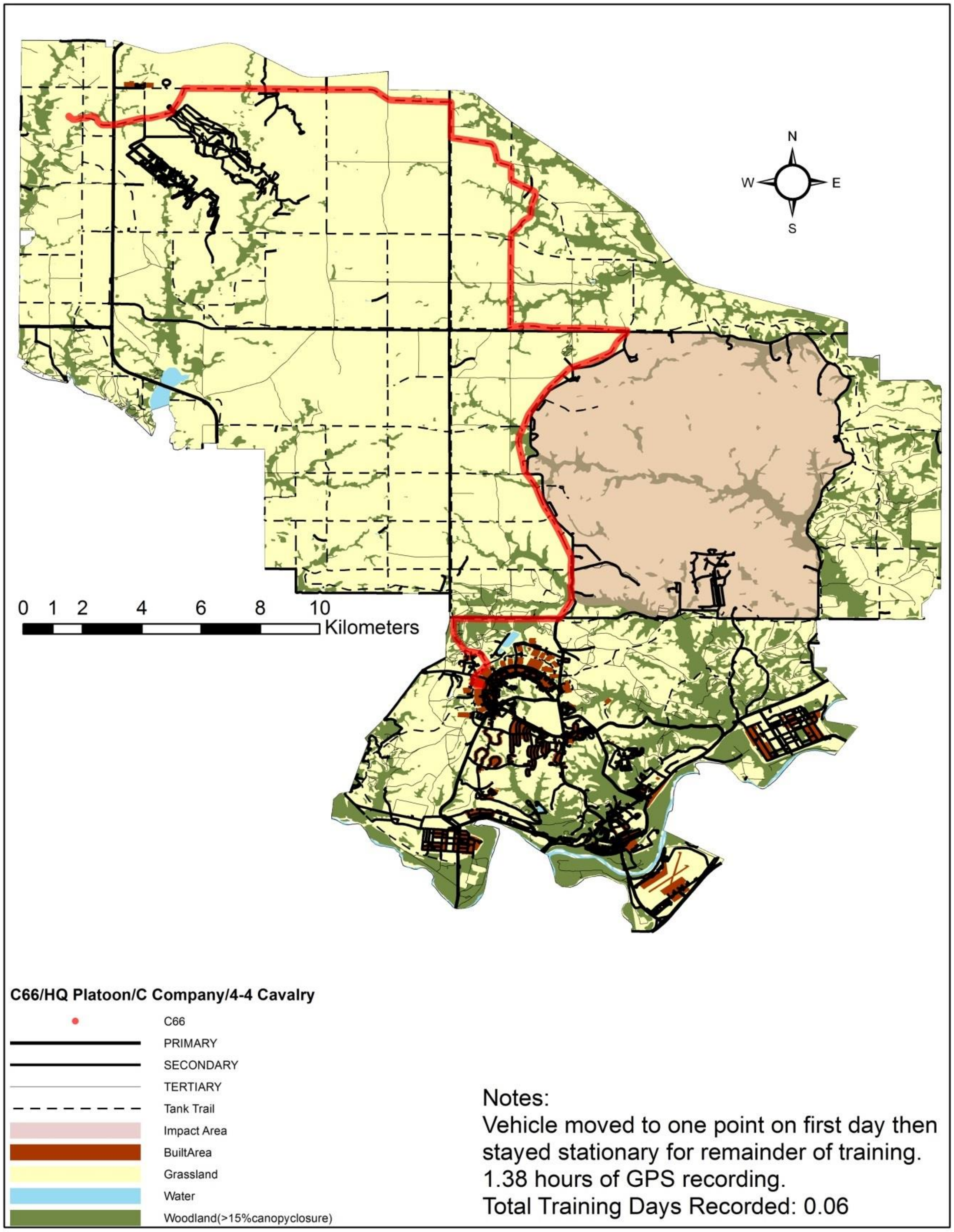


Figure B-115 GPS Points C77 4-4 Cavalry Squadron

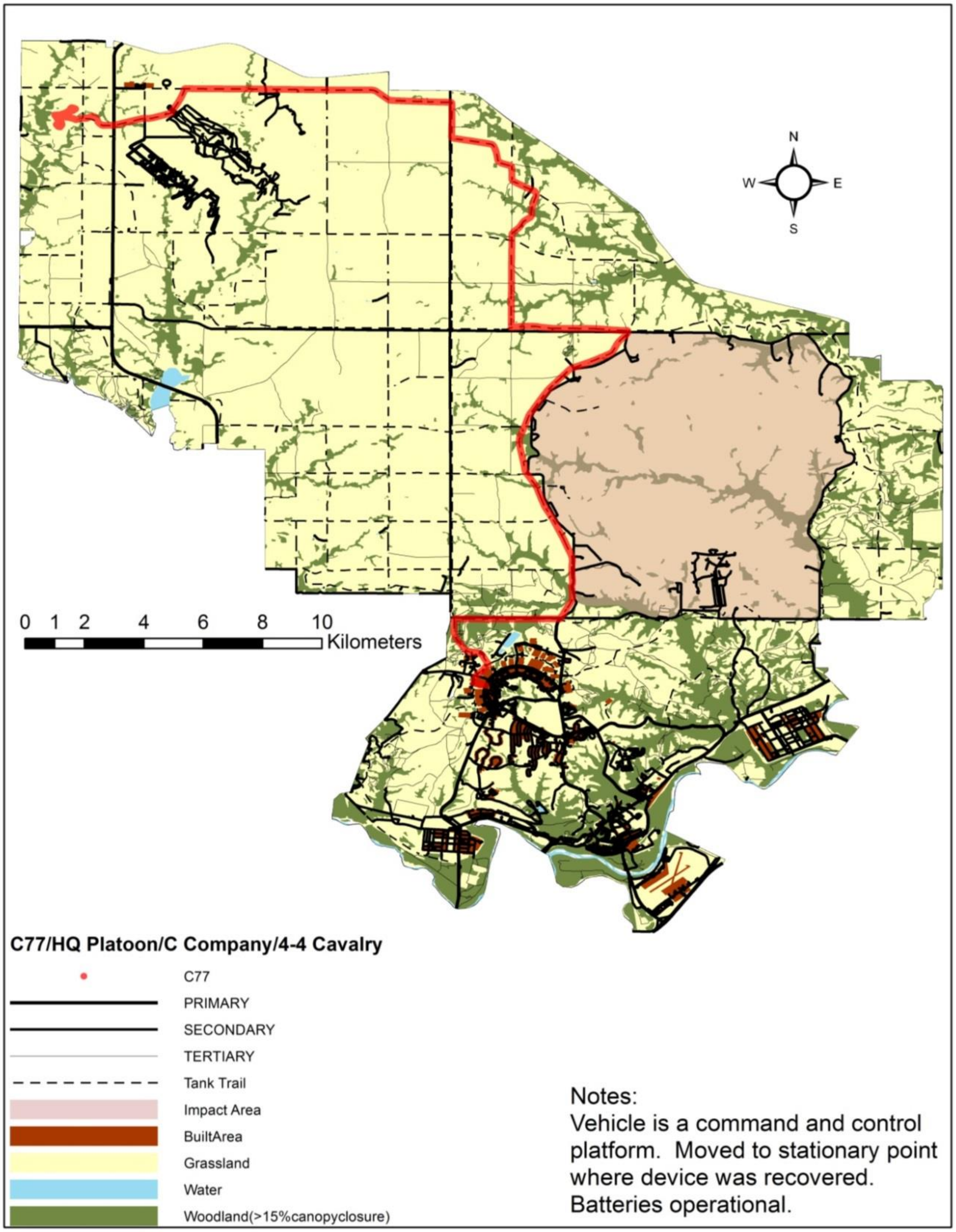
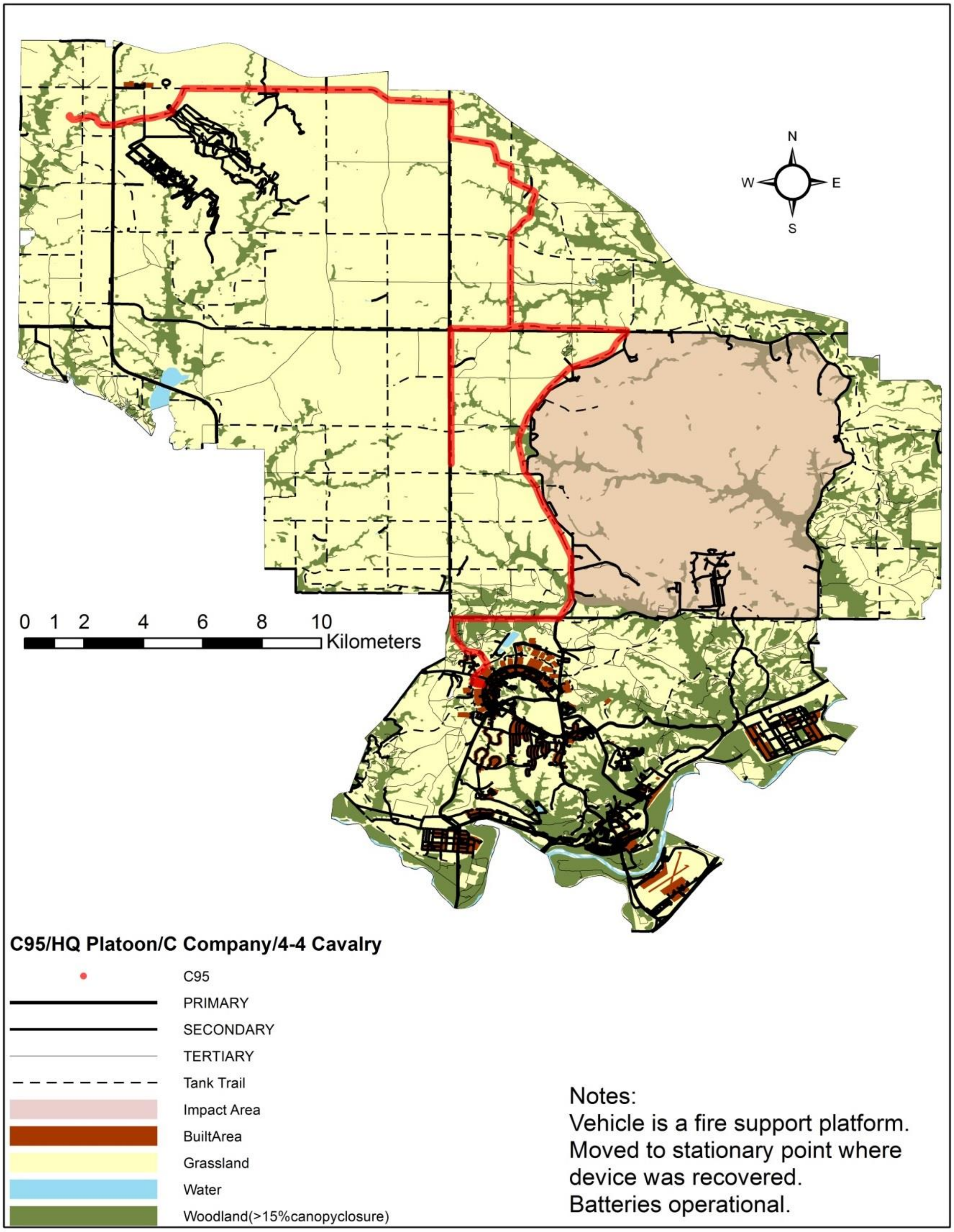

N
W
E
S
0 1 2 4 6 8 10
Kilometers
C77/HQ Platoon/C Company/4-4 Cavalry
C77
PRIMARY
SECONDARY
TERTIARY
Tank Trail
Impact Area
BuiltArea
Grassland
Water
Woodland(>15%canopyclosure)
Notes:
Vehicle is a command and control platform. Moved to stationary point where device was recovered.
Batteries operational.

Figure B-116 GPS Points C95 4-4 Cavalry Squadron



Appendix C - Off-Road Maps for Each Battalion/Squadron

Figure C-1 Off Road GPS Points for 4-4 Cavalry Squadron

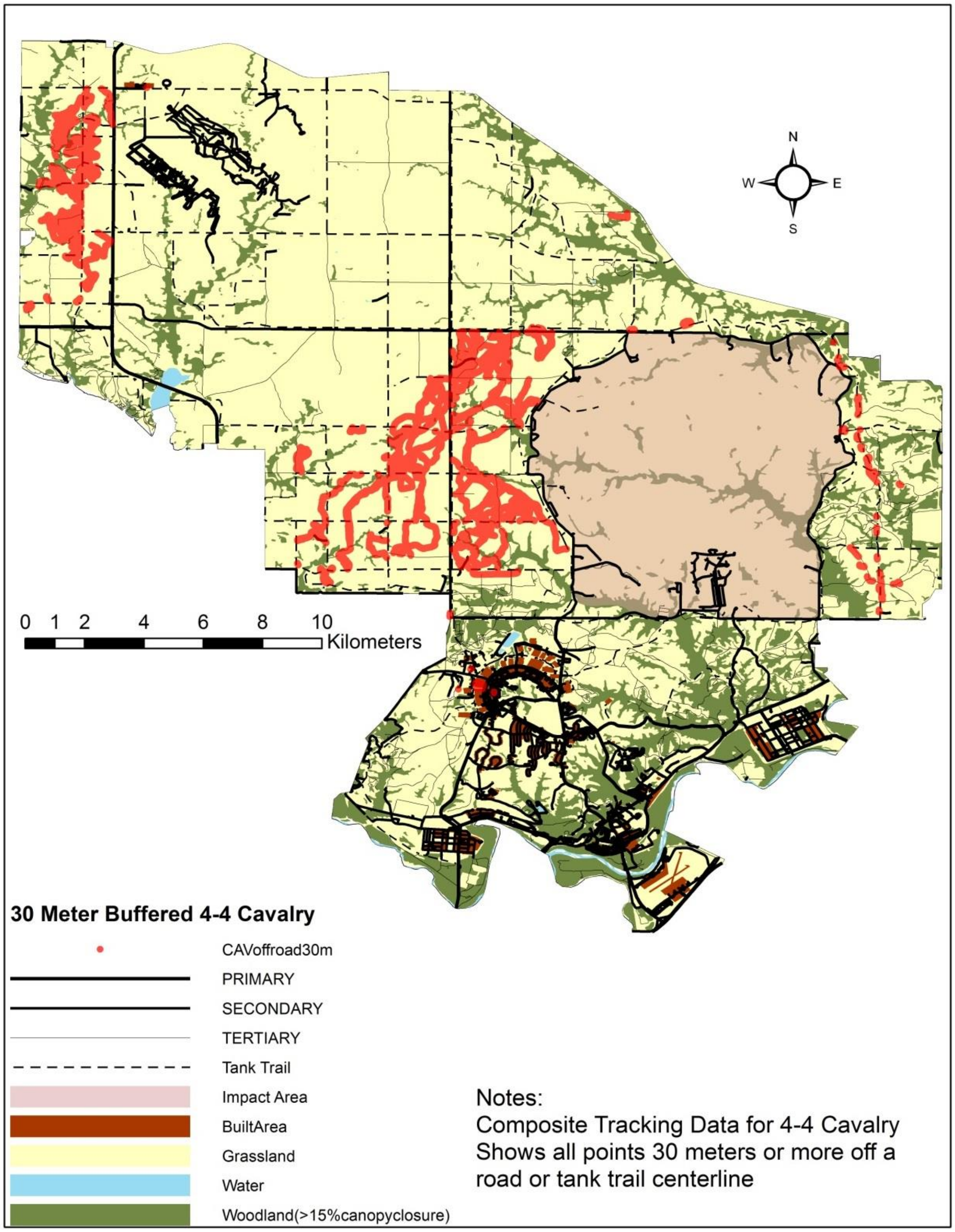


Figure C-2 Off Road GPS Points for 1-16 Infantry Battalion

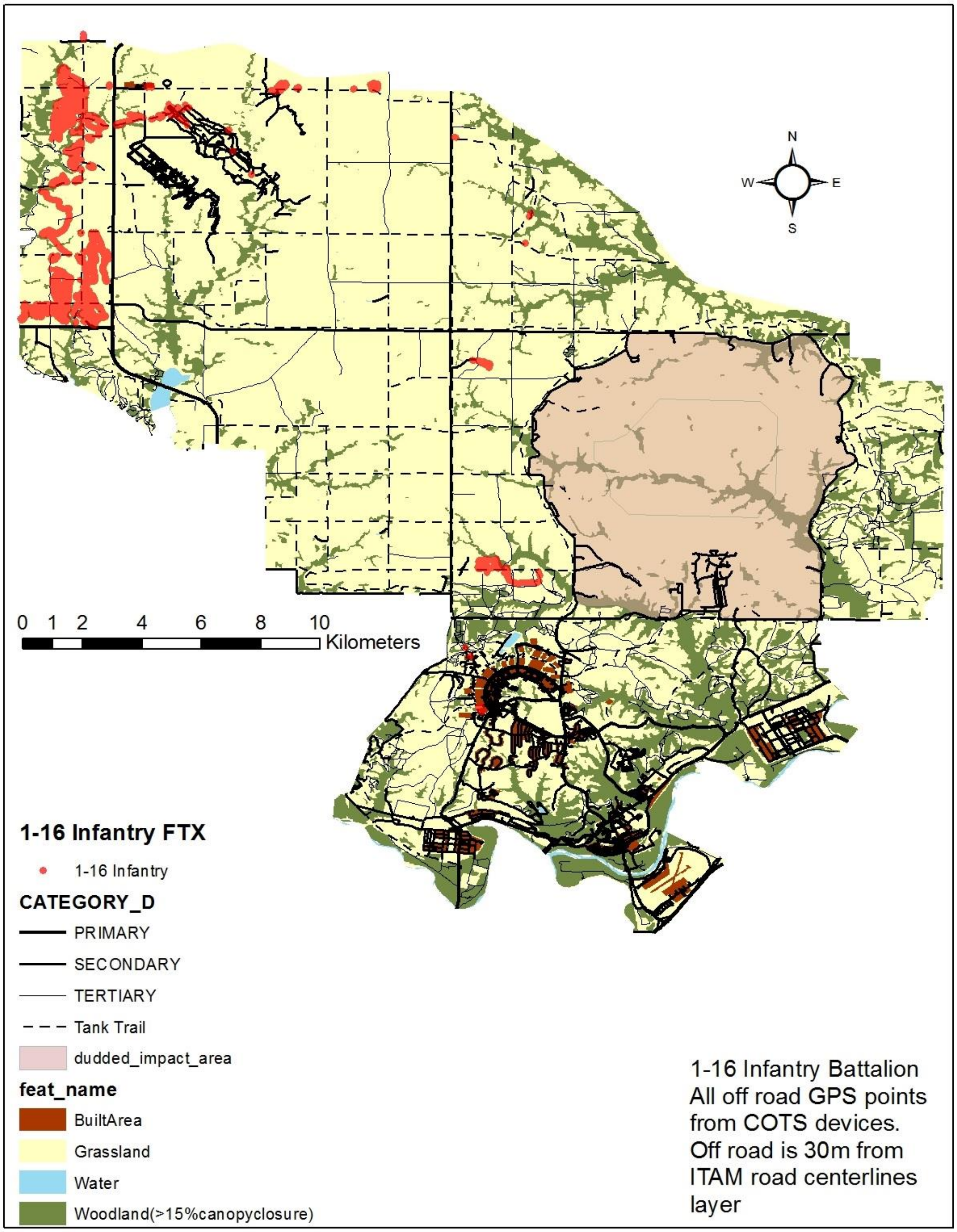
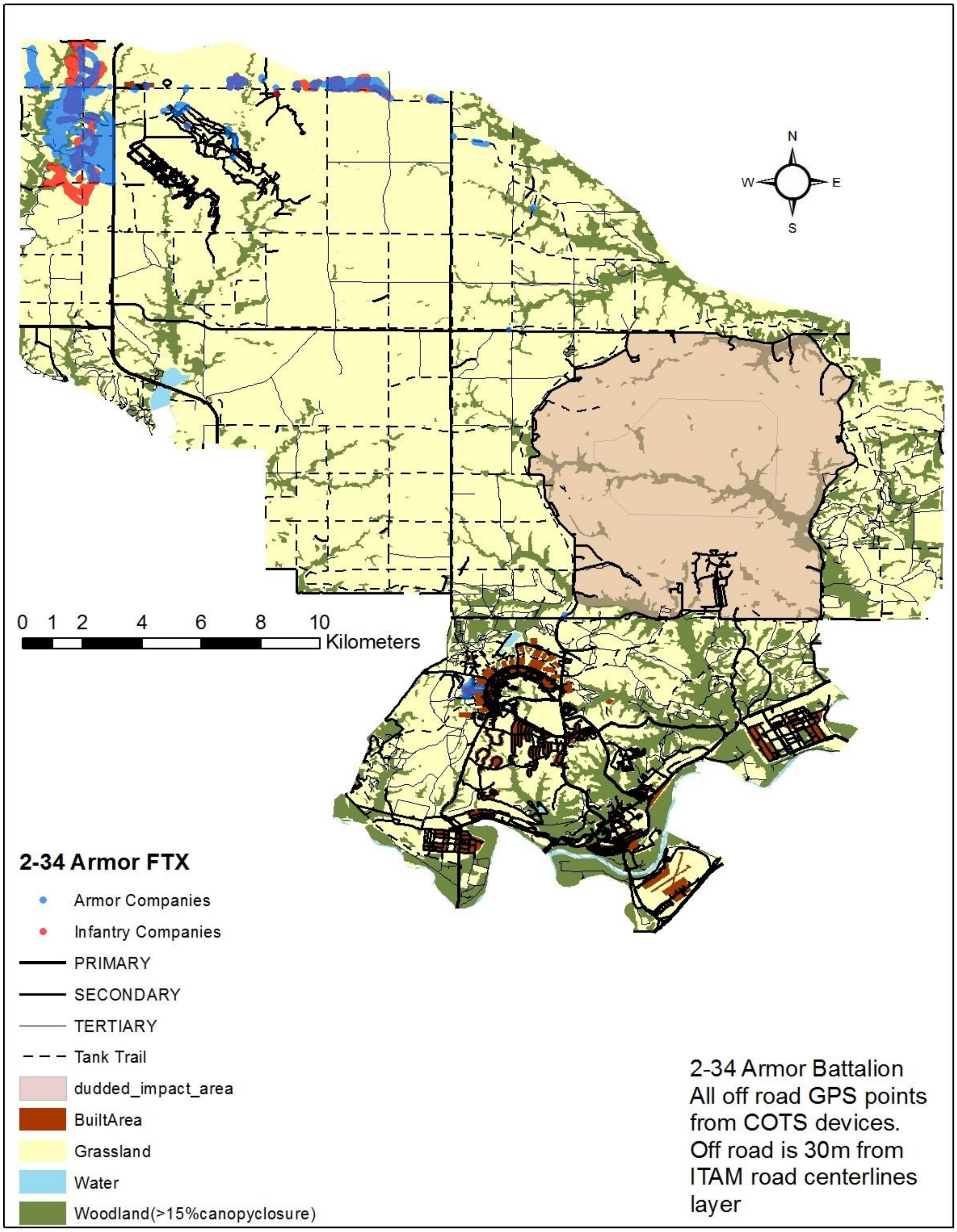


Figure C-3 Off Road GPS Points for 2-34 Armor Battalion



Appendix D - Pairwise Comparison Statistical Results

Question 1, 1a, 1b

Table D-1Question 1 to Chapter 5 Results

Platoon Code

PLT_Code_SAS	Unique Platoon ID
7	HQ/C/4-4 CAV
17	HQ/D/1-16IN
20	HQ/A/2-34AR
28	HQ/C/2-34AR
32	HQ/D/2-34AR

% of Training Time Spent Moving   F=0.96, p-value=0.5554

PLT	7	17	20	28	32
7 (**0.02370**)		≠ (0.0134)	=	=	=
17 (**0.08968**)			=	=	=
20 (**0.04046**)				=	=
28 (**0.02954**)					=
32 (**0.03819**)					

Means: 7=17=20=28=32

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	-3.0119	0.2213	14	-13.61	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	4	14	2.31	0.1093
7 vs ave(17,28,32)	1	14	2.70	0.1225
20 vs ave(17,28,32)	1	14	0.12	0.7372

% of Moving Time Spent off Road   F=2.04, p-value=0.0780

PLT	7	17	20	28	32
7 (**0.1659**)		=	=	=	=
17 (**0.1065**)			=	=	≠ (0.0372)
20 (**0.1037**)				=	≠ (0.0320)
28 (**0.1116**)					=
32 (**0.2214**)					

Means: not all are equal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	-1.8197	0.1681	14	-10.82	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	2.45	0.0946
7 vs ave(17,28,32)	1	14	0.55	0.4710
20 vs ave(17,28,32)	1	14	0.90	0.3599

Total Distance Traveled   F=1.78, p-value=0.1268

PLT(log)	7	17	20	28	32
7 (**4.7012**)		=	=	=	=
17 (**5.0404**)			=	≠ (0.0137)	=
20 (**4.8571**)				=	=
28 (**4.4834**)					≠ (0.0191)
32 (**4.9541**)					

Means: 7=17=20=28=32

Not normal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	4.8260	0.07427	14	64.98	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	2.80	0.0673
7 vs ave(17,28,32)	1	14	0.97	0.3415
20 vs ave(17,28,32)	1	14	0.04	0.8421

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
53	**15**	**1**	**1-16IN**	**Armor**
50	**14**	**1**	**1-16IN**	**Armor**
75	**20**	**2**	**2-34AR**	**Headquarters**
74	**20**	**2**	**2-34AR**	**Headquarters**
100	**29**	**1**	**2-34AR**	**Armor**
40	**11**	**2**	**1-16IN**	**infantry**

Distance Traveled off Road   F=4.20, p-value=0.0032

PLT(log10)	7	17	20	28	32
7 (**3.3744**)		≠ (0.0479)	=	=	≠ (**0.0043**)
17 (**3.7905**)			=	≠ (**0.0390**)	=
20 (**3.5636**)				=	=
28 (**3.2728**)					≠ (**0.0057**)
32 (**3.9591**)					

Means: not all are equal

Not normal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	3.6741	0.08595	14	42.75	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	4.34	0.0172
7 vs ave(17,28,32)	1	14	4.05	0.0639
20 vs ave(17,28,32)	1	14	0.41	0.5300

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
75	**20**	**2**	**2-34AR**	**Headquarters**
100	**29**	**1**	**2-34AR**	**Armor**
74	**20**	**2**	**2-34AR**	**Headquarters**
40	**11**	**2**	**1-16IN**	**infantry**

Average Total Speed F=1.63, p-value=0.1659

PLT(log10)	7	17	20	28	32
7 (**0.9055**)		=	≠ (**0.0497**)	≠ (**0.0017**)	≠ (**0.0499)**
17 (**0.8161**)			=	=	=
20 (**0.7993**)				=	=
28 (**0.7065**)					=
32 (**0.8151**)					

Means: not all are equal

Not normal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	0.7792	0.02164	14	36.00	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	3.94	0.0239
7 vs ave(17,28,32)	1	14	11.75	0.0041
20 vs ave(17,28,32)	1	14	0.20	0.6617

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
100	29	1	2-34AR	Armor
10	3	5	4-4 CAV	Cavalry
74	20	2	2-34AR	Headquarters
75	20	2	2-34AR	Headquarters
19	4	5	4-4 CAV	Cavalry

Average Speed off Road F=1.47, p-value=0.2235

PLT(log10)	7	17	20	28	32
7 (**0.3958**)		≠ (**0.0208**)	=	=	=
17 (**0.5618**)			=	=	=
20 (**0.5046**)				=	=
28 (**0.4824**)					=
32 (**0.4850**)					

Means: 7<17=20=28=32

Not normal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	0.5098	0.02797	14	18.23	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	4	14	1.89	0.1679
7 vs ave(17,28,32)	1	14	5.72	0.0314
20 vs ave(17,28,32)	1	14	0.01	0.9300

Outliers:

Obs	**PLTNo**	**VehNo**	**Battlaion**	**Platoon_Type**
105	**31**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
77	**22**	**2**	**2-34AR**	**Infantry**
93	**27**	**1**	**2-34AR**	**Armor**
94	**27**	**1**	**2-34AR**	**Armor**
116	**32**	**6**	**2-34AR**	**Headquarters**

%Off Road time with Turing Radius less than 30m F=6.12, p-value=0.0004

PLT	7	17	20	28	32
7 (**0.7250**)		≠ (**0.0002**)	≠ (**0.0043**)	≠ (**0.0304**)	≠ (**0.0002**)
17 (**0.5539**)			=	=	=
20 (**0.6119**)				=	=
28 (**0.6358**)					=
32 (**0.5628**)					

Means: 17=32=20=28<7

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	0.3421	0.06575	14	5.20	0.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	4	14	8.63	0.0010
7 vs ave(17,28,32)	1	14	26.07	0.0002
20 vs ave(17,28,32)	1	14	0.78	0.3921

Question 1 gamma

Total Distance Traveled F=1.85, p-value=0.1116

PLT	7	17	20	28	32
7 (**50504**)		=	=	=	=
17 (**111168**)			=	≠ (**0.0172**)	=
20 (**81753**)				=	=
28 (**33982**)					≠ (**0.0261**)
32 (**90551**)					

Means: 7=17=20=28=32 based on 0.05

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(17,28,32)	11.1553	0.1647	14	67.74	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	4	14	2.76	0.0698
7 vs ave(17,28,32)	1	14	1.34	0.2659

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
20 vs ave(17,28,32)	1	14	0.21	0.6536

Distance Traveled off Road F=4.28, p-value=0.0029

PLT	7	17	20	28	32
7 (**2433.63**)		≠ (**0.0304**)	=	=	≠ (**0.0014**)
17 (**6356.43**)			=	≠ (**0.0240**)	=
20 (**5195.17**)				=	=
28 (**1937.40**)					≠ (**0.0021**)
32 (**9711.17**)					

Means: not all are equal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(17,28,32)	8.5025	0.1769	14	48.07	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	5.76	0.0059
7 vs ave(17,28,32)	1	14	5.37	0.0361
20 vs ave(17,28,32)	1	14	0.02	0.8847

Average Total Speed F=1.59, p-value=0.1784

PLT	7	17	20	28	32
7 (**8.0464**)		=	=	≠ (**0.0019**)	=
17 (**6.5587**)			=	=	=
20 (**6.3722**)				=	=
28 (**5.0879**)					=
32 (**6.5563**)					

Means: not all are equal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(17,28,32)	1.7960	0.05045	14	35.60	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	3.81	0.0269
7 vs ave(17,28,32)	1	14	11.35	0.0046
20 vs ave(17,28,32)	1	14	0.28	0.6019

Average Speed off Road F=1.69, p-value=0.1477

PLT	7	17	20	28	32
7 (**2.4920**)		≠ (**0.0158**)	=	=	=
17 (**3.6571**)			=	=	=
20 (**3.2041**)				=	=
28 (**3.0427**)					=
32 (**3.0973**)					

Means: 7=17=20=28=32

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(17,28,32)	1.1800	0.06152	14	19.18	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	4	14	2.11	0.1337
7 vs ave(17,28,32)	1	14	6.44	0.0237
20 vs ave(17,28,32)	1	14	0.02	0.9040

Appendix E - Pairwise Comparison Statistical Results

Question 2, 5

Table E-1 Chapter 5 Questions 2 & 5 Results

PLT_Code_SAS	Unique Platoon ID
8	1/A/1-16IN
9	2/A/1-16IN
10	3/A/1-16IN
11	1/B/1-16IN
12	2/B/1-16IN
13	3/B/1-16IN
18	1/A/2-34AR
19	2/A/2-34AR
21	3/A/2-34AR
22	1/B/2-34AR
23	2/B/2-34AR
25	3/B/2-34AR

Question 2 beta log10

% of Training Time Spent Moving   F=2.39, p-value=0.0632

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**0.03933**)		=	=	=	=	=	=	=	=	=	≠	=
9 (**0.05690**)			=	=	=	=	=	=	=	=	=	=
10 (**0.03713**)				=	=	=	=	=	=	=	≠	=
11 (**0.07380**)					=	=	=	=	=	=	=	=
12 (**0.05373**)						=	=	=	=	=	≠	=
13 (**0.05483**)							=	=	=	=	=	=
18 (**0.07121**)								=	=	=	=	=
19 (**0.06213**)									=	=	=	=
21 (**0.04437**)										=	≠	=
22 (**0.04624**)											≠	=
23 (**0.09441**)												≠

25 (**0.04534**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25 based on 0.05

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	-2.9174	0.1108	11	-26.33	<.0001
ave(18,19,21,22,23,25)	-2.7812	0.08727	11	-31.87	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	11	11	1.84	0.1638
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	0.93	0.3549

% of Moving Time Spent off Road   F=2.32, p-value=0.0485

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**0.2844**)		≠	≠	=	=	≠	=	=	=	=	≠	=
9 (**0.1432**)			=	=	=	=	=	≠	=	=	=	=
10 (**0.1276**)				=	=	=	=	≠	=	=	=	=
11 (**0.1651**)					=	=	=	≠	=	=	=	=
12 (**0.1828**)						=	=	≠	=	=	=	=
13 (**0.1169**)							=	≠	=	=	=	=
18 (**0.1817**)								≠	=	=	≠	≠
19 (**0.3588**)									=	=	=	=
21 (**0.2080**)										=	=	=
22 (**0.2125**)											≠	=
23 (**0.1028**)												=

25 (**0.1648**)												

Means: not all are equal

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	-1.6292	0.1170	11	-13.92	<.0001
ave(18,19,21,22,23,25)	-1.4204	0.1087	11	-13.07	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	11	11	2.74	0.0544
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	1.71	0.2177

Total Distance Traveled F=1.51, p-value=0.2390

PLT(log10)	8	9	10	11	12	13	18	19	21	22	23	25
8 (**5.0204**)		=	=	=	=	=	=	=	=	=	=	=
9 (**5.2529**)			=	=	=	=	=	=	=	=	=	=
10 (**5.0883**)				=	=	=	=	=	=	=	=	=
11 (**5.1960**)					=	=	=	=	=	=	=	=
12 (**5.2804**)						=	=	=	=	≠	=	=
13 (**4.9604**)							=	=	=	=	=	=
18 (**5.0555**)								=	=	=	=	=
19 (**5.0341**)									=	=	=	=
21 (**4.9200**)										=	=	=

22 (**4.7411**)											=	=
23 (**4.9724**)												=
25 (**4.9278**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25

Not normal

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	5.1331	0.07294	11	70.38	<.0001
ave(18,19,21,22,23,25)	4.9418	0.07053	11	70.07	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	11	11	0.78	0.6557
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	3.55	0.0861

Outliers:

Obs	**PLTNo**	**VehNo**	**Battlaion**	**Platoon_Type**
52	**15**	**1**	**1-16IN**	**Armor**
49	**14**	**1**	**1-16IN**	**Armor**
73	**20**	**2**	**2-34AR**	**Headquarters**
78	**23**	**2**	**2-34AR**	**Infantry**
72	**20**	**2**	**2-34AR**	**Headquarters**

Distance Traveled off Road F=4.93, p-value=0.0038

PLT(log10)	8	9	10	11	12	13	18	19	21	22	23	25
8 (**4.2315**)		=	=	=	=	≠	=	=	=	≠	≠	=

9 (**4.1043**)			=	=	=	≠	=	=	=	=	=	=
10 (**3.9507**)				=	=	=	=	=	=	=	=	=
11 (**4.0640**)					=	=	=	=	=	=	=	=
12 (**4.2237**)						≠	=	=	=	≠	≠	=
13 (**3.5798**)							≠	≠	=	=	=	=
18 (**4.0851**)								=	=	=	=	=
19 (**4.3441**)									=	≠	≠	≠
21 (**3.9889**)										=	=	=
22 (**3.7259**)											=	=
23 (**3.7700**)												=
25 (**3.8018**)												

Means: not all are equal

Not normal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	4.0257	0.06204	11	64.89	<.0001
ave(18,19,21,22,23,25)	3.9526	0.05549	11	71.23	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	2.52	0.0707

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	4.0257	0.06204	11	64.89	<.0001
ave(18,19,21,22,23,25)	3.9526	0.05549	11	71.23	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	0.77	0.3989

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
73	**20**	**2**	**2-34AR**	**Headquarters**
98	**29**	**1**	**2-34AR**	**Armor**
72	**20**	**2**	**2-34AR**	**Headquarters**
39	**11**	**2**	**1-16IN**	**infantry**

Average Total Speed   F=1.76, p-value=0.1591

PLT(log10)	8	9	10	11	12	13	18	19	21	22	23	25

8 (**0.7603**)		=	=	=	=	=	=	=	=	=	=	=
9 (**0.7971**)			=	=	=	=	=	=	=	=	=	=
10 (**0.8072**)				=	=	=	=	=	=	=	=	=
11 (**0.8426**)					=	=	≠	=	=	=	=	=
12 (**0.8477**)						=	≠	=	=	=	=	=
13 (**0.8919**)							≠	=	≠	=	≠	=
18 (**0.6956**)								=	=	=	=	=
19 (**0.7484**)									=	=	=	=
21 (**0.7279**)										=	=	=
22 (**0.8020**)											=	=
23 (**0.7327**)												=
25 (**0.8081**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25

Not normal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	0.8245	0.01944	11	42.42	<.0001
ave(18,19,21,22,23,25)	0.7524	0.01877	11	40.08	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	1.47	0.2677
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	7.10	0.0220

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
98	**29**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
72	**20**	**2**	**2-34AR**	**Headquarters**

Average Speed off Road F=6.31, p-value=0.0013

PLT(log10)	8	9	10	11	12	13	18	19	21	22	23	25
8 (**0.5186**)		=	=	=	=	=	=	=	=	=	=	=
9 (**0.4957**)			=	=	=	=	=	=	=	=	=	=
10 (**0.5646**)				=	=	=	=	=	=	≠	=	=
11 (**0.4960**)					=	=	=	=	=	=	=	=
12 (**0.5318**)						=	=	=	=	=	=	=
13 (**0.4644**)							=	=	=	=	=	=
18 (**0.4683**)								=	=	=	=	=
19 (**0.5043**)									=	=	=	=
21 (**0.4828**)										=	=	=
22 (**0.4637**)											=	=
23 (**0.5262**)												=
25 (**0.4954**)												

Means: not all are equal

Normality is ok

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	0.5119	0.01267	11	40.39	<.0001
ave(18,19,21,22,23,25)	0.4901	0.01075	11	45.57	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	0.97	0.5228
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	1.71	0.2176

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
103	**31**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**

%Off Road time with Turing Radius less than 30m F=6.22, p-value=0.0014

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**0.5667**)		=	=	=	=	=	=	=	=	=	=	=
9 (**0.6094**)			=	=	=	=	=	=	=	=	≠	=
10 (**0.5563**)				=	=	=	=	=	=	=	=	=
11 (**0.5753**)					=	=	=	=	=	=	=	=
12 (**0.5670**)						=	=	=	=	=	=	=
13 (**0.6438**)							=	=	=	=	≠	=
18 (**0.5930**)								=	=	=	=	=
19 (**0.5656**)									=	=	=	=
21 (**0.6295**)										=	≠	=
22 (**0.6055**)											=	=
23 (**0.5346**)												=
25 (**0.5646**)												

Means: not all are equal

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	0.3507	0.04506	11	7.78	<.0001
ave(18,19,21,22,23,25)	0.3329	0.03812	11	8.73	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	11	11	1.62	0.2190
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	0.09	0.7681

Question 2 gamma

Total Distance Traveled F=1.58, p-value=0.2111

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**106391**)		=	=	=	=	=	=	=	=	=	=	=
9 (**179091**)			=	=	=	=	=	=	=	=	=	=
10 (**123257**)				=	=	=	=	=	=	=	=	=
11 (**167660**)					=	=	=	=	=	=	=	=
12 (**191220**)						=	=	=	=	≠	=	=
13 (**99003**)							=	=	=	=	=	=
18 (**114101**)								=	=	=	=	=
19 (**109245**)									=	=	=	=
21 (**83830**)										=	=	=
22 (**56062**)											=	=
23 (**105701**)												=
25 (**86212**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(8,9,10,11,12,13)	11.8477	0.1609	11	73.64	<.0001
ave(18,19,21,22,23,25)	11.4083	0.1556	11	73.33	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	11	11	0.83	0.6176
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	3.85	0.0754

Distance Traveled off Road F=5.08, p-value=0.0033

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**17390**)		=	=	=	=	≠	=	=	=	≠	≠	=
9 (**12736**)			=	=	=	=	=	=	=	=	=	=
10 (**8966.93**)				=	=	=	=	=	=	=	=	=
11 (**13847**)					=	=	=	=	=	=	=	=
12 (**16742**)						≠	=	=	=	≠	=	=
13 (**5003.91**)							=	≠	=	=	=	=
18 (**12306**)								=	=	=	=	=
19 (**22481**)									=	≠	≠	≠
21 (**9999.45**)										=	=	=
22 (**5667.08**)											=	=
23 (**6440.69**)												=
25 (**7037.13**)												

Means: not all are equal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	9.3494	0.1356	11	68.93	<.0001
ave(18,19,21,22,23,25)	9.1534	0.1255	11	72.94	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	2.25	0.0970
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	1.13	0.3114

Average Total Speed F=1.72, p-value=0.1704

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**5.7583**)		=	=	=	=	=	=	=	=	=	=	=
9 (**6.2695**)			=	=	=	=	=	=	=	=	=	=
10 (**6.4146**)				=	=	=	=	=	=	=	=	=
11 (**6.9654**)					=	=	≠	=	=	=	=	=
12 (**7.0420**)						=	≠	=	=	=	=	=
13 (**7.7975**)							≠	=	≠	=	≠	=
18 (**4.9619**)								=	=	=	=	=
19 (**5.6031**)									=	=	=	=
21 (**5.3451**)										=	=	=
22 (**6.3679**)											=	=
23 (**5.4232**)												=
25 (**6.4522**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	1.8986	0.04521	11	42.00	<.0001
ave(18,19,21,22,23,25)	1.7346	0.04361	11	39.77	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	1.44	0.2780
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	6.82	0.0242

Average Speed off Road F=6.08, p-value=0.0015

PLT	8	9	10	11	12	13	18	19	21	22	23	25
8 (**3.3182**)		=	=	=	=	=	=	=	=	=	=	=
9 (**3.1388**)			=	=	=	=	=	=	=	=	=	=
10 (**3.6753**)				=	=	=	=	=	=	=	=	=
11 (**3.1650**)					=	=	=	=	=	=	=	=
12 (**3.4102**)						=	=	=	=	=	=	=
13 (**2.9200**)							=	=	=	=	=	=
18 (**2.9480**)								=	=	=	=	=
19 (**3.1976**)									=	=	=	=
21 (**3.0438**)										=	=	=
22 (**2.9449**)											=	=
23 (**3.3604**)												=
25 (**3.1619**)												

Means: 8=9=10=11=12=13=18=19=21=22=23=25

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(8,9,10,11,12,13)	1.1826	0.02962	11	39.93	<.0001
ave(18,19,21,22,23,25)	1.1333	0.02513	11	45.09	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	11	11	0.89	0.5743
ave(8,9,10,11,12,13) vs ave(18,19,21,22,23,25)	1	11	1.61	0.2311

Appendix F - Pairwise Comparison Statistical Results Question 3, 6

Table F-1 Chapter 5 Questions 3 & 6 Results

PLT_Code_SAS	Unique Platoon ID
14	1/D/1-16IN
15	2/D/1-16IN
16	3/D/1-16IN
26	1/C/2-34AR
27	2/C/2-34AR
29	3/C/2-34AR
30	1/D/2-34AR
31	2/D/2-34AR
33	3/D/2-34AR

Question 3 beta log10

% of Training Time Spent Moving   F=2.39, p-value=0.0632

PLT	14	15	16	26	27	29	30	31	33
14 (**0.06750**)		=	=	=	=	=	=	=	=
15 (**0.09880**)			=	≠	≠	≠	≠	≠	≠
16 (**0.08093**)				=	=	=	=	=	=
26 (**0.04418**)					=	=	=	=	=
27 (**0.05211**)						=	=	=	=
29 (**0.04498**)							=	=	=
30 (**0.05173**)								=	=
31 (**0.05091**)									=
33 (**0.04521**)									

Means: 14=15=16=26=27=29=30=31=33 based on 0.05

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(14,15,16)	-2.4221	0.1475	11	-16.43	<.0001
ave(26,27,29,30,31,33)	-2.9858	0.09910	11	-30.13	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	8	11	2.25	0.1065
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	10.07	0.0089

% of Moving Time Spent off Road F=3.35, p-value=0.0186

PLT	14	15	16	26	27	29	30	31	33
14 (**0.1548**)		=	=	=	=	=	≠	≠	=
15 (**0.1153**)			=	=	=	=	≠	≠	≠
16 (**0.09705**)				=	=	=	≠	=	≠
26 (**0.1978**)					=	=	=	≠	=
27 (**0.1952**)						=	=	≠	=
29 (**0.1233**)							≠	≠	≠
30 (**0.2984**)								≠	=
31 (**0.04318**)									≠
33 (**0.2517**)									

Means: not all are equal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	-1.9887	0.1912	11	-10.40	<.0001
ave(26,27,29,30,31,33)	-1.6369	0.1150	11	-14.23	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	4.78	0.0097
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	2.49	0.1431

Total Distance Traveled F=1.51, p-value=0.2390

PLT(log10)	14	15	16	26	27	29	30	31	33
14 (**5.1103**)		=	=	=	=	=	=	=	=
15 (**5.1688**)			=	=	=	=	=	=	=
16 (**5.2418**)				=	=	=	=	=	=
26 (**4.8522**)					=	=	=	=	=
27 (**4.9045**)						=	=	=	=
29 (**4.7963**)							=	=	=
30 (**4.9844**)								=	=
31 (**4.9542**)									=
33 (**4.9879**)									

Means: 14=15=16=26=27=29=30=31=33

Not normal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(14,15,16)	5.1736	0.1083	11	47.78	<.0001
ave(26,27,29,30,31,33)	4.9133	0.07122	11	68.98	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	0.64	0.7344
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	4.04	0.0697

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
52	15	1	1-16IN	Armor
49	14	1	1-16IN	Armor
73	20	2	2-34AR	Headquarters
78	23	2	2-34AR	Infantry
72	20	2	2-34AR	Headquarters
98	29	1	2-34AR	Armor

Distance Traveled off Road F=4.93, p-value=0.0038

PLT(log10)	14	15	16	26	27	29	30	31	33
14 (**4.1021**)		=	=	=	=	≠	=	≠	=
15 (**4.0173**)			=	=	=	=	=	≠	=
16 (**3.9221**)				=	=	=	=	≠	=
26 (**3.9153**)					=	=	=	≠	=
27 (**4.0724**)						≠	=	≠	=
29 (**3.6310**)							≠	≠	≠
30 (**4.2615**)								≠	=
31 (**3.2008**)									≠
33 (**4.1791**)									

Means: not all are equal

Not normal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	4.0139	0.1006	11	39.90	<.0001
ave(26,27,29,30,31,33)	3.8767	0.05744	11	67.49	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	5.61	0.0052
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	1.40	0.2613

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
73	20	2	2-34AR	Headquarters
72	20	2	2-34AR	Headquarters
39	11	2	1-16IN	infantry
10	3	5	4-4 CAV	Cavalry

Average Total Speed F=1.76, p-value=0.1591

PLT(log10)	14	15	16	26	27	29	30	31	33
14 (**0.7672**)		=	=	=	=	=	=	=	=
15 (**0.7717**)			=	=	=	=	=	=	=
16 (**0.8431**)				=	=	=	=	=	=
26 (**0.6979**)					=	=	=	=	=
27 (**0.7436**)						=	=	=	=
29 (**0.7219**)							=	=	=
30 (**0.7191**)								=	=
31 (**0.7949**)									=
33 (**0.7480**)									

Means: 14=15=16=26=27=29=30=31=33

Not normal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	0.7940	0.02891	11	27.47	<.0001
ave(26,27,29,30,31,33)	0.7376	0.01896	11	38.89	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	0.74	0.6568

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	0.7940	0.02891	11	27.47	<.0001
ave(26,27,29,30,31,33)	0.7376	0.01896	11	38.89	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	2.67	0.1308

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
98	**29**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
72	**20**	**2**	**2-34AR**	**Headquarters**
19	**4**	**5**	**4-4 CAV**	**Cavalry**
95	**29**	**1**	**2-34AR**	**Armor**

Average Speed off Road   F=6.31, p-value=0.0013

PLT(log10)	14	15	16	26	27	29	30	31	33
14 (**0.5944**)		=	=	≠	=	≠	=	≠	=
15 (**0.5623**)			=	=	=	=	=	≠	=
16 (**0.5361**)				=	=	=	=	=	=
26 (**0.4749**)					≠	=	=	=	=
27 (**0.6299**)						≠	≠	≠	≠
29 (**0.4826**)							=	=	=
30 (**0.5228**)								≠	=
31 (**0.4308**)									≠
33 (**0.5393**)									

Means: not all are equal

Normality is ok

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(14,15,16)	0.5643	0.02151	11	26.24	<.0001
ave(26,27,29,30,31,33)	0.5134	0.01134	11	45.29	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	8	11	5.34	0.0064
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	4.38	0.0603

Outliers:

Obs	**PLTNo**	**VehNo**	**Battlaion**	**Platoon_Type**
103	**31**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**

%Off Road time with Turing Radius less than 30m F=6.22, p-value=0.0014

PLT	14	15	16	26	27	29	30	31	33
14 (**0.5355**)		=	=	≠	=	≠	=	≠	=
15 (**0.5778**)			=	≠	≠	=	=	≠	=
16 (**0.6012**)				=	=	=	=	=	=
26 (**0.6859**)					≠	=	≠	=	≠
27 (**0.5047**)						≠	=	≠	≠
29 (**0.6373**)							=	=	=
30 (**0.5726**)								≠	=
31 (**0.6625**)									≠
33 (**0.5811**)									

Means: not all are equal

Contrasts:

Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(14,15,16)	0.2887	0.07628	11	3.79	0.0030
ave(26,27,29,30,31,33)	0.4429	0.04092	11	10.82	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	6.09	0.0038
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	3.17	0.1025

Question 3 gamma

Total Distance Traveled F=1.58, p-value=0.2111

PLT	14	15	16	26	27	29	30	31	33
14 (**147704**)		=	=	=	=	=	=	=	=
15 (**175175**)			=	=	=	=	=	=	=
16 (**174499**)				=	=	=	=	=	=
26 (**74416**)					=	=	=	=	=
27 (**80502**)						=	=	=	=
29 (**67674**)							=	=	=
30 (**99310**)								=	=
31 (**91959**)									=
33 (**97360**)									

Means: 14=15=16=26=27=29=30=31=33

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	12.0154	0.2389	11	50.30	<.0001
ave(26,27,29,30,31,33)	11.3429	0.1571	11	72.19	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	0.81	0.6051
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	5.53	0.0383

Distance Traveled off Road F=5.08, p-value=0.0033

PLT	14	15	16	26	27	29	30	31	33
14 (**12697**)		=	=	=	=	=	=	≠	=
15 (**11511**)			=	=	=	=	=	≠	=
16 (**8357.97**)				=	=	=	=	≠	=
26 (**9641.16**)					=	=	=	≠	=
27 (**12009**)						=	=	≠	=
29 (**5878.88**)							≠	≠	=

30 (**18432**)								≠	=
31 (**1791.33**)									≠
33 (**15226**)									

Means: not all are equal

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	9.2771	0.2124	11	43.68	<.0001
ave(26,27,29,30,31,33)	9.0316	0.1285	11	70.30	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	5.00	0.0082
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	0.98	0.3440

Average Total Speed F=1.72, p-value=0.1704

PLT	14	15	16	26	27	29	30	31	33
14 (**5.8699**)		=	=	=	=	=	=	=	=
15 (**5.9288**)			=	=	=	=	=	=	=
16 (**6.9677**)				=	=	=	=	=	=
26 (**4.9887**)					=	=	=	=	=

27 (**5.5794**)						=	=	=	=
29 (**5.3385**)							=	=	=
30 (**5.2396**)								=	=
31 (**6.2383**)									=
33 (**5.6016**)									

Means: 14=15=16=26=27=29=30=31=33

Contrasts:

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
ave(14,15,16)	1.8303	0.06732	11	27.19	<.0001
ave(26,27,29,30,31,33)	1.7019	0.04407	11	38.61	<.0001

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	8	11	0.71	0.6819
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	2.55	0.1387

Average Speed off Road F=6.08, p-value=0.0015

PLT	14	15	16	26	27	29	30	31	33
14 (**3.9352**)		=	=	≠	=	≠	=	≠	=
15 (**3.6557**)			=	=	=	=	=	≠	=
16 (**3.4367**)				=	=	=	=	=	=

26 (**2.9904**)					≠	=	=	=	=
27 (**4.3334**)						≠	≠	≠	≠
29 (**3.0578**)							=	=	=
30 (**3.3349**)								=	=
31 (**2.7550**)									≠
33 (**3.4711**)									

Means: not all are equal

Contrasts:

Estimates

Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ave(14,15,16)	1.3003	0.05027	11	25.87	<.0001
ave(26,27,29,30,31,33)	1.1903	0.02649	11	44.93	<.0001

Contrasts

Label	**Num DF**	**Den DF**	**F Value**	**Pr > F**
overall	8	11	5.07	0.0078
ave(14,15,16) vs ave(26,27,29,30,31,33)	1	11	3.74	0.0791

Appendix G - Pairwise Comparison Statistical Results

Question 4,7

Table G-1 Chapter 5 Questions 4 & 7 Results

PLT_Code_SAS	Unique Platoon ID
1	1/A/4-4 CAV
2	2/A/4-4 CAV
3	1/B/4-4 CAV
4	2/B/4-4 CAV
5	1/C/4-4 CAV
6	2/C/4-4 CAV

Question 4 beta log10

% of Training Time Spent Moving   F=2.39, p-value=0.0632

PLT	1	2	3	4	5	6
1 (0.07726)		=	=	=	=	=
2 (0.1026)			=	=	=	=
3 (0.06829)				=	=	=
4 (0.08550)					=	=
5 (0.07410)						=
6 (0.09135)						

Means: 1=2=3=4=5=6 based on 0.05

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	0.79	0.5779

% of Moving Time Spent off Road   F=3.35, p-value=0.0186

PLT	1	2	3	4	5	6
1 (0.2305)		=	≠	=	=	=
2 (0.2700)			≠	=	=	=
3 (0.1206)				≠	=	=
4 (0.2585)					=	=
5 (0.1962)						=
6 (0.1781)						

Means: not all are equal

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	2.91	0.0648

Total Distance Traveled   F=1.51, p-value=0.2390

PLT(log10)	1	2	3	4	5	6
1 (5.3217)		=	=	=	=	=
2 (5.3680)			=	=	=	=
3 (5.1407)				=	=	=
4 (5.2462)					=	=
5 (5.0800)						=
6 (5.1136)						=

Means: 1=2=3=4=5=6

Not normal

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	0.60	0.7041

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
52	15	1	1-16IN	Armor
49	14	1	1-16IN	Armor
73	20	2	2-34AR	Headquarters
78	23	2	2-34AR	Infantry
72	20	2	2-34AR	Headquarters
98	29	1	2-34AR	Armor

Distance Traveled off Road F=4.93, p-value=0.0038

PLT(log10)	1	2	3	4	5	6
1 (4.2712)		=	≠	=	=	=
2 (4.3824)			≠	=	=	=
3 (3.6843)				≠	=	=
4 (4.2231)					=	=
5 (3.9192)						=
6 (3.9255)						=

Means: not all are equal

Not normal

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	4.79	0.0143

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
73	**20**	**2**	**2-34AR**	**Headquarters**
98	**29**	**1**	**2-34AR**	**Armor**
72	**20**	**2**	**2-34AR**	**Headquarters**
39	**11**	**2**	**1-16IN**	**infantry**
10	**3**	**5**	**4-4 CAV**	**Cavalry**

Average Total Speed   F=1.76, p-value=0.1591

PLT(log10)	1	2	3	4	5	6
1 (0.8601)		=	=	=	=	=
2 (0.8221)			=	=	=	=
3 (0.8481)				=	=	=
4 (0.7912)					=	=
5 (0.8400)						=
6 (0.8254)						

Means: 1=2=3=4=5=6

Not normal

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	0.49	0.7744

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
98	**29**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
72	**20**	**2**	**2-34AR**	**Headquarters**
73	**20**	**2**	**2-34AR**	**Headquarters**

19	**4**	**5**	**4-4 CAV**	**Cavalry**

Average Speed off Road F=6.31, p-value=0.0013

PLT(log10)	1	2	3	4	5	6
1 (0.4299)		=	≠	=	=	=
2 (0.4146)			=	=	=	=
3 (0.3533)				=	=	=
4 (0.3745)					=	=
5 (0.3983)						=
6 (0.3872)						=

Means: not all are equal

Normality is ok

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	1.29	0.3343

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
103	**31**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
75	**22**	**2**	**2-34AR**	**Infantry**
91	**27**	**1**	**2-34AR**	**Armor**
39	**11**	**2**	**1-16IN**	**infantry**

%Off Road time with Turing Radius less than 30m F=6.22, p-value=0.0014

PLT	1	2	3	4	5	6
1 (0.6443)		=	≠	=	=	=
2 (0.6430)			≠	=	=	=
3 (0.7112)				=	=	=
4 (0.6960)					=	=
5 (0.6881)						=
6 (0.6882)						

Means: 1=2=3=4=5=6

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	1.86	0.1819

Question 4 gamma

Total Distance Traveled F=1.58, p-value=0.2111

PLT	1	2	3	4	5	6
1 (212049)		=	=	=	=	=
2 (233346)			=	=	=	=
3 (141486)				=	=	=
4 (177749)					=	=
5 (120325)						=
6 (129976)						=

Means: 1=2=3=4=5=6

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	0.65	0.6693

Distance Traveled off Road F=5.08, p-value=0.0033

PLT	1	2	3	4	5	6
1 (19260)		=	≠ (0.0056)	=	=	=
2 (24994)			≠ (0.0037)	=	≠ (0.0458)	≠ (0.0394)
3 (5653.49)				≠ (0.0051)	=	=
4 (17356)					=	=
5 (8766.48)						=
6 (8422.86)						=

Means: not all are equal

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	4.63	0.0161

Average Total Speed F=1.72, p-value=0.1704

PLT	1	2	3	4	5	6
1 (7.2660)		=	=	=	=	=
2 (6.6578)			=	=	=	=
3 (7.0866)				=	=	=
4 (6.2011)					=	=
5 (6.9207)						=
6 (6.6905)						

Means: 1=2=3=4=5=6

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	0.49	0.7770

Average Speed off Road F=6.08, p-value=0.0015

PLT	1	2	3	4	5	6
1 (2.6998)		=	=	=	=	=
2 (2.5977)			=	=	=	=
3 (2.2871)				=	=	=
4 (2.3775)					=	=
5 (2.5052)						=
6 (2.4400)						=

Means: 1=2=3=4=5=6

Contrasts:

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
overall	5	11	1.11	0.4068

Appendix H - Pairwise Comparison Statistical Results

Question 8

Table H-1 Chapter 5 Question 8 Results

Vehicle_Code_SAS	VEHICLE TYPE
1	M1A2
2	M2A3
3	M3A3
4	M7 BFIST
5	HMMWV
6	M113
7	LMTV

Question 8 beta log10

% of Training Time Spent Moving   F=2.24, p-value=0.0826

Veh	1	2	3	4	5
1 (0.05619)		=	≠ (0.0489)	=	=
2 (0.05605)			≠ (0.0400)	=	=
3 (0.07701)				≠ (0.0155)	=
4 (0.03872)					=
5 (0.06613)					

Means: 4=2=1=5=3 based on 0.05

% of Moving Time Spent off Road   F=1.55, p-value=0.2059

Veh	1	2	3	4	5
1 (0.1545)		=	=	=	=
2 (0.1750)			=	=	=
3 (0.1933)				=	=
4 (0.1129)					≠ (0.0338)
5 (0.2048)					

Means: 4=1=2=3=5

Total Distance Traveled F=3.47, p-value=0.0161

Veh(log10)	1	2	3	4	5
1 (4.9686)		=	≠ (0.0186)	=	=
2 (5.0205)			=	≠ (0.0222)	=
3 (5.1943)				≠ (0.0010)	=
4 (4.7587)					≠ (0.0172)
5 (5.0683)					

Means: 4<1=2=5<3

Not normal

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
52	15	1	1-16IN	Armor
49	14	1	1-16IN	Armor
73	20	2	2-34AR	Headquarters
78	23	2	2-34AR	Infantry
72	20	2	2-34AR	Headquarters
98	29	1	2-34AR	Armor

Distance Traveled off Road F=2.10, p-value=0.0994

Veh(log10)	1	2	3	4	5
1 (3.9041)		=	=	≠ (0.0272)	=
2 (3.9601)			=	≠ (0.0117)	=
3 (4.0256)				≠ (0.0104)	=
4 (3.4868)					≠ (0.0463)
5 (3.9028)					

Means: 4=5=1=2=3 based on 0.05

Not normal

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
73	**20**	**2**	**2-34AR**	**Headquarters**
52	**15**	**1**	**1-16IN**	**Armor**
98	**29**	**1**	**2-34AR**	**Armor**
72	**20**	**2**	**2-34AR**	**Headquarters**

Average Total Speed F=5.91, p-value=0.0008

Veh(log10)	1	2	3	4	5
1 (0.7483)		≠ (0.0442)	≠ (0.0009)	=	≠ (0.0001)
2 (0.7897)			=	=	≠ (0.0107)
3 (0.8380)				=	=
4 (0.7964)					=
5 (0.8560)					

Means: 1≠2, 1≠3, 1≠5, 2≠5

Not normal

Outliers:

Obs	PLTNo	VehNo	Battlaion	Platoon_Type
98	**29**	**1**	**2-34AR**	**Armor**
10	**3**	**5**	**4-4 CAV**	**Cavalry**
72	**20**	**2**	**2-34AR**	**Headquarters**

Average Speed off Road F=12.79, p-value<0.0001

Veh(log10)	1	2	3	4	5
1 (0.5315)		=	≠ (<0.0001)	=	≠ (<0.0001)
2 (0.5021)			≠ (<0.0001)	=	≠ (<0.0001)
3 (0.3973)				≠ (0.0141)	=
4 (0.4875)					≠ (0.0096)

5 (0.3906)					

Means: 3=5<2=4<1

Normality is ok

%Off Road time with Turing Radius less than 30m F=8.97, p-value<.0001

Veh	1	2	3	4	5
1 (0.5927)		=	≠ (0.0002)	=	≠ (0.0004)
2 (0.5855)			≠ (<.0001)	=	≠ (0.0001)
3 (0.6880)				≠ (0.0151)	=
4 (0.6078)					≠ (0.0200)
5 (0.6855)					

Means: 2=1=4<5=3

Based on gamma:

Total Distance Traveled   F=3.64, p-value=0.0130

Veh	1	2	3	4	5
1 (97927)		=	≠ (0.0121)	=	=
2 (109681)			≠ (0.0414)	≠ (0.0241)	=
3 (164124)				≠ (0.0008)	=
4 (62847)					≠ (0.0207)
5 (120141)					

Means: not all are equal

Distance Traveled off Road   F=2.68, p-value=0.0456

Veh	1	2	3	4	5
1 (8622.64)		=	=	≠ (0.0122)	=
2 (10057)			=	≠ (0.0038)	=
3 (10778)				≠ (0.0058)	=

4 (3158.82)					≠ (0.0270)
5 (8368.23)					

Means: not all are equal

Average Total Speed F=5.82, p-value=0.0009

Veh	1	2	3	4	5
1 (5.6194)		≠ (0.0461)	≠ (0.0010)	=	≠ (0.0001)
2 (6.1775)			=	=	≠ (0.0107)
3 (6.8960)				=	=
4 (6.2772)					=
5 (7.2025)					

Means: not all are equal

Average Speed off Road F=13.38, p-value<0.0001

Veh	1	2	3	4	5
1 (3.4263)		=	≠ (<0.0001)	=	≠ (<0.0001)
2 (3.1919)			≠ (<0.0001)	=	≠ (<0.0001)
3 (2.5000)				≠ (0.0103)	=
4 (3.1031)					≠ (0.0083)
5 (2.4748)					

Means: not all are equal

Appendix I - Statistical Results SAS Output

The SAS output based on the questions from chapter 5 may be useful and important for follow up research. Within many of the pairwise comparisons made in this research there are multiple different statistically significant groupings. Not all groupings could be discussed within this work nor reasonably displayed in one write-up. Appendix D thru H above provide overviews of each of the pairwise comparisons conducted, but do not provide all of the necessary data for within group individual platoon or vehicle comparisons. For brevity of this document, the complete statistical results have been left out, but are attached as a separate PDF file uploaded along with this thesis to the Kansas State University KREX website and available for further review. The file name of the attached statistical results is Appendix_I_ TRACKING MILITARY MANEUVER TRAINING DISTURBANCE WITH LOW COST GPS DEVICES_DENKER_2013.

Appendix J - GPS Points Removed During Processing (Assumed Error)

Table J-1 Points Removed by Vehicle 1-16 Infantry Battalion

Vehicle ID	Platoon/ Troop/ Squadron	Number of GPS points removed during processing	Percent of points removed (obvious errors)
A11	1/A/1-16IN	8	0.04%
A13	1/A/1-16IN	3	0.02%
A14	1/A/1-16IN	7	0.04%
A21	2/A/1-16IN	4	0.01%
A22	2/A/1-16IN	7	0.03%
A23	2/A/1-16IN	6	0.02%
A24	2/A/1-16IN	5	0.02%
A31	3/A/1-16IN	3	0.01%
A34	3/A/1-16IN	4	0.02%
B11	1/B/1-16IN	11	0.05%
B12	1/B/1-16IN	4	0.04%
B13	1/B/1-16IN	9	0.03%
B14	1/B/1-16IN	8	0.03%
B21	2/B/1-16IN	2	0.01%
B22	2/B/1-16IN	13	0.05%
B23	2/B/1-16IN	4	0.01%
B24	2/B/1-16IN	3	0.01%
B31	3/B/1-16IN	1	0.01%
B34	3/B/1-16IN	7	0.04%
D11	1/D/1-16IN	17	0.07%
D12	1/D/1-16IN	71	0.16%
D13	1/D/1-16IN	5	0.03%
D14	1/D/1-16IN	5	0.03%
D21	2/D/1-16IN	93	0.16%
D22	2/D/1-16IN	10	0.05%
D23	2/D/1-16IN	3	0.02%
D24	2/D/1-16IN	20	0.10%
D31	3/D/1-16IN	61	0.24%
D40	HQ/D/1-16IN	4	0.02%
D65	HQ/D/1-16IN	4	0.03%
D66	HQ/D/1-16IN	1122	6.99%

Table J-2 Points Removed by Vehicle 4-4 Cavalry Squadron

Vehicle ID	Platoon/ Troop/ Squadron	Number of GPS points removed during processing	Percent of points removed (obvious errors)
A11	1/A/4-4 CAV	22	0.08%
A12	1/A/4-4 CAV	16	0.05%
A14	1/A/4-4 CAV	6	0.02%
A15	1/A/4-4 CAV	6	0.02%
A21	2/A/4-4 CAV	16	0.05%
A22	2/A/4-4 CAV	21	0.06%
A25	2/A/4-4 CAV	17	0.05%
B11	1/B/4-4 CAV	24	0.08%
B12	1/B/4-4 CAV	11	0.04%
B13	1/B/4-4 CAV	3	0.04%
B14	1/B/4-4 CAV	7	0.05%
B16	1/B/4-4 CAV	8	0.04%
B17	1/B/4-4 CAV	15	0.08%
B21	2/B/4-4 CAV	3	0.01%
B22	2/B/4-4 CAV	29	0.08%
B23	2/B/4-4 CAV	14	0.05%
B24	2/B/4-4 CAV	8	0.04%
B25	2/B/4-4 CAV	24	0.06%
B26	2/B/4-4 CAV	6	0.02%
B27	2/B/4-4 CAV	98	0.53%
B28	2/B/4-4 CAV	10	0.05%
C11	1/C/4-4 CAV	14	0.09%
C14	1/C/4-4 CAV	3	0.02%
C21	2/C/4-4 CAV	9	0.05%
C26	2/C/4-4 CAV	7	0.03%
C66	HQ/C/4-4 CAV	2	0.04%
C7	HQ/C/4-4 CAV	281	3.95%
C77	HQ/C/4-4 CAV	2	0.03%
C95	HQ/C/4-4 CAV	3	0.04%

Table J-3 Points Removed by Vehicle 2-34 Armor Battalion

Vehicle ID	Platoon/ Troop/ Squadron	Number of GPS points removed during processing	Percent of points removed (obvious errors)
A11	1/A/2-34AR	10	0.04%
A12	1/A/2-34AR	9	0.04%
A13	1/A/2-34AR	10	0.04%
A14	1/A/2-34AR	9	0.04%
A21	2/A/2-34AR	8	0.04%
A22	2/A/2-34AR	7	0.03%
A23	2/A/2-34AR	5	0.03%
A24	2/A/2-34AR	9	0.05%
A30	HQ/A/2-34AR	10	0.06%
A31	3/A/2-34AR	31	0.17%
A32	3/A/2-34AR	2	0.01%
A33	3/A/2-34AR	12	0.08%
A34	3/A/2-34AR	17	0.12%
A65	HQ/A/2-34AR	1	0.03%
A66	HQ/A/2-34AR	5	0.02%
B11	1/B/2-34AR	7	0.07%
B12	1/B/2-34AR	0	0.00%
B13	1/B/2-34AR	3	0.03%
B14	1/B/2-34AR	0	0.00%
B21	2/B/2-34AR	1	0.02%
B22	2/B/2-34AR	14	0.06%
B23	2/B/2-34AR	10	0.04%
B24	2/B/2-34AR	8	0.03%
B30	HQ/B/2-34AR	0	0.00%
B31	3/B/2-34AR	2	0.02%
B32	3/B/2-34AR	4	0.03%
B33	3/B/2-34AR	4	0.02%
B34	3/B/2-34AR	4	0.04%
C11	1/C/2-34AR	54	0.27%
C13	1/C/2-34AR	26	0.16%
C14	1/C/2-34AR	5	0.05%
C21	2/C/2-34AR	9	0.05%
C22	2/C/2-34AR	1	0.01%
C23	2/C/2-34AR	3	0.02%
C24	2/C/2-34AR	2	0.02%
C30	HQ/C/2-34AR	84	3.56%
C31	3/C/2-34AR	6	0.03%
C32	3/C/2-34AR	31	0.21%
C33	3/C/2-34AR	6	0.04%
C34	3/C/2-34AR	4	0.09%
C66	HQ/C/2-34AR	5	0.03%
D11	1/D/2-34AR	7	0.03%
D12	1/D/2-34AR	5	0.03%
D14	1/D/2-34AR	5	0.04%
D21	2/D/2-34AR	58	0.45%
D22	2/D/2-34AR	3	0.03%
D23	2/D/2-34AR	10	0.06%
D24	2/D/2-34AR	5	0.03%
D30	HQ/D/2-34AR	2	0.01%
D31	3/D/2-34AR	6	0.03%
D32	3/D/2-34AR	5	0.03%
D33	3/D/2-34AR	1	0.01%
D34	3/D/2-34AR	65	0.40%
D6	HQ/D/2-34AR	2	0.02%
D65	HQ/D/2-34AR	6	0.05%
D77	HQ/D/2-34AR	1	0.01%

Appendix K - Intensity Maps for Maneuver Area N

Figure K-1 All Movement in MA N by Vehicle Type

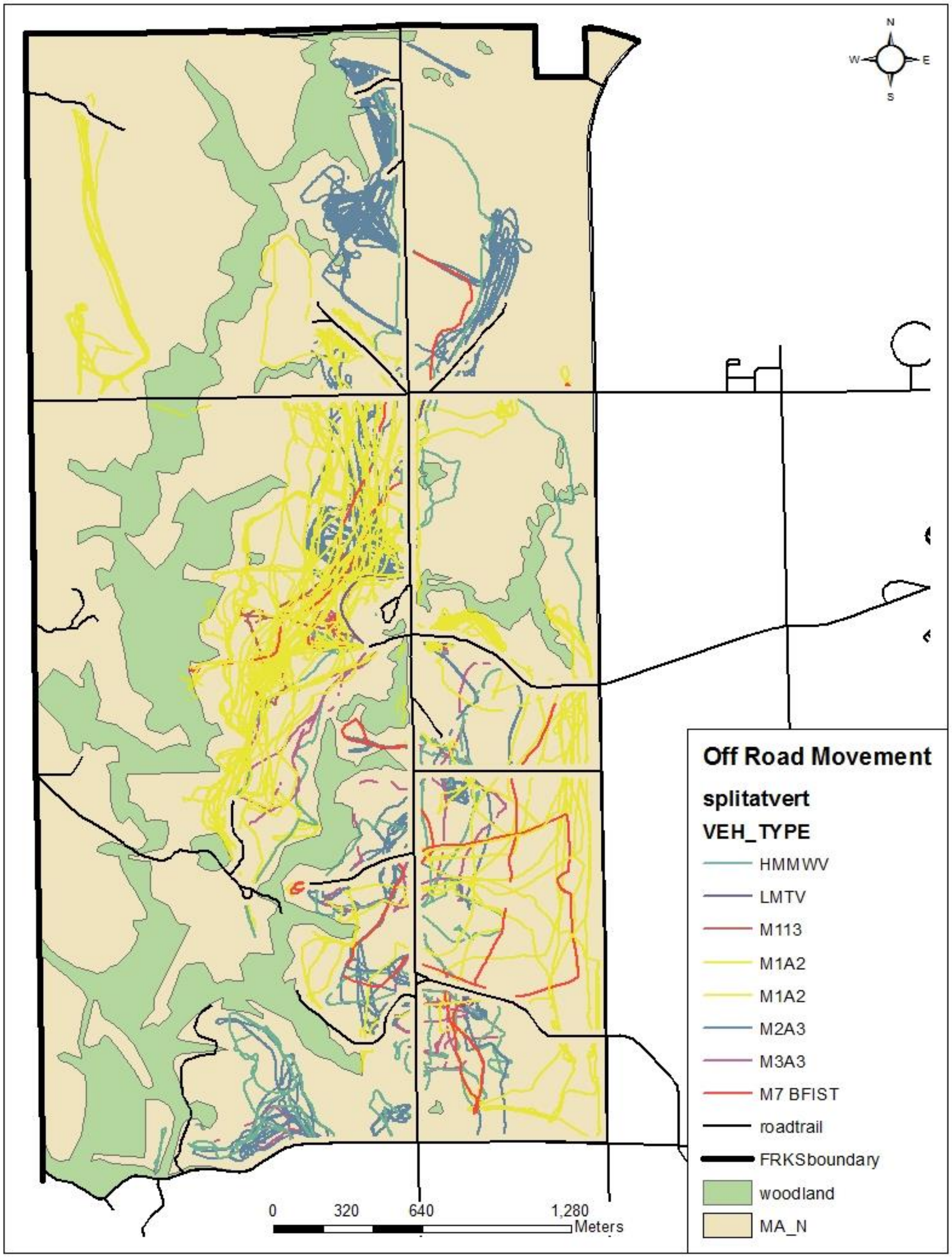


Figure K-2 Relative Intensity Map for MA N GPS Point Counts

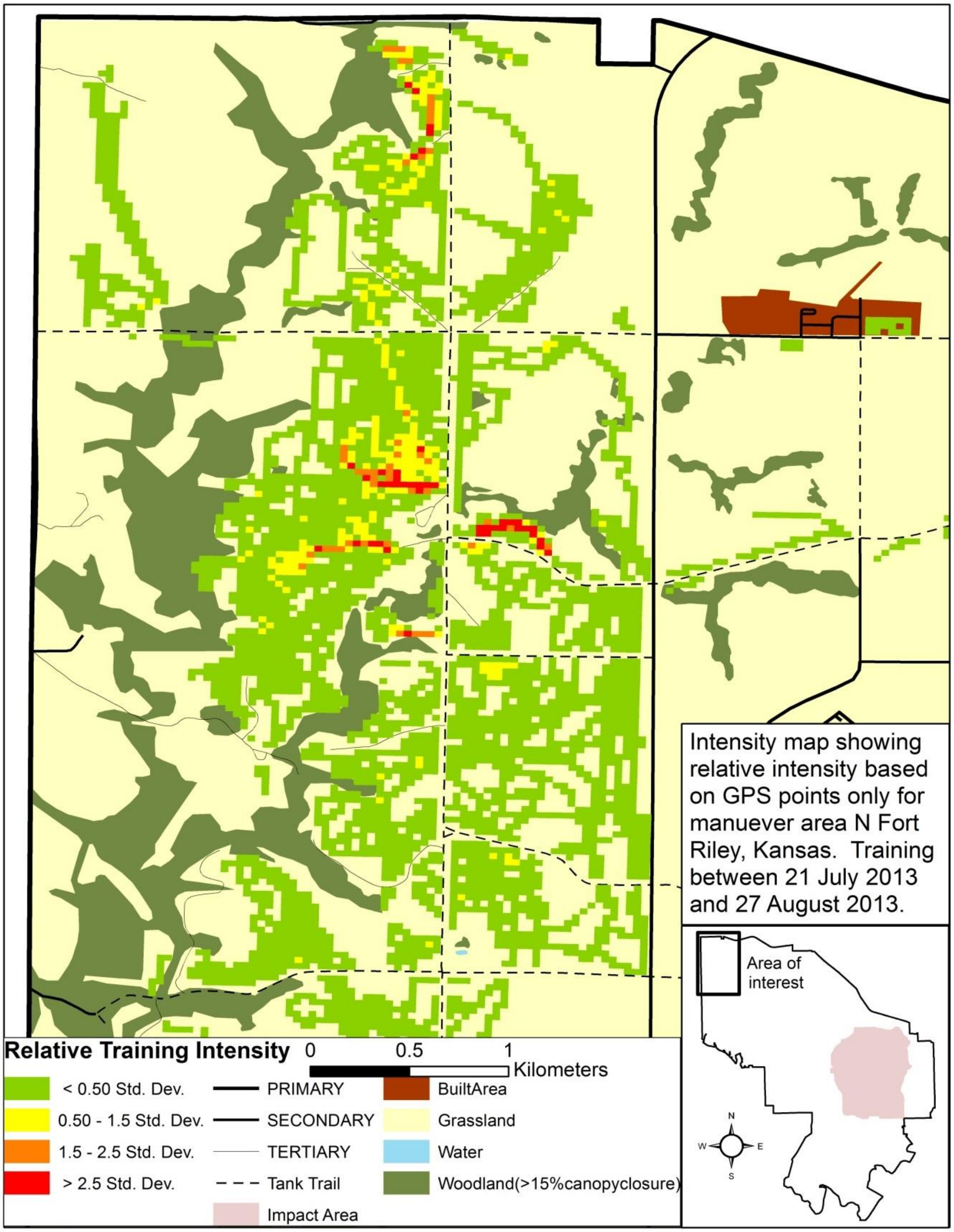


Figure K-3 Relative Intensity Map for MA N GPS Points With Calculated VSF and LCF