An Urban Forest Inventory at Redstone Arsenal in Huntsville, Alabama

by

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Abstract

Redstone Arsenal (RSA) is a United States Army Post in Huntsville, Alabama. To promote RSA's management goals, an urban forest inventory was conducted to make good land management decisions in urban areas and maintain healthy, native flora. There were two primary objectives; (1) conduct an urban forest inventory at Redstone Arsenal and, (2) determine urban areas of hydrologic concern and assess potential benefits of the addition of urban trees. The urban forest inventory contains data on measurements, assessments, location, and presence of invasive and high-risk trees. Changing land cover from grass to tree/shrub showed significant benefits using i-Tree Canopy in Priority Area 1. Incorporating more trees on the landscape gave an estimated value of approximately $630,000 in carbon storage, and over 78,000 gallons of water in hydrological benefits. Future studies can be done to assess what native trees should be planted in urban areas, and the implementation of green infrastructure.

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List of Abbreviations

RSA	Redstone Arsenal
HR	Housing and Recreation
ADM	Administration
GC	Golf Course
FIA	Forest Inventory and Analysis
ISA	International Society of Arboriculture
DBH	Diameter at Breast Height
RTC	Redstone Test Center

Chapter 1: Introduction

Redstone Arsenal Urban Forest Inventory and Green Infrastructure

Redstone Arsenal (RSA) is a United States Army Post in Huntsville, Alabama. RSA is located near the Tennessee River in northern Alabama (Figure 1). This Army Post is also home to part of The National Aeronautics and Space Administration (NASA) and the Federal Bureau of Investigation (FBI). Founded in 1941 during World War II, the Post was originally two arsenals used for the production of chemical weapons (Baker 1993). The two arsenals were combined in 1943 to form Redstone Arsenal. Currently, it serves as the center of the US Army's missile and rocket programs which utilizes the expansive, open space that RSA has to offer.

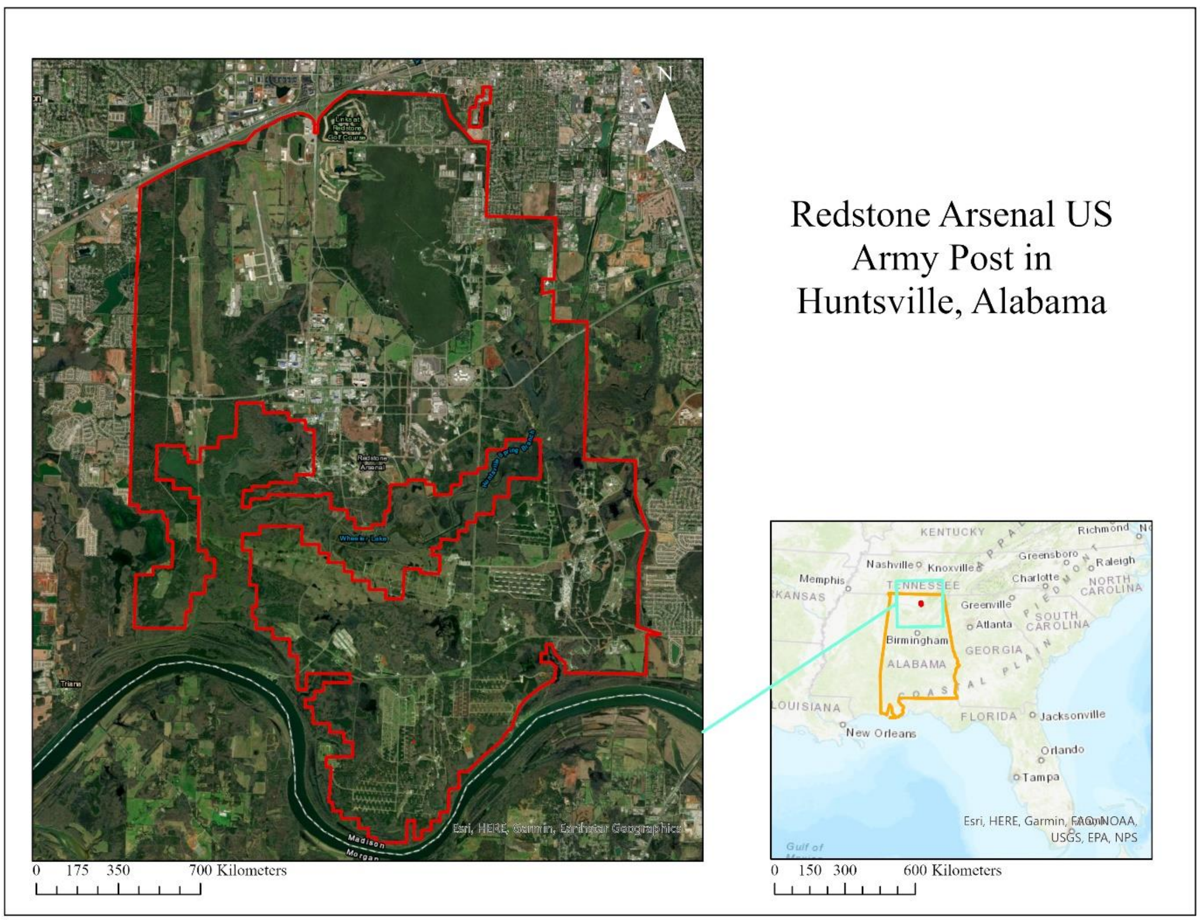

Figure 1. Map of Redstone Arsenal US Army Post located in Huntsville, Alabama, USA.

The Army Post occupies approximately 15,148 hectares. There are approximately 6,475 hectares in improved administrative and housing areas containing urban forest areas. Ecological studies are often done on military installations, bases, and posts to evaluate flora and fauna resources. RSA is committed to sustainable land management practices that support the missions of the customers on the Post through sound ecological management. These practices are designed to provide for wildlife habitat enhancement and revenue generation from forest products. RSA currently has an environmental management division called the US Army Garrison department. Through the US Army Garrison department has completed a forest inventory, established The Path to Nature wildlife trail and wetland education center, and received the fiscal 2007 Secretary of the Army Environmental Award for Cultural Resources (US Army 2008). Research on RSA spans from water quality assessment, flora such as lichen and trillium, and fauna such as mice and bats (McGregor et al. 2003, Hansen 2018, Swick 2019, Molina et al. 2021, and Gardner 2008). There is currently no data available at RSA on their urban natural resources, in particular urban trees. An urban forest inventory is needed to make good land management decisions and to maintain healthy, native flora. The incorporation of urban trees can not only provide social benefits, but also economic and environmental benefits to urban areas all while promoting sustainability practices (Nitoslawski et al. 2019 and Huff et al. 2020). In regard to research done on urban forestry at military institutions, there are very few studies. In Adkins et al. (1997), the study concluded that urban forestry programs in military communities allow for inventory and evaluation of resources for betterment of the base or post. Overall, including urban forestry in RSA's environmental management can increase sustainability efforts while aiding in proper land management practices.

Planning can play a crucial role when it comes to managing for natural resources in urban settings. Unutilized land in the United States was sought after for urban development. Towns and cities began to expand their urbanization at rapid rates. As these urban areas experience organic growth there was concern of meeting the needs of the environment, economy, and equity (Campbell 1996). Ideally, urban areas would find a balance between being environmentally friendly, economically prosperous, and equitable for those residing there. Urban planning has changed over the course of the last thirty years as many cities are trying to incorporate the environment as part of their planning process (Wolch et al. 2014). Natural resources were not always thought of in the planning process but are now considered a focal point in many urban areas. Green spaces are areas in an urban setting that are semi-open containing grass and vegetation (Belmeziti et al. 2018). These areas usually exist naturally on their own or are incorporated for the use and enjoyment of people. Vegetation and trees are now an important consideration in urban planning to enhance urban places, add to green spaces, and provide environmental benefits.

Natural resources, such as forests, have become fragmented to meet the demands of an ever-growing society. Vegetation in an urban setting provides economic, social, and environmental values. Urban trees help reduce the urban heat island affect, reduce air pollution, aids in runoff infiltration, and increases biodiversity. Added biodiversity benefits include unique micro habitats and climates (Adams et al. 2005). Resource inventory, monitoring, and health need to be evaluated in urban areas focused on green infrastructures (Dwyer et al. 2002). Not only do urban natural resources provide environmental and ecological benefits, but they also provide social benefits such as creating community green spaces (Westphal 2003). Community green spaces can include public parks, recreation areas, reserves, gardens, greenways and trails, and street trees (Wolch et al. 2014). These spaces engage the community to utilize outdoor spaces which can result in benefits to physical and mental health. Urban green space management can provide environmental benefits such as increased vegetation cover, adding to native biodiversity, and reducing air and water pollution (Nitoslawski et al. 2019).

The Urban Forestry Inventory and Analysis (FIA) program was created extending the FIA sampling frame to urban areas. This program has three components consisting of 1) Urban Forest Inventory and Analysis, 2) Urban National Landowner Survey (UNLS), and 3) Urban Wood Flows (USDA Forest Service 2022). Data collection for the Urban FIA program includes tree species, size, crown condition, damage, ground cover, ownership, and continual re-measurement to understand how the tree is changing over time in urban areas (USDA Forest Services 2022). The Urban FIA program collaborates with i-Tree to quantify urban trees and the environmental services they provide (USDA Forest Service 2022). The i-Tree suite of programs can be used at a variety of scales such as individual or community level. Tools such as i-Tree can be used to further understand the benefits of urban trees in a particular area. I-Tree provides baseline data to evaluate urban tree environmental and economic services while setting priorities for more effective decision making (USDA Forest Service 2006).

I-Tree is offered free to the public and supported by contributions from the public/private partnerships: USDA Forest Service, State and Private Forestry; Davey Tree Expert Company; International Society of Arboriculture, Society of Municipal Arborists; Arbor Day Foundation, and Casey Trees. The i-Tree suite of programs offers analysis tools for managing urban and rural forests. This program was developed to engage the public in assessing and valuing their forest resources (Nowak et al. 2018). Services offered through i-Tree such as analysis of environmental benefits, estimating tree canopy, prioritizing tree planting areas, and carbon storage estimation help develop sustainable management plans to improve environmental quality and human health (Nowak et al. 2018). I-Tree offers tools planting, individual trees, and tree canopy assessment. Tools for planting include i-Tree Planting, Species, and TrillionTrees. These programs can also assist in the decision of what trees to plant in the future. Individual trees can be examined through MyTree, i-Tree Eco, and i-Tree Design. I-Tree Canopy and i-Tree Design can be used for assessing land cover and canopy benefits. Utilizing i-Tree can also provide cost-benefit analyses and management recommendations when it comes to planting new trees. Factors such as shading, heat reduction, and water infiltration could all be factors in the planting phase of an urban tree program. Programs such as i-Tree are often used when considering the addition of green infrastructure in urban areas.

Green infrastructure is defined as natural or semi-natural structures characterized by their vegetation in urban settings to provide environmental services (Hewitt et al. 2020 and Van Oijstaeijen et al. 2020). Green infrastructure is commonly implemented in green spaces to further enhance environmental services or to mitigate a specific environmental issue. The goal of sustainability in an urban area is often one the main drivers when considering the addition of green infrastructure to ensure environmental stability in these urban areas (Benedict and McMahon 2002). Green infrastructure can also utilize gray infrastructure but in a way that can provide social and environmental benefits. Gray infrastructure consists of developed areas containing concrete, sewers, utilities, etc., while green infrastructure incorporates the environment to achieve a balance between urban zones and nature (McMahon and Benedict 2000). Green infrastructure bridges the gap between environmental and economic benefits. The goal of sustainability in an urban area is often one the main driver when considering the addition of green infrastructure (Benedict and McMahon 2002). The use of green infrastructure can mitigate costs associated with stormwater management, urban heating, and air pollution. Stormwater management can become an issue in areas where there is increased impervious surfaces such as urban or developed areas. The addition of green infrastructure such as rain gardens or bioswales can aid in the management of stormwater in an urban setting.

As RSA has changed over the past few decades once permeable land has been replaced by impermeable surfaces. Flat and permeable surfaces will allow movement of surface water into local aquifers on the Army Post but increased impermeable surfaces at RSA can impede this water movement causing erosion or flooding (Cook et al. 2015). Green infrastructure can benefit urban landscapes by providing more controlled infiltration due to permeable soil enhanced by roots, which reduces runoff. The addition of urban trees and green infrastructure can help return water to the atmosphere through transpiration (Scharenbroch et al. 2016 and Caplan et al. 2019). Excess water in urban areas can contain more pollutants than rural areas. Toxic contaminants found in runoff can impact microhabitats associated with urban habitats (Anderson et al. 2016). The addition of bioswales, rain gardens, or permeable pavement can reduce water pollutants at RSA. In addition to impermeable surfaces and excess runoff, soil hydrologic groups play a role in the relationship between water and urban trees. Soil type and volume can be contributing factors to the overall health of an urban tree stand (Yung Jim 2019). RSA is located within the Wheeler Basin watershed which consists of eight counties in northern Alabama that have proximity to the Tennessee River (Sheppard et al. 2001). Soil groups within the Wheeler Basina range in hydrology and runoff. Redstone Arsenal can benefit from implementing green infrastructure in areas where soil infiltration is considered poor and/or where runoff levels are considered high. Urban streams tend to rise more quickly during storms than rural streams, and bioswales can mitigate extra water coming onto the installation (Konrad 2016). Green infrastructure can also be used in making management decisions on what native tree species would be suitable on the Army post. Adding green infrastructure and planting native trees within them can help achieve the Army post's urban forestry goals. Overall, urban trees combined with green infrastructure will contribute to the goal of utilizing sustainable practices while providing environmental benefits on the Army post.

The goal of this thesis is to generate information to support the management of urban trees at RSA. To achieve this there were two primary objectives; (1) conduct an urban forest inventory at Redstone Arsenal and, (2) determine urban areas of hydrologic concern and assess potential benefits of the addition of urban trees. These objectives will aid in providing RSA recommendations that achieves their mission of sustainable land management practices. Objective 1 is addressed in Chapter 2 of the thesis; Objective 2 is addressed in Chapter 3 of the thesis and Conclusions and Recommendations are described in Chapter 4.

Chapter 2:

Towards a Comprehensive Urban Forest Inventory: Insights from a Study of Urban Forests at Redstone Arsenal

2.1 Introduction

Redstone Arsenal (RSA) is a United States Army Post in Huntsville, Alabama. Since RSA's founding in 1943, expansion of the Post has continued as residential operations have grown. As new structures and buildings are built every year at RSA, urban natural resources need to be evaluated, particularly, the urban trees. An urban forest inventory can be used to aid in land management decisions and to maintain healthy, native, urban trees. However, an urban forest inventory has never been conducted at RSA. This work establishes a comprehensive knowledge of what urban trees reside on Post, and their health, structural condition, and the risk these trees might have on urban areas.

Urban forestry is the maintenance, planting, and management of trees in an urban setting. An urban forest inventory commonly consists of tree measurements (i.e., tree height, DBH, crown width), species identification, and an assessment of risk for potential impacts to urban structures, streets, sidewalks, and overall human safety. Adkins et al. (1997) noted species diversity, tree size, tree condition, utility line interference, and tree value in their study on a military installation. Collecting data, such as an urban forest inventory, can provide information on the distribution and community structure of flora, services that urban flora can provide, and distribution information on invasive species (Abd-Elrahman et al. 2010). Urban areas are defined as densely developed residential and commercial areas (Edgar et al. 2021). The need for urban forest inventories was recognized in the 2000s as they could support natural resource management decisions along with environmental policy at local and state levels (Edgar et al.

2021). As urbanization increases, natural resources have become part of the planning process to better manage urban green spaces. As cities grew, many became conscious of their ecological footprint and value of natural resources in an urban setting (Agudelo-Vera et al. 2011). Natural resources in urban areas soon became sought after to combat the environmental issues urbanization brings. Many municipalities have included urban forestry in the planning and management of their natural resources (Abd-Elrahman et al. 2010 and Kuchelmeister 2000).

Urban forestry contributes to an area's overall flora and can provide habitat to fauna. Microhabitats can be created through urban ecosystems for smaller species such as reptiles, amphibians, rodents, birds, and even insects. Managing urban ecosystems can provide an area's physiological, sociological, environmental, economic, and aesthetic benefits (Konijnendijk et al. 2006). Urban forest features such as parks and trails add to physiological benefits for people while contributing sociologically. Adding vegetation, particularly trees, can aid urban areas in mitigating pollution as well as connect urban ecosystems. Economically, urban trees can combat urban heat island effect and provide shade to reduce cooling costs (Baggett 2019). Urban trees can also aid in mitigating stormwater, preventing costs associated with urban flooding. Trees are also used for aesthetic purposes and play a role in landscape architecture (Boris 2012).

Data collection methodology for an urban forest inventory can be derived from i-Tree applications and the International Society of Arboriculture (ISA). The suite of i-Tree applications is freely available to the public and supported by contributions from the public/private partnerships (Nowak et al. 2018 and Nowak 2020). This program was developed to engage the public in assessing and valuing their forest resources (Nowak et al. 2018) and Nowak 2020). The i-Tree suite offers a variety of programs with built-in analysis tools for managing urban and rural forests. Services offered through i-Tree, such as analyzing environmental benefits, estimating tree canopy, prioritizing tree planting areas, and estimating carbon storage, help develop sustainable management plans to improve environmental quality and human health (Nowak et al. 2018 and Nowak 2020).

The i-Tree Canopy application is used to classify land cover using a random sampling of aerial imagery (i-Tree 2006 and Nowak 2020). Users can select from existing geographic boundaries, draw a boundary using Google maps, or upload a shapefile. The i-Tree Canopy application randomly generates sample points and zooms into the location allowing the user to define the cover type (i-Tree 2006 and Nowak 2020). Cover classes include Tree/Shrub, Grass/Herbaceous, Impervious Buildings, Impervious Roads, Impervious Other, Water, and Soil/Bare Ground or Tree and Non-Tree. Based on land cover classification by the user, i-Tree The i-Tree Canopy program can assess overall canopy benefits but cannot assess individual trees.

The i-Tree Eco program was developed based on the Urban Forest Effects (UFORE) Model which is used to quantify urban forest structure and function (Nowak and Crane 2000). The public did not commonly use UFORE, and the development of i-Tree Eco made it easier for people to assess their urban forests. Users can input data collected and i-Tree Eco will conduct analyses based on entered data. This program is unique as it can operate at different spatial scales; i-Tree Eco may be used for small public areas or private properties to complete a full urban forest inventory, while a sample of the area rather than a full inventory can be used for a larger area. These analyses provided by i-Tree Eco allow for assessment of urban forests and individual trees. Functional analyses through i-Tree Eco includes pollution removal and human health impacts, carbon sequestration and storage, hydrology effects (avoided run-off, interception, transpiration), building energy effects, tree bio-emissions, avian habitat suitability (plot-based), and ultraviolet radiation (UV) tree effects (i-Tree 2006). Data such as urban ecosystem services can be used by urban resource managers (Song et al. 2020). These analyses can be calculated through field data from randomly located plots throughout an area combined with local hourly air pollution and meteorological data to quantify urban forest structure with environmental effects (i-Tree 2006). The i-Tree Eco program also offers structure and composition analyses through species condition and distribution, leaf area and biomass, species importance values, and diversity indices and relative performance. Formerly known as Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM), i-Tree Streets, is another program that uses a sample or existing inventory. The i-Tree Streets program used street tree data to evaluate current benefits, costs, and management needs; this application has been merged into i-Tree Eco and is no longer standalone (McPherson 2010; i-Tree 2006). Management information calculated through i-Tree Eco consists of pest risk analysis, user-defined field options, and cost-benefit analysis. Assessing biophysical aspects with economic value through i-Tree Eco allows urban resource managers a more in depth, comprehensive understanding of their urban trees (Raum et al. 2019).

Another source for evaluating urban trees is the International Society of Arboriculture (ISA). Arboriculture is the cultivation, management, and study of trees and other woody plants. ISA is a non-profit organization that promotes the professional practice of arboriculture and brings awareness to trees' benefits (International Society of Arboriculture 2022). (International Society of Arboriculture 2022). The guiding principles of ISA are research, public awareness, membership, professional development, promoting the profession, and safety. ISA’s Science and Research Committee continuously works to provide up-to-date and accurate research in urban forestry. A valuable resource in evaluating of urban trees is ISA’s ‘Basic Tree Risk Assessment Form’ which stems from the ISA publication Best Management Practices: Tree Risk Assessment

(Koeser et al. 2016). This form was created for utility foresters and arborists to access the risk of an urban tree to its surroundings. Due to location or proximity to structures urban trees can have increased risk if they "fail" (Koeser and Smiley 2017). Failure is part or the entirety of a tree falling on a target, such as a car, sidewalk, powerline, building, or person. On the Basic Tree Risk Assessment Form, the Likelihood Matrix (Matrix 1) combines the 'Likelihood of Failure' rating with 'Likelihood of Impacting a Target'. Once the Likelihood Matrix portion is complete, users can move onto the Risk Rating Matrix (Matrix 2) to access 'Likelihood of Failure and Impact' and overall 'Consequences of Failure'. These matrices allow urban foresters or arborists to give a yearly overall risk rating and identify trees that need maintenance or additional follow-up over the year.

The overall goal of this study was to establish an urban forest inventory of RSA. Specific objectives were to: 1) assess urban forest resources at RSA through an urban forest inventory, and 2) determine and evaluate urban tree health and risk at RSA using I-Tree and ISA programs.

2.2 Methodology

In collaboration with the Garrison Environmental Division at RSA, three zones under the jurisdiction of the US Army were determined to be priority areas of the study. These priority areas were 1) Housing and Recreation (HR), 2) Administration (ADM), and 3) Golf Course (GC). Field measurements were required to meet each of the objectives for this study. For Objective 1, field measurements were collected at plot and tree-levels. Objective 2 involved utilizing data from Objective 1 in conjunction with information based on i-Tree Eco Health Assessment and ISA Risk Assessment for urban trees. Findings from Objectives 1 and 2 were synthesized to determine recommendations for the future direction of urban forestry management at RSA.

2.2.1 Study Site

The study site (Figure 2) was Redstone Arsenal United States Army Post in Huntsville, Alabama in Madison County. RSA occupies approximately 15,418 hectares, and approximately 6,475 of those hectares are in improved administrative and housing areas containing urban trees. The HR area (Priority Area 1) includes residential homes, an on-post school, a church, and recreational areas such as sports fields and parks. The ADM area (Priority Area 2) includes US Army buildings' parking lots. The GC area (Priority Area 3) consists of two golf courses, Warrior and Patriot.

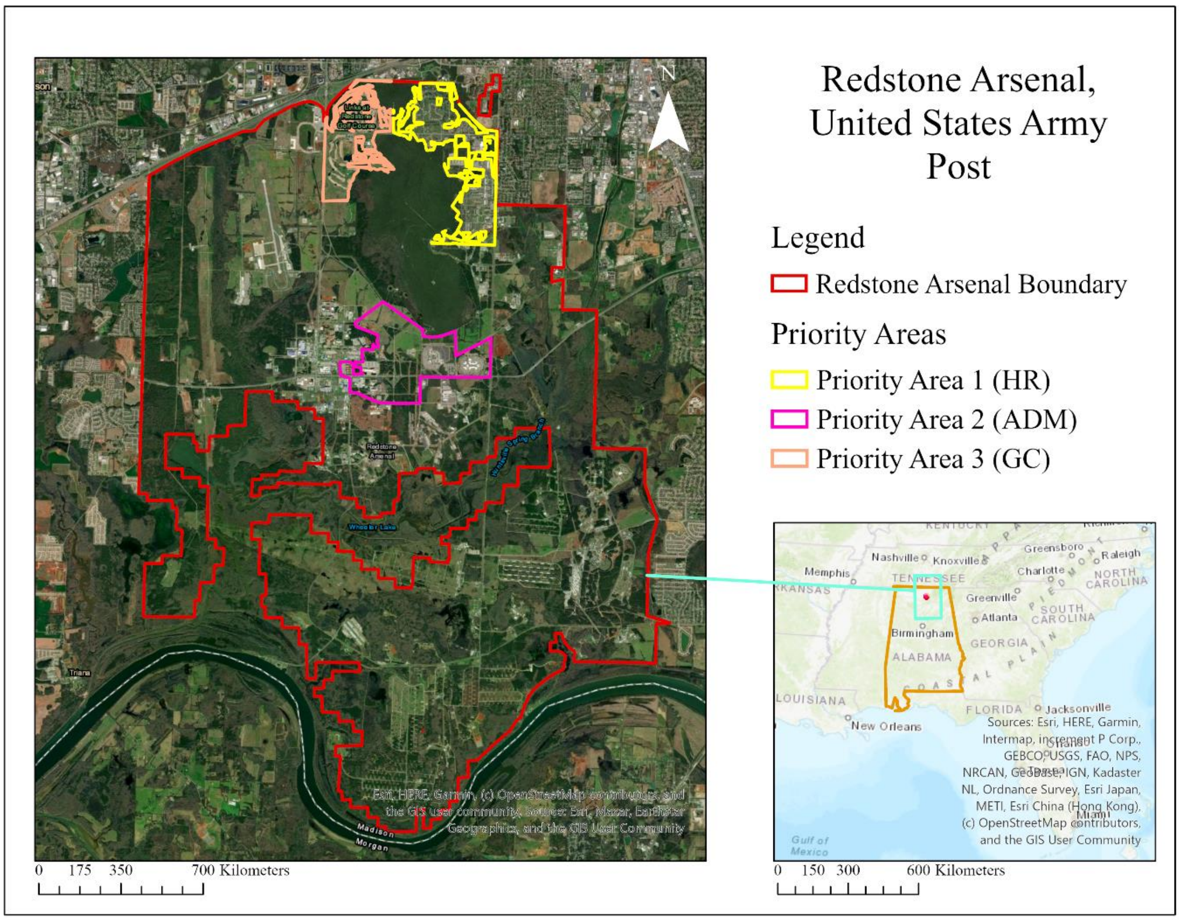

Figure 2. Priority Areas used as study sites for an urban forest inventory at RSA with secondary map showing RSA location in relation to the United States. Three areas, 1) Housing and

Recreation (HR), 2) Administration (ADM), and 3) Golf Course (GC), were used as study sites at RSA for data collection.

2.2.2 Data Collection

Data was collected using methods derived from i-Tree and International Society of Arboriculture (ISA). Field measurements taken were diameter at breast height (DBH), tree height, height to crown, and crown width. For each tree, species was determined, and the condition and health were evaluated and recorded. Both i-Tree Eco and i-Tree Streets were used to develop plot and road transect forms. The ISA Tree Risk assessment matrix was utilized to assess impact risk of sampled trees. Once the ground data were collected, a geodatabase was developed for the urban forest inventory using ArcGIS Pro (ESRI 2022). All inventory data was compiled into a report for Garrison Environmental Division at RSA. This report includes inventory results organized and presented by priority areas and management recommendations.

2.2.3 Priority Area 1: Housing & Recreation

The i-Tree Eco manual states that 200 plots in a random sample will yield a standard error of about 10%. For this study, 200 randomized plots over 338 hectares were created using coordinates created by i-Tree Canopy located in the HR area of the Post (Figure 3). This program allows the user to assign land cover types to randomized points in an uploaded shapefile. These randomized points were used to create plot locations delineated from roads, parking lots, and structures resulting in plots falling only within urban green spaces. Plot locations (latitude and longitude) were recorded using a handheld GPS unit (Forge Series, Windows Embedded Handheld 6.5 Classic, F4 Tech, Tallahassee, FL), and azimuth and distance (meters) to each tree from the center of the plot were collected. Plots were circular and 0.040 hectare in size (radius of 11.3 meters). The tree species, diameter, height to crown, crown width, and condition/health were recorded within each plot. A measuring tape was used for diameter, distance to tree, and crown width. A clinometer was used for tree height and height to crown. Trees were also evaluated using the ISA Tree Risk Assessment matrix. Road transects inventories were also conducted in priority area one. Road transects were designed and conducted based on i-Tree Street's manual; these transects cover 6% of all road segments in both areas. Trees within 9.1 meters of the centerline of each road segment were included in the road transects. The presence of invasive species was also noted in a drive-by visual assessment and their locations (coordinates) were collected.

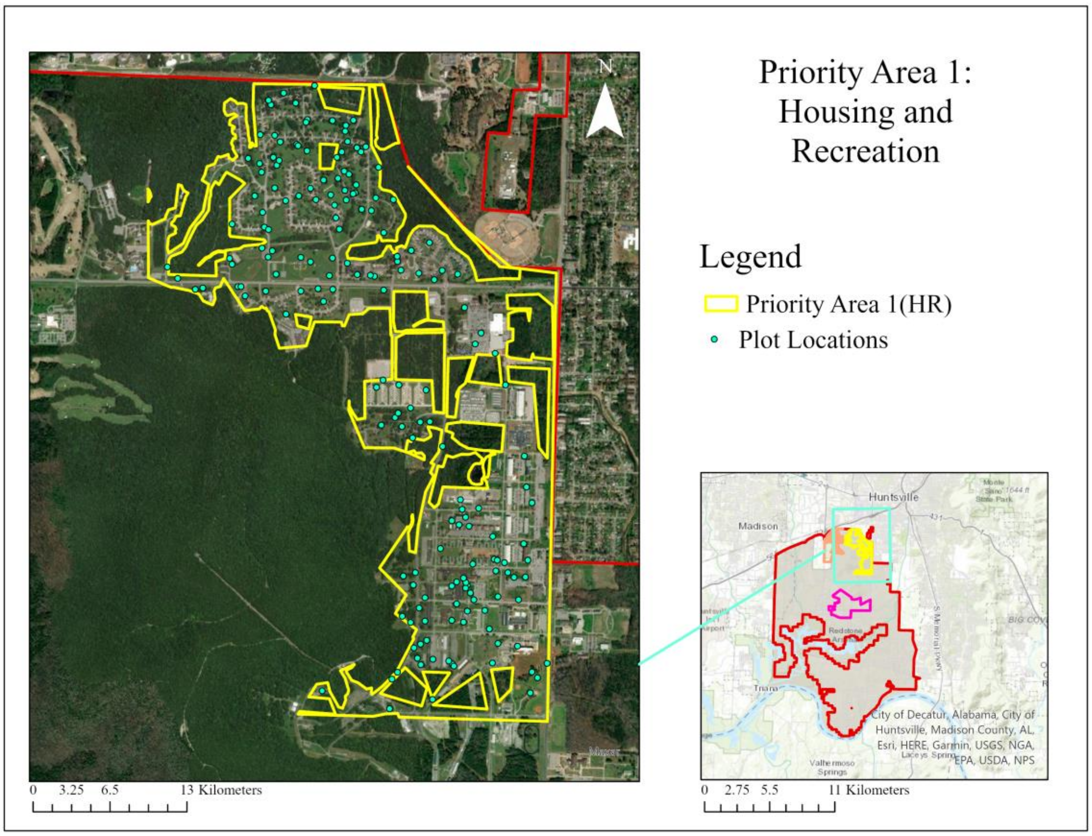

Figure 3. Priority Area 1 - Housing and Recreation (HR) plot locations. Priority Area 1 (HR) location in relation to Redstone Arsenal boundary map.

2.2.4 Priority Area 2: Administration

ADM was comprised of three parking areas: 1) the Sparkman Center, 2) Von Braun Complex, and 3) Redstone Test Center (RTC) parking lots (Figure 4). The total area was 435 hectares. Since there were no plots in this area, the location of each tree was recorded using the GPS unit. The species, diameter, height to crown, crown width, and condition/health were recorded within each parking lot for all trees. A measuring tape was used for diameter, distance to tree, and crown width. A clinometer was used for tree height and height to crown. Trees were evaluated using the ISA Tree Risk Assessment matrix. In addition, road transects inventories and visual assessment of invasive and exotic tree species were conducted and their locations were recorded. As in HR, road transects were designed to cover 6% of all road segments in ADM and trees. All trees within 9.1 meters of the centerline of each road segment were included.

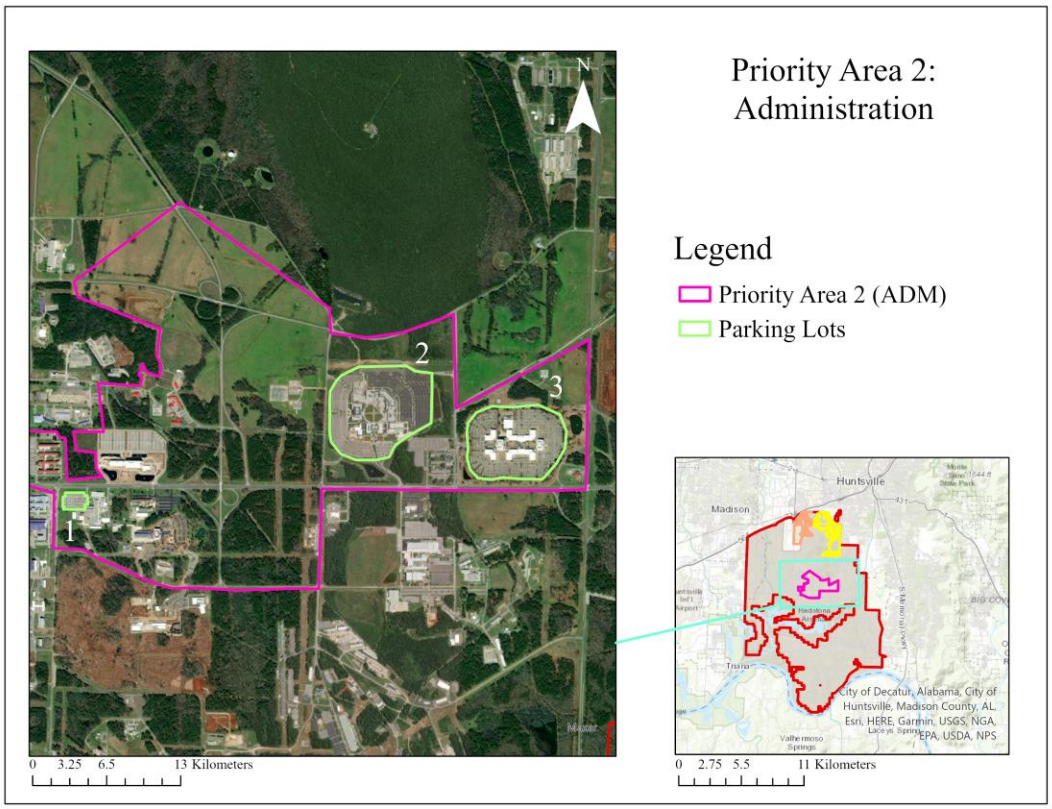

Figure 4. Priority Area 2 - Administration (ADM) with secondary map of location in relation to RSA. Within the ADM area three parking lots, 1) Redstone Test Center (RTC), 2) Von Braun Complex, and 3) Sparkman Center, had location of individual trees taken along with tree measurements and assessments.

2.2.5 Priority Area 3: Golf Course

Two golf courses, Patriot and Warrior, were inventoried at RSA covering a total area of 216 hectares (Figure 5). All trees located within the course playing boundaries that were not part of a forested area were inventoried. For each tree, location information was recorded, and species, condition, and health were assessed using the ISA Tree Risk Assessment matrix, along with DBH, height, height to crown, and crown width. A measuring tape was used for diameter, distance to tree, and crown width. A clinometer was used for tree height and height to crown.

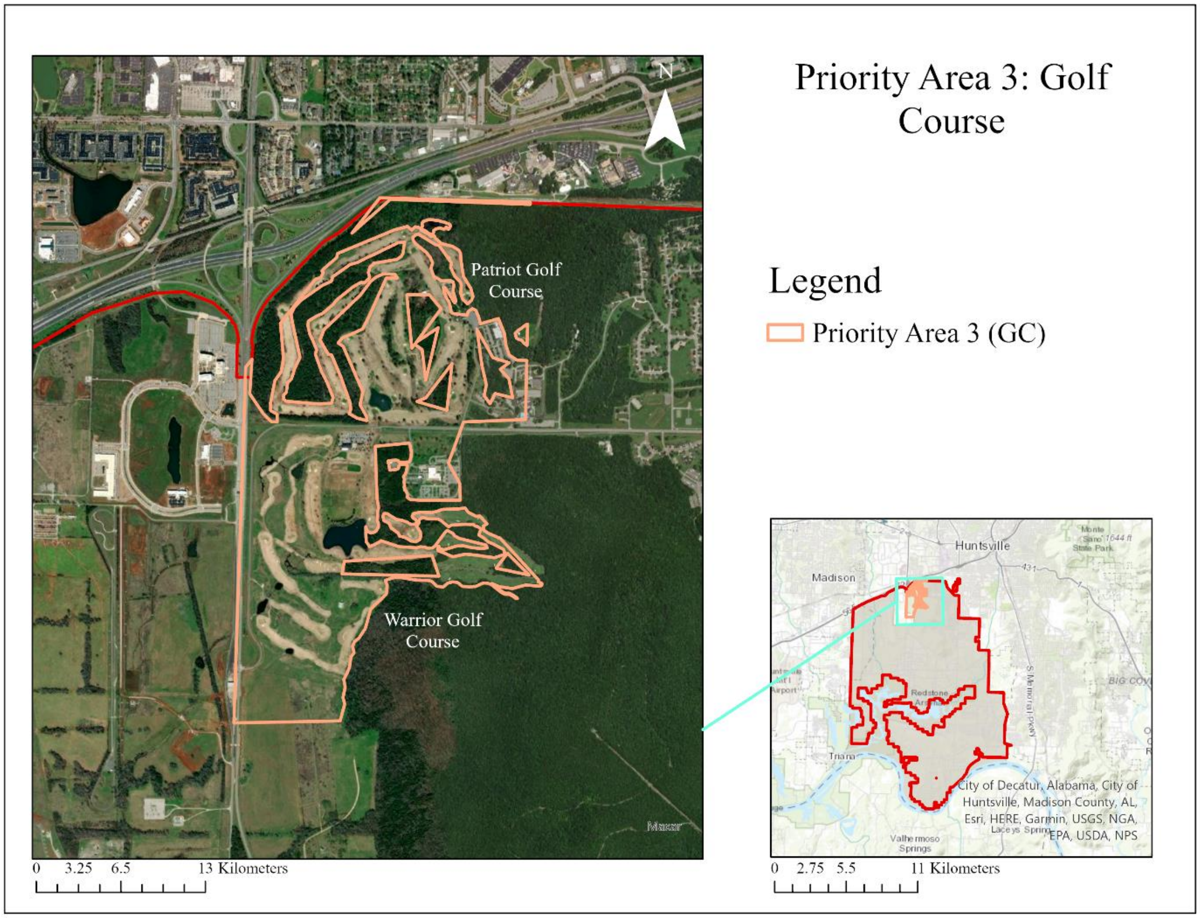

Figure 5. Priority Area 3 – Golf Course (GC) with secondar map of location in relation to RSA. The GC area consisted of locations of individual trees not in forested areas along with their measurements and assessments.

2.2.6 Urban Forest Inventory Geodatabase

Shapefiles of road centerlines and boundaries were provided by RSA personnel. Three feature datasets were created, one for each of the Priority Areas: Housing and Recreation (HR), Administration (ADM), and Golf Course (GC). Within the Housing and Recreation feature dataset, four feature classes were added: 1) Priority Area 1 (HR) boundary (polygon), 2) plot centers (points), 3) road transects (lines), and 4) high-risk/invasive tree species (points). Included in the Housing and Recreation feature dataset is a standalone table containing plot ID and location, species, measurements, and assessments created in Excel. Four feature classes were imported to the Administration feature dataset: 1) Priority Area 2 (ADM) boundary (polygon), 2) trees (points), 3) road transects (lines), and 4) high-risk/invasive tree species (points). Two feature classes imported to the Golf Course feature dataset were: 1) Priority Area 3 (GC) boundary (polygon) and 2) trees (point). With all the tree feature classes, there is a standalone table created from Excel that contains locations, measurements, assessments, and species.

2.3 Results

Overall, 1,488 trees representing over 60 species were measured and assessed across three priority areas at RSA (Appendix A). The most abundant species were crape myrtle (*Lagerstroemia indica*), willow oak (*Quercus phellos*), and red maple (*Acer rubrum*) which made up 56.5% of all trees in the study areas. The average height of all trees was 9.9 meters (Figure 6). Average DBH of trees in all priority areas was 38.3 centimeters (Figure 7). If DBH was not measurable in crape myrtle number of stems was recorded. The average number of stems in crape myrtle was 6. Average crown height was 2.8 meters with average crown width being 8.3 meters.

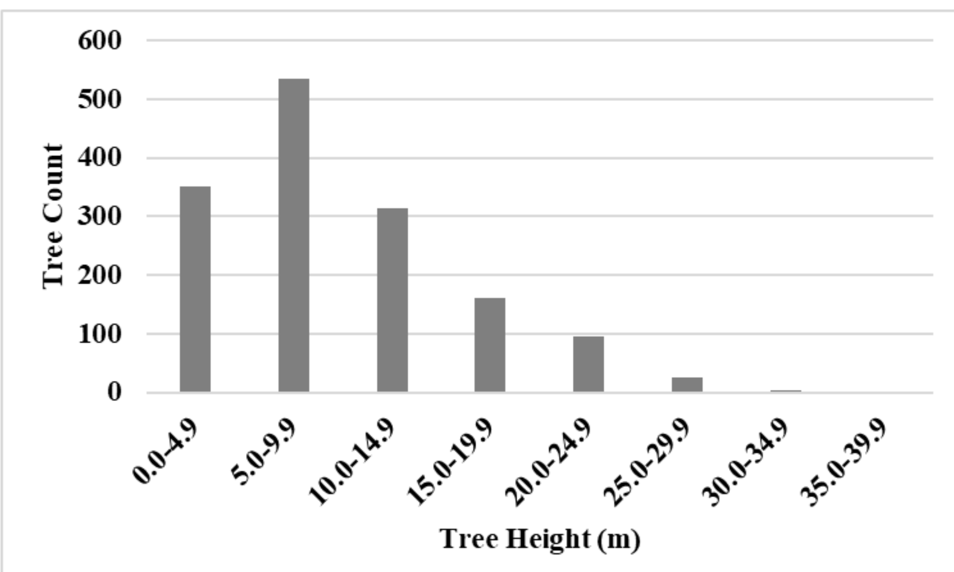

Figure 6. Height distribution and abundance per height of inventoried trees in all Priority Areas at RSA.

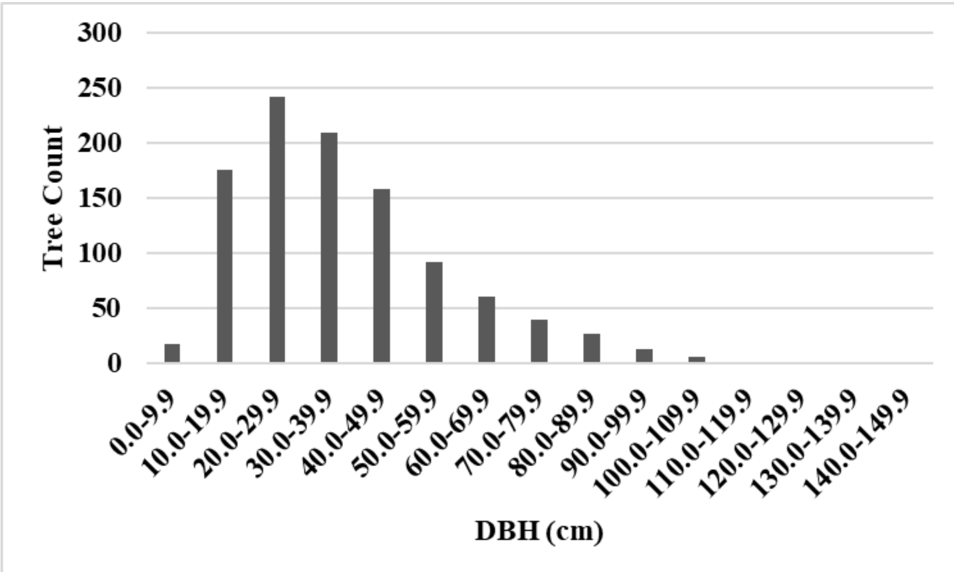

Figure 7. Diameter distribution at diameter breast height (DBH) of inventoried trees in all Priority Areas at RSA.

Two assessments were conducted: 1) i-Tree Eco Health Assessment and 2) ISA Risk Assessment. Across all areas in the i-Tree Health assessment, most trees were found to be in 'good' condition (Figure 8). These trees were found to have minimal trunk/bark, root, or crown issues. The highest number of 'poor' trees were found in the Housing/Recreation area. Human interaction and disturbance are highest in this area due to trees being located on people's properties, school grounds, and recreational areas. HR also had the highest number of 'excellent' ratings as maintenance and care in this area is suspected to be higher. The ISA Risk Assessment ranks trees from low, moderate, high, and extreme based on likelihood that the tree will fail (falling). Across all priority areas 1,487 trees were assessed and received a rank of 'low', and one tree received a rating of 'moderate'.

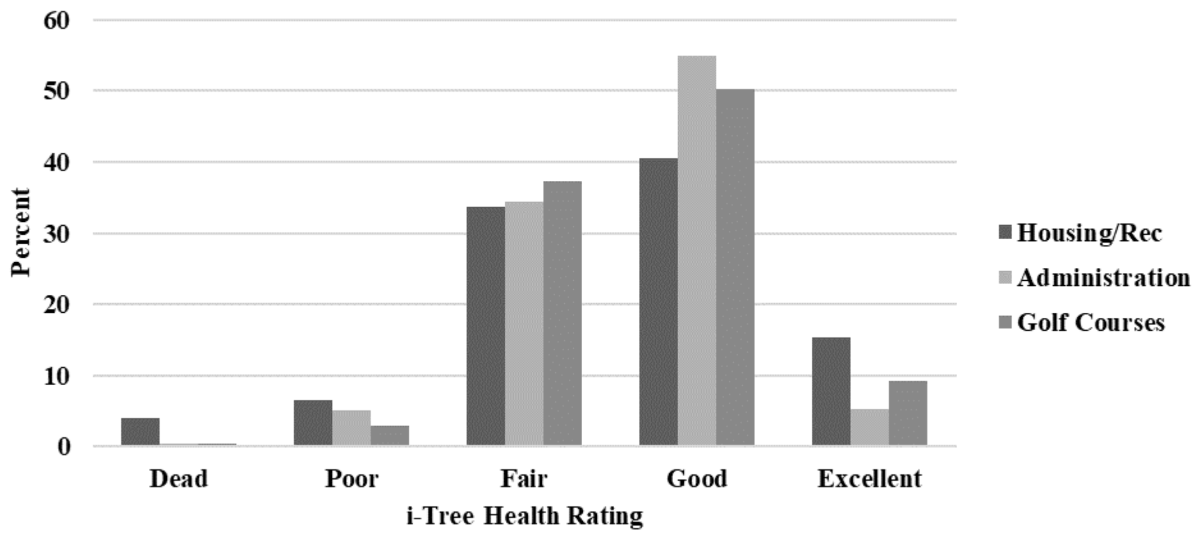

Figure 8. Percentage of trees per i-Tree Eco Health Rating assessed in each Priority Area at RSA.

Visual drive-by assessments were done to mark any tree that was at risk or invasive. These trees were strictly assessed on health and risk, and no measurements were taken. Location of these trees were noted as their condition denotes an issue or risk to their surroundings. These assessments were taken in the HR and ADM areas. Due to GC having a maintenance team, there is no need for additional assessment from the data already collected. Across Priority Areas 1 and 2, a total of 232 trees were marked as high-risk trees or an invasive species. Bradford pear made up 54.7% of trees (127) marked and was the number one invasive tree in these areas. The two species with the highest at-risk ratings were Virginia pine (*Pinus virginiana*) and miscellaneous snags consisting of pines and hardwoods. All Bradford pear (*Pyrus calleryana*) received ratings of 'low' on the ISA Risk Assessment but pose a threat to native tree species in these areas. Results were also examined individually for each Priority Area. Results for each Priority Area are presented in Sections 3.4.

2.3.1 Priority Area 1: Housing and Recreation

Across HR, 227 trees were measured and assessed. Approximately 51% of trees were composed of 32 different species. The top five species inventoried in this area (Figure 8) were crape myrtle (*Lagerstroemia indica*), eastern red cedar (*Juniperus virginiana)*, red maple (*Acer rubrum)*, loblolly pine (*Pinus taeda),* and Bradford pear (*Pyrus calleryana).* The average DBH of trees in this area was 41.6 centimeters. Average tree heigh was recorded as 11.1 meters with average crown height being 3.7 meters. The average width of the crown was found to be 9.4 meters. After conducting the i-Tree Eco Health and ISA Risk Assessment, the average tree health was found to be 'good' (rating of 4) with a risk rating of 'low'.

Table 1. Abundance and total percentage of top ten species inventoried in Priority Area 1 (HR) at RSA.

Species	Abundance (Number)	Percentage of Total
Crape Myrtle (*Lagerstroemia indica*)	36	15.9
Eastern Red Cedar *(Juniperus virginiana)*	28	12.3
Red Maple *(Acer rubrum)*	20	8.8
Loblolly Pine *(Pinus taeda)*	18	7.9
Bradford Pear *(Pyrus calleryana)*	12	5.3
Pin Oak *(Quercus palustris)*	11	4.8
Sugar Maple *(Acer saccharum)*	11	4.8
Willow Oak *(Quercus phellos)*	9	4.0
Common Hackberry *(Celtis occidentalis)*	9	4.0
Southern Magnolia *(Magnolia grandiflora)*	7	3.1
Other (22)	66	29.1
Total	227	100.0

2.3.2 Priority Area 2: Administration

In ADM, 955 trees were measured and assessed across 16 different species. The top five species inventoried in this area were crape myrtle (*Lagerstroemia indica*), willow oak (*Quercus phellos*), red maple (*Acer rubrum),* Virginia pine (*Pinus virginiana),* and eastern redbud (*Cercis canadensis).* The average DBH was 29.5 centimeters. Average tree heigh was recorded as 7.5

meters with average crown height being 2.2 meters. The average width of the crown was found to be 6.9 meters. Similar to the HR area, the ADM area also had average marks of 'good' for the i-Tree Eco Health assessment and 'low' for the ISA Risk Assessment.

Table 2. Abundance and total percentage of top ten species inventoried in Priority Area 2 (ADM) at RSA.

Species	Abundance (Number)	Percentage of Total
Crape Myrtle (*Lagerstroemia indica*)	357	37.4
Willow Oak *(Quercus phellos)*	194	20.3
Red Maple *(Acer rubrum)*	153	16.0
Virginia Pine *(Pinus virginiana)*	63	6.6
Eastern Redbud *(Cercis canadensis)*	38	4.0
Pin Oak *(Quercus palustris)*	37	3.9
Shumard Oak *(Quercus shumardii)*	32	3.3
Northern Red Oak *(Quercus rubra)*	22	2.3
Overcup Oak *(Quercus lyrata)*	20	2.1
Loblolly Pine *(Quercus taeda)*	18	1.9
Other (6)	21	2.2
Total	955	100.0

2.3.3 Priority Area 3: Golf Course

Across GC, a total of 304 trees were measured and assessed from 42 different species. The top five species inventoried in this area (Figure 10) were red maple (*Acer rubrum*), loblolly pine (*Pinus taeda*), southern magnolia (*Magnolia grandiflora*), crape myrtle (*Lagerstroemia indica*), and southern red oak (*Quercus falcata*). The average DBH was 55.7 centimeters. Average tree height was recorded as 16.1 meters with average crown height being 3.9 meters. The average width of the crown was found to be 11.8 meters. After conducting the i-Tree Eco Health and ISA Risk Assessment, the average tree health was found to be 'good' (rating of 4) with a risk rating of 'low'.

Table 3. Abundance and total percentage of top ten species inventoried in Priority Area 3 (GC) at RSA.

Species	Abundance (Number)	Percentage of Total
Red Maple *(Acer rubrum)*	36	11.8
Loblolly Pine *(Pinus taeda)*	30	9.8
Southern Magnolia *(Magnolia grandiflora)*	27	8.8
Crape Myrtle (*Lagerstroemia indica*)	23	7.5
Southern Red Oak (*Quercus falcata)*	15	4.9
Eastern Red Cedar (*Juniperus virginiana*)	12	3.9
Water Oak (*Quercus nigra)*	12	3.9
Winged Elm (*Ulmus alata)*	12	3.9
Common Hackberry *(Celtis occidentalis)*	11	3.6
Sassafras (*Sassafras albidum)*	10	3.3
Other (32)	118	38.6
Total	306	100.0

2.3.4 Visual Drive-By Assessment Results

The visual drive-by assessment in identified 189 trees that were at high risk of failure (falling) or that are considered invasive to RSA (Figure 9). Approximately 55% of these trees were the invasive Bradford pear. The remaining 45% were trees at high risk after conducting the ISA Risk Assessment. These trees were severely damage or snags. Road transects were also completed in this priority area resulting in 16 transects. Location, measurements, and assessments were taken of 41 trees on the road transects. Approximately 51% of the 41 trees on road transects in this area were Virginia pine. The Virginia pine trees were rated ‘fair’ in the i-Tree Eco Health assessment and ‘low’ in the ISA Risk Assessment.

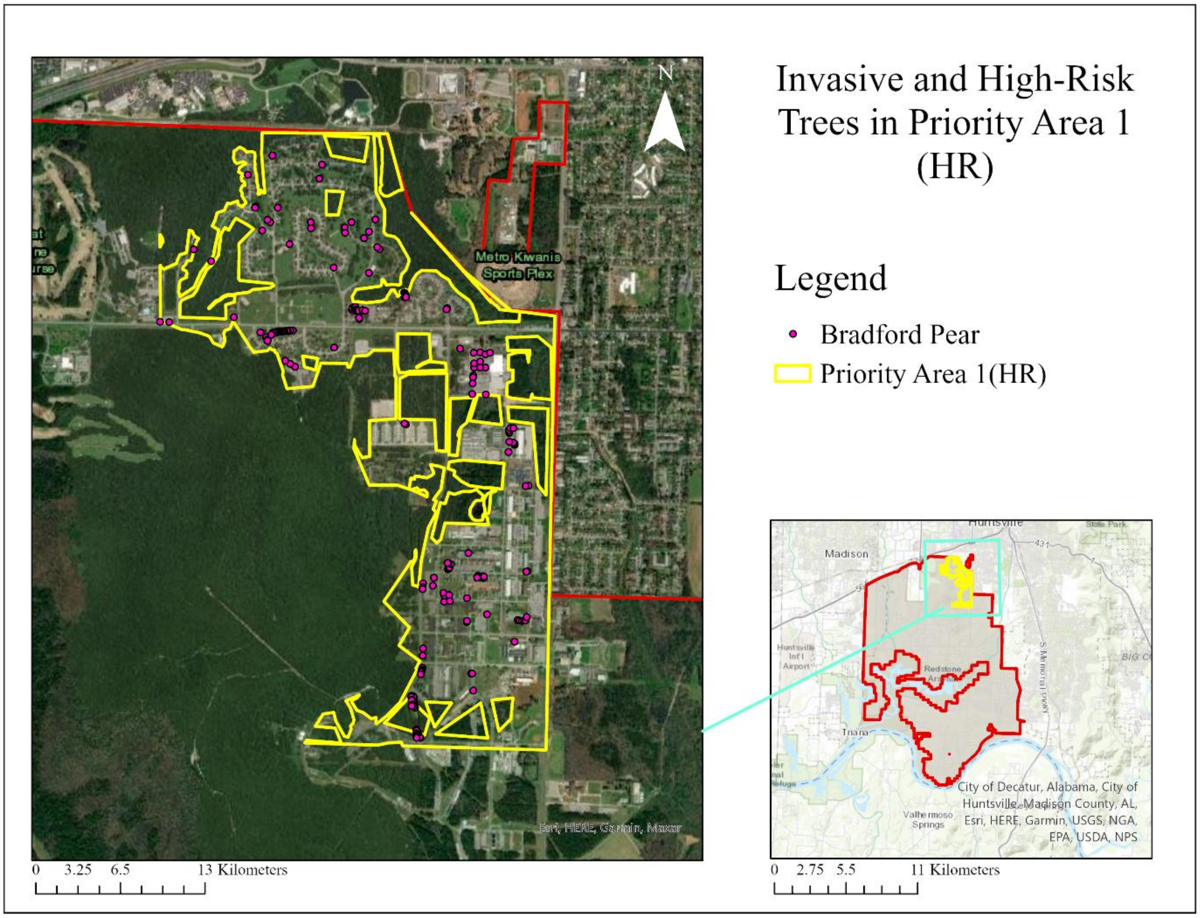

Figure 9. Location of invasive species and high-risk trees in Priority Area 1 (HR) at RSA located from visual drive-by assessments with secondary map showing location of area in relation to RSA boundary.

In ADM, the visual drive-by assessment identified 34 trees that were at high risk of failure (falling) or that are considered invasive to RSA. Approximately 68% of these trees were the invasive Bradford pear. The remaining 32% were trees at high risk after conducting the ISA Risk Assessment. These trees were severely damage or snags. Road transects were also completed in this priority area resulting in 16 transects, but only 4 trees were found on the transects. Majority of trees in this priority area were found in the Von Braun Center, Sparkman Complex, and RTC parking lots.

2.4 Discussion

The Forest Inventory and Analysis (FIA) Program through the US Forest Service allows for the evaluation of America's forests through status and trend information. The FIA program recognized that urban trees usually are not inventoried as typical forested land would be. The FIA program continual collaborates with i-Tree to quantify urban trees and the environmental services they provide to create the Urban FIA protocols (USDA Forest Service 2022). This FIA collects data on tree species, size, crown condition, and damage, but goes into more depth as it also collects data on ground cover, urban markets, and ownership and societal values. As this study was limited to certain locations across RSA under US Army jurisdiction, it was conducted as a sample inventory and only contains data on tree species, size, crown, and health condition and risk.

Expectations were that the HR area would have the most trees rank poorly through the i-Tree Eco Health Assessment; this area had the highest number of 'dead' or 'poor' rankings. This area is prone to increased human activity which could result in more disruption to urban trees. Many municipalities encourage the planting of urban trees through educating residents or providing free or low-cost trees or services (Conway and Bang 2017). RSA has landscape maintenance crews who work across the Post that provides basic services such as mowing lawns and tree trimming. Residents can add vegetation to their yards sparingly as it must be approved through the Post. Due to regulations on Post and lack of education on urban tree benefits amongst residents, the urban trees in the HR area are often left unmanaged. Urban trees have environmental and sociological benefits that could enhance the HR area (Westphal 2003). Urban heat island effect as well as water and air pollution can be mitigated through the use of urban trees (Nitoslawski et al. 2019). Trees found in urban areas can also increase biodiversity as they have their own microhabitats and climates (Adams et al. 2005). Increasing urban forest management of the maintenance plan for this area could not only improve environmental conditions but also have a positive impact on residents.

Majority of the area in ADM is surrounded by old agricultural fields. Urban trees were not evenly dispersed through the area as almost all resided around the parking lots inventoried. Most of the trees in the ADM area were smaller, had support stakes, and fresh mulch; it was suspected that majority of these trees were planted fairly recent. The younger trees in this area resulted in lower average measurements than the other two Priority Areas. These trees were also closer in location to one another than other areas; majority of trees were found on parking lot islands and dividers (Figure 9). Urban trees face challenges such as poor soil quality, pollution, and lack of growing space (Jim et al. 2018). As these trees continue to grow in the ADM area parking lots, they may later have issues adapting to harsh conditions, spreading roots, and competing for resources in this urban area.

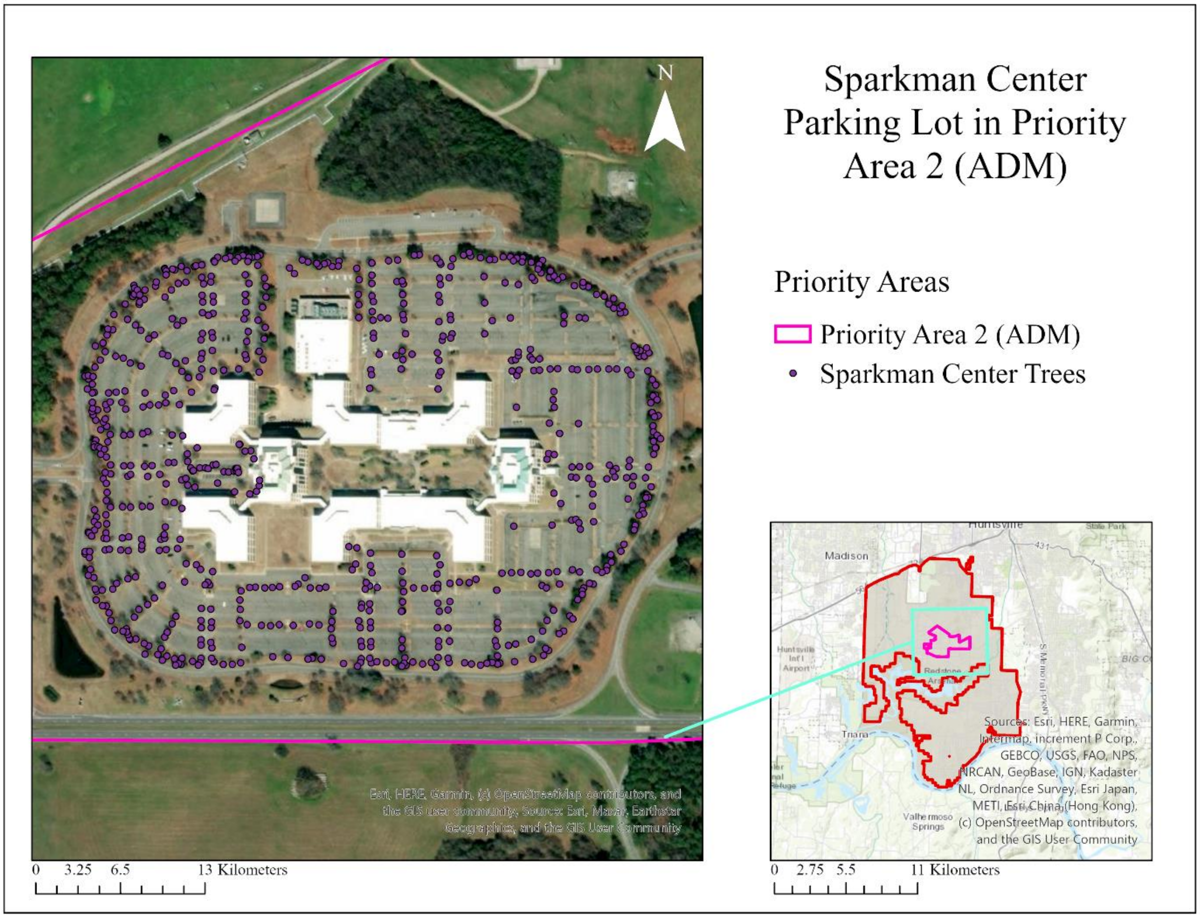

Figure 10. Location of measured trees in the Sparkman Center Parking Lot in Priority Area 2 (ADM) with secondary map showing location of area in relation to RSA boundaries.

There was uncertainty before inventorying the GC area about the condition of the trees as there is a lot of human activity but also constant maintenance of the area. The GC area had the largest trees overall and also the greatest number of species recorded. Both golf courses have plenty of space for trees to grow as well as a diverse terrain that can support a number of different species. The maintenance team works strictly on the golf courses which may explain the overall good condition of the urban trees. This area may be subject to over maintenance as trees can be over trimmed and exposed to pesticides to increase playability for golfers. Management of this area's natural resources seems adequately addressed; the urban forest inventory data may provide insightful data for the maintenance team's future management decisions.

To improve the urban areas' trees at RSA it is recommended to remove all trees found to be at high-risk of failure in HR and ADM. These trees are expected to fail within the next year which resulted in their high-risk ratings. Leaving these trees in areas where they could fall and damage buildings, vehicles, or hurt people can be dangerous and costly. Removal of these trees could result in less damage to local infrastructure and increase safety across all priority areas.

The introduction of invasive species in urban areas is not a new concept, but rather one that has been battled for years. Urban areas often inhibit the spread of invasive species deliberately and accidentally (Borden and Flory 2021). Ornamental species are often introduced for aesthetic purposes, but many ornamental species are nonnative and in turn can be invasive. Urban areas usually have high land cover change due to alteration or disruption. This land cover change can make it hard for native species to occupy habitats due to alteration. Invasive species can spread rapidly and occupy habitats that may be unsuitable for native species. The movement of invasive species, particularly trees, in an urban setting can be quite easy. Seeds, branches, flowers, etc. can be spread through an urban area by landscapers, citizens, and animals. This dispersal mechanism along with the ease of establishment for some species can make an invasion difficult to eliminate (Padayachee et al. 2017). Invasive species were assessed in each Priority Area. The number of Bradford pear, an invasive species, is an issue across all priority areas. Bradford pear at RSA was most likely planted as an ornamental in their urban areas. Due to the fast-spreading nature of the Bradford pear, it has invaded many different areas across the Post including urban and forested areas through purposeful planting and seed movement by wildlife. Urban environments create new pressures on organisms that reside there. These pressures can make it difficult for native species to thrive and spread (Borden and Flory 2021). An "urbanized invader" such as Bradford pear can exasperate the pressures put on native species (Borden and Flory 2021). RSA should address invasive tree issues in these priority areas and replace them with native species. Three native species that showed overall good health ratings in all Priority Areas that could be used to replace Bradford pear are willow oak, red maple, and loblolly pine. How can improvements be made to the Bradford pear issue in the HR area where it's worst? One answer is to attempt to contain the Bradford pear to this area as it does not seem to be a prevalent issue in the other priority areas. This would involve regularly scheduled landscape maintenance as well as proper disposal of Bradford pear clippings or branches, especially those that contain fruit. The practice of girdling these trees could be utilized while combined with strategic use of herbicides. These practices could be costly but if the invasion spreads it will end up costing more in the long run. Another option is to allow residents to engage in the maintenance of their lawns. Many residents do not have a choice or need approval when it comes to what plants occupy their yard or the maintenance provided by the Post. Incorporating more native, urban trees while removal of Bradford pear could strengthen microhabitats and ecological functions that native plants provide in the environment.

2.5 Conclusion

RSA has prioritized sustainable land management practices; part of those practices involved the completion of an urban forest inventory on the Post. As an urban forest inventory has never been conducted at RSA, this work provides support to make sound land management decisions and to maintain healthy, native flora. Completion of this inventory has provided comprehensive knowledge of what urban trees reside on Post, and their health, structural condition, and the risk these trees might have on urban areas. Each Priority Area exhibited strengths and weaknesses when it came to the quality and condition of RSA's urban trees. Increased maintenance of urban trees in HR could provide environmental and sociological benefits at individual and community level. ADM has minor issues at present but could see problems arise in the future due to the proximity of urban trees in the area. GC receives proper maintenance; species specific data provided through the inventory can add to future management plans. A reoccurring issue across all Priority Areas were high-risk trees as well as the prevalence of Bradford pear. High-risk trees should be properly removed within the next year to prevent damage to infrastructure and danger to people. Bradford pear removal will be tedious, but necessary to prevent this invasive species from overtaking the urban area from native species. Further research could involve Post stakeholder views on urban natural resources, bringing more native flora species to RSA, and a plan to combat invasive species issues in these urban areas.

Chapter 3:

Hydrological Benefits of Urban Trees in the Residential and Recreational Areas at Redstone Arsenal

3.1 Introduction

Redstone Arsenal (RSA) is a United States (US) Army post located in Huntsville, Alabama. RSA has had continued development since its founding in 1943; as RSA handles missile defense on their Post, expansion of new training areas, storage facilities, and operations buildings continues to increase to provide proper and safe handling of weaponry. Growth of the Post has led to increased urbanization resulting in permeable soil being replaced with impermeable surfaces such as concrete and asphalt or structures. Anthropogenic activities, such as urbanization, can exacerbate issues such as flooding (Suriya and Mudgal 2012). Urban areas have increased land modification and impervious surfaces which can disrupt the flow of water causing these areas to be prone to flooding (Barbosa et al. 2012). RSA has added urban natural resource planning across the Post to their overall environmental management goals. In particular, an urban forest inventory was conducted to accomplish the goals of understanding species composition, tree condition, and risk to US Army facilities and urban areas. As the Post progresses in their goals of incorporating urban natural resource planning into their management plan, it is crucial to understand how their urban trees can play a role in mitigating excess water coming into RSA's urban areas. Using information acquired from the recently completed urban forest inventory for RSA, this work can combine information regarding urban trees with the use of green infrastructure.

Urbanization has increased across the US through the conversion of agricultural and forested land (Alig et al. 2004). The southeast United States in particular is outpacing the rest of the country when it comes to urban growth as they're experiencing urban sprawl (Suttles et al. 2018). With this continued increase, resource planning has become a crucial part of municipalities incorporating and engaging natural resources on the urban landscape (Mazzotti and Morganstern 1997 and Kaur and Garg 2019). One way that natural resources have been reincorporated into the urban landscape is through the use of green infrastructure instead of gray infrastructure (Monteiro et al. 2020). The goal of green infrastructure is to limit negative ecological consequences caused by urbanization (Madden 2010). Gray infrastructure is characterized by increased human engineering involving concrete, brick, and paved or covered surfaces creating impervious cover of the surface below (Madden 2010). Green infrastructure can utilize gray infrastructure but aims to connect urban areas. Gray and green infrastructure can be used in mutualistic ways that will create less damage to the environment while providing benefits to urban spaces. A simple and easy way many cities use green infrastructure is by incorporating trees in urban areas (Carlyle-Moses et al. 2020).

Urban forestry is all trees and associated vegetation within an urban area (Nitoslawski et al. 2019). The planning, maintenance, and management of these trees are pertinent to the success of any urban forestry program. Benefits of urban trees can be sociological and psychological for people who live in urban areas. These benefits include feeling connected to nature, reduced symptoms of depression, and increased life satisfaction (Turner-Skoff and Cavander 2019). Urban trees also contribute to commonly used public areas such as parks, trails, and playgrounds by providing shade. There are many ecological benefits of urban trees, such as creating microhabitats, adding native flora back to the landscape, and increasing species richness in an area (Dwivedi et al. 2009). Environmental benefits of urban trees can include reducing air and water pollution, reducing additional heat caused by urban heat island effect, and mitigating stormwater.

Urban areas can create complex issues when it comes to managing stormwater. As there is an increase in impervious surfaces in urban areas, stormwater can take longer to drain leading to flood issues. Urban areas create impermeable surfaces from the construction of roads, parking lots, and sidewalks through the replacement of permeable soil (Konrad 2016). As a result, the area of permeable soil is reduced leading to more excess stormwater. This excess stormwater with a lack of space for infiltration can create public health and environmental issues. Components of runoff, such as, road salt and pavement permeability, can impact soil health which can be detrimental to trees in an urban setting (Mullaney et al. 2015 and Equiza et al. 2017). Stormwater flooding can lead to dangerous situations such as undrivable streets, impacting power lines, and flooding buildings (Barbosa et al. 2012). Health is also at risk during urban flooding as unsanitary water can sit for prolonged periods, and possibly even death to those caught in extreme flooding events. In terms of environmental impacts of excess stormwater, pollution, habitat degradation, and soil erosion and composition can be increased (Suttles et al. 2018 and Hodgkins et al. 2019). Understanding local hydrology can help municipalities mitigate excess water in urban areas.

Tools, like i-Tree Canopy, can be used at local levels to understand the relationship between land cover and hydrological impacts at various scales. Through the use of aerial imagery, the i-Tree Canopy can be used to manually classify land cover (Nowak 2020). The i-Tree Canopy application allows the user to define cover type through generation of random points within a geographic boundary (Nowak 2020). The user can then examine the randomized point to assign it a cover class. Users can upload their own shapefile, use Google maps to draw a boundary, or select pre-existing geographic boundaries. In a study conducted by Busca and Revelli 2022, i-Tree Canopy was used to determine land cover distribution which was entered in i-Tree Hydro under ‘Land Cover Scenarios’. As ‘Land Cover Scenarios’ is filled in by the user, it is useful to determine cover class percentage of one’s study area. Before starting the i-Tree Canopy program, it suggested 500-1000 survey points be used to obtain cover estimates (Nowak 2020). The i-Tree Canopy program provides tree benefit estimates based on the randomized survey points. Estimates of tree benefits can include made for carbon, air pollution, and hydrology. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points (Nowak 2020). The i-Tree Canopy program can provide the annual amount of air pollutants removed through the dry deposition process by trees, and in turn the associated monetary value of this removal (Hirabayashi 2014). Air pollutants included in the i-Tree Canopy analysis include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter greater than 2.5 microns and less than 10 microns (PM10*), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO_2) removed annually. These values are reported as removal rate (lbs/ac/yr) and monetary value ($/T/yr). Hydrological benefits are also reported by i-Tree Canopy through parameters of avoided runoff (AVRO), evaporation (E), interception (I), transpiration (T), potential evaporation (PE), and potential evapotranspiration (PET). These reports include the tree effects (gal/yd^2/yr) and monetary value ($/$yd^2$/yr) from the parameters of the hydrological benefits. Carbon benefits calculated by i-Tree Canopy include carbon sequestered annually in trees and stored in trees (per area of tree cover). These benefits are reported through carbon rate (T/ac/yr) and CO_2 equivalent rate (T/ac/yr). Through the i-Tree Canopy program impacts of urban trees and impervious surfaces on hydrological benefits can be quantified (Nowak 2020). Trees can impact stream flow rates in three different ways, canopy rainfall interception, evapotranspiration, and soil water infiltration (Coville et al. 2020). Hydrological issues can be examined through Understanding urban hydrological issues can help guide management decisions when it comes to the negative impacts of excess water and pollution.

Management methods could be combined with green infrastructure, such as rain gardens and bioswales, to combat urban stormwater issues. Active stormwater harvesting is the storage of water for reuse, while passive stormwater harvesting infiltrates into the ground. Passive stormwater harvesting can reduce water flow, bring water back to the landscape and recharge groundwater. Passive stormwater harvesting can allow water to filtrate into the soil rather than cause flooding and runoff. This method can be used in many ways from retention ponds, rain gardens, pervious surfaces, gravel paths, and bioswales or swaled drainage depressions (Xiao and McPherson 2011).

Urban trees can be used with green infrastructure to help mitigate pollution that may reside in stormwater while improving water quality. Certain tree species have low tolerance to excess water; too much water can drown roots which can be detrimental to tree health and longevity causing issues such as root rot or fungus (Coville et al. 2020). Flat and permeable surfaces allow the movement of surface water into local aquifers, but impermeable surfaces can impede this water movement causing erosion or flooding (Cook et al. 2015). In addition to impermeable surfaces and excess runoff, soil hydrologic groups play a role in the relationship between water and urban trees. Soil type and volume can be contributing factors to the overall health of an urban tree stand (Yung Jim 2019). RSA is located in Madison County which is one of eight counties in northern Alabama that are close to the Tennessee River (Sheppard et al. 2001). This proximity to the Tennessee River can add more, unwanted water in urban areas as the river rises. RSA can benefit from implementing green infrastructure and urban vegetation where soil infiltration is poor, or runoff levels are high. Urban streams tend to rise more quickly during storms than rural streams, and green infrastructure with the use of vegetation and trees can mitigate extra water coming onto the installation (Konrad 2016). Utilizing soil hydrologic group and runoff from the Wheeler Basin Soil Survey Geographic Database (ArcGIS 2017) and urban forest inventory data can be used to determine areas where green infrastructure can be beneficial to mitigate the adverse effects of excess stormwater. Green infrastructure can also benefit urban landscapes by providing more controlled infiltration through permeable soil enhanced by roots, reducing runoff. Adding urban trees to green infrastructure can help return water to the atmosphere through transpiration (Scharenbroch et al. 2016 and Caplan et al. 2019).

Trees and green infrastructure can have positive benefits in urban areas while mitigating other natural resource issues such as those caused by urban hydrology. The overall goal of this study was to evaluate urban stormwater issues at RSA while developing recommendations for the use of green infrastructure that includes urban trees. Specific objectives were to: 1) identify areas that are of hydrologic concern based on soil hydrologic group and runoff class. and 2) assess how land cover changes can improve areas of hydrologic concern using the i-Tree Canopy program.

3.2 Methodology

This study was conducted using Priority Area 1 (HR) described in Chapter 2. Objective 1 involved using data from the United States Geological Survey (USGS) and Soil Survey Geographic Database (SSURGO) to determine low water infiltration and high runoff soil groups across RSA. Objective 2 involved using the i-Tree Canopy program to assess how changes in land cover could improve areas with poor hydrology. These areas were then assessed to understand the urban tree benefits and how they can be increased. For areas meeting these criteria, recommendations for the use of urban trees and green infrastructure to mitigate stormwater issues such as pollution and infiltration were developed.

3.2.1 Study Site

The study site was at Redstone Arsenal United States Army Post in Huntsville, Alabama in Madison County. RSA resides in northern Alabama with proximity to the Tennessee River. Within RSA, Priority Area 1 which consists of residential areas such as homes and recreational was used as the study site (Figure 1). Priority Area 1 is of interest to the US Army Garrison Environmental Division as it has the most residential activities that could impact urban natural resource areas.

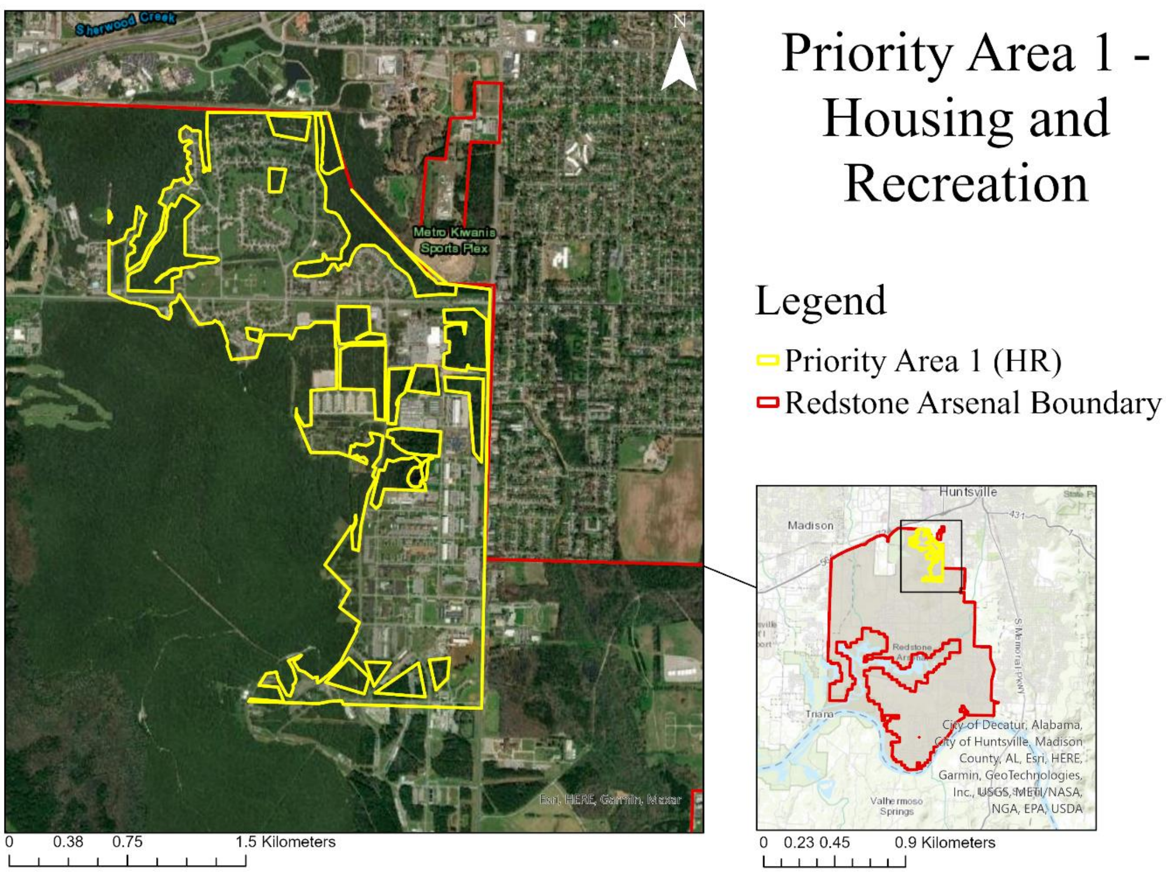

Figure 11. Priority Area 1 - Housing and Recreation (HR) location in relation to Redstone Arsenal boundary map (secondary map). The HR area is the residential and recreational area of the Post.

3.2.2 Hydrologic Concerns

Wheeler Basin hydrologic group data was obtained using publicly available data from the SSURGO (ArcGIS 2017). From this data, Soil Hydrologic Groups and Runoff shapefiles (vector format) were extracted for use in ArcGIS Pro (Wheeler Basin SSURGO). A feature dataset was used from an urban forest inventory previously developed for RSA was used. Within this feature dataset, the boundary of Priority Area 1 and urban tree locations within the area were utilized. From this data, Soil Hydrologic Groups and Runoff shapefiles were extracted for use in ArcGIS Pro. A query was used to select features from 'Soil Hydrologic Group' and 'Runoff'. Fields contained soil hydrologic groups B/D, C/D, and D, and runoff classes of Medium, High, and Very High. Any soil hydrologic groups containing 'D' are defined by the SSURGO as slow infiltration rate were selected. The final selection, meeting both criteria, was exported as a new feature class called 'Hydrologic Concern'. Within the Priority Area 1 boundary, features from the Soil Hydrologic Groups and Runoff shapefile that did not meet criteria od hydrologic concern were exported as a separate feature class called 'Ideal Conditions'.

3.2.3 i-Tree Canopy

In addition to using i-Tree Canopy to define land cover classes for land cover parameters in i-Tree Hydro, i-Tree Canopy was used to define land cover classes in Priority Area 1. Two separate shapefiles, 'Ideal Conditions and 'Hydrologic Concern', were uploaded into i-Tree Canopy. Each shapefile was assessed using 500 randomized survey points (1000 total). Land cover classes were user defined as 1) Grass/Herbaceous, 2) Impervious, 3) Tree/Shrub, 4) Soil/Bare Ground, and 5) Water. After survey points were placed, tree benefit estimates of carbon, air pollution, and hydrological were assessed. The ‘Hydrologic Concern’ survey points were altered, the Tree/Shrub class replaced Grass/Herbaceous and Soil/Bare Ground classes. These alterations were made in 10% intervals until tree benefit estimates of ‘Hydrologic Concern’ matched those of ‘Ideal Condition’.

3.3 Results

HR was found to have soil hydrologic groups B/D, C/D, and D. This area also had runoff classes Medium, High, and Very High. Together, ‘Soil Hydrologic Group’ and ‘Runoff’ created the ‘Hydrologic Concern’ area (Figure 12). Any areas not in the ‘Hydrologic Concern’ area within Priority Area 1 were in the ‘Ideal Conditions’ area concerning their hydrology.

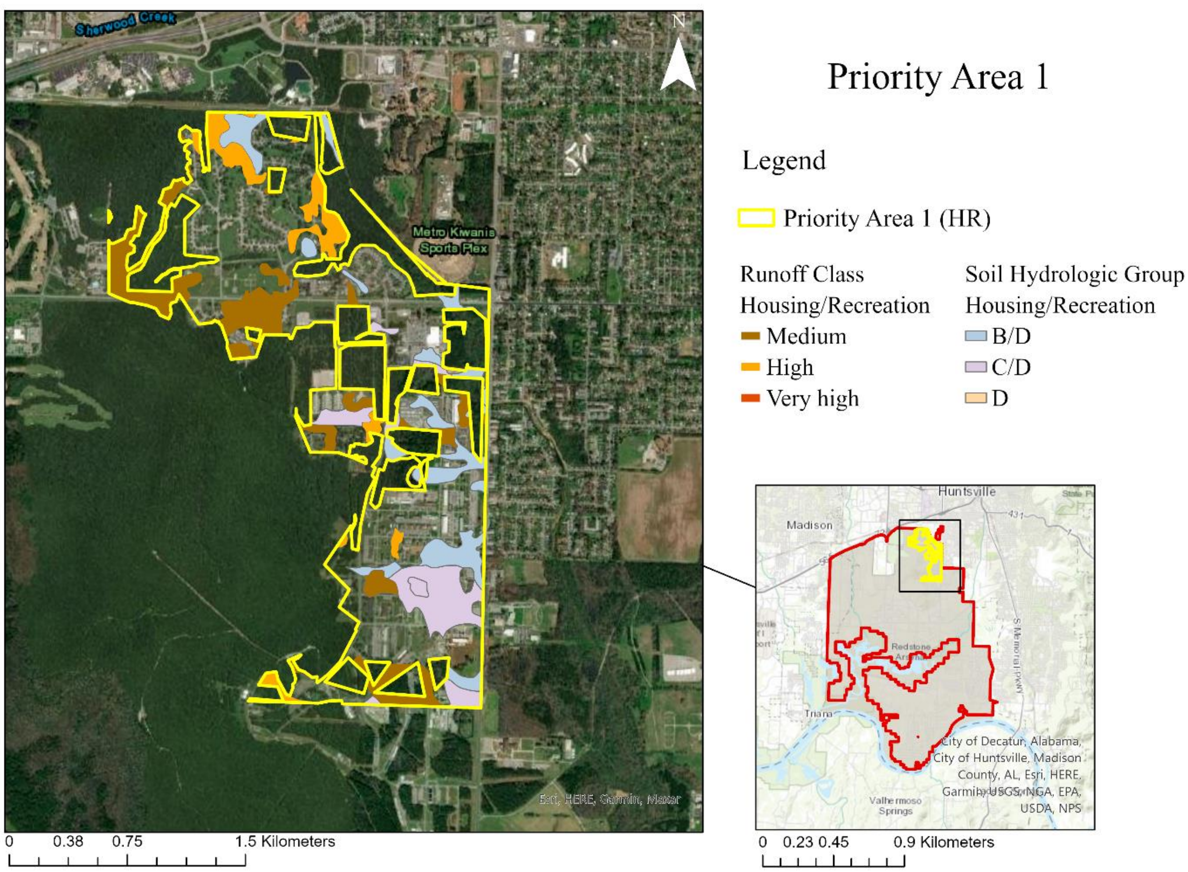

Figure 12. Hydrology Issues in Priority Area 1 (HR) with secondary map showing location in relation to Redstone Arsenal boundary map. Areas in Priority Area 1 with Soil Hydrologic Groups of poor infiltration (B/D, C/D, D) and Runoff Classes (Medium, High, and Very High) of concern.

Each area had 500 survey points for a total of 1000 survey points; five cover classes were assessed using i-Tree Canopy: 1) Grass/Herbaceous, 2) Impervious, 3) Soil/Bare Ground, 4) Tree/Shrub, and 5) Water for both ‘Ideal Conditions’ and ‘Hydrologic Concern’ (Table 4). Overall, the ‘Ideal Conditions’ survey points covered approximately 216 hectares, while the ‘Hydrologic Concern’ survey points covered approximately 123 hectares (Table 5). The cover class ‘Grass/Herbaceous’ was changed from 50.4% to 28.6%; ‘Tree/Shrub’ replaced ‘Grass/Herbaceous’ survey points in ‘Hydrologic Concern’ until benefits matched the ‘Ideal Conditions’ area (Table 6). For this study, tree benefit estimates of carbon and hydrological value were assessed (Table 7 and 8). The ‘Ideal Conditions’ area had monetary values of $25,111 in carbon sequestered in trees annually and $630,626 in carbon stored in trees (per hectare) (Table 9). The initial area for ‘Hydrologic Concern’ was approximately $9,000 lower in carbon sequestered in trees annually, and $218,000 lower in carbon stored in trees (Table 9). After 30% of Grass/Herbaceous cover class were changed to Tree/Shrub in ‘Hydrologic Concern’, tree benefit estimates were equal to or greater than ‘Ideal Conditions’.

Table 4. Number of survey points per cover class type based on hydrology status. Survey points were changed in 10% intervals.

Cover Class	Hydrologic Concerns	10% Change	20% Change	30% Change	Ideal Conditions
Grass/Herbaceous	205	184	164	143	202
Impervious	150	150	150	150	188
Soil/Bare Ground	29	29	29	29	9
Tree/Shrub	116	137	157	178	101
Water	0	0	0	0	0

Total	500	500	500	500	500

Table 5. Area (hectares) of survey points per cover class based on hydrology status. Survey points were changed in 10% intervals with Grass/Herbaceous changed to Tree/Shrub in 'Hydrologic Concern'.

Cover Class	Hydrologic Concern Area (h)	10% Change Area (h)	20% Change Area (h)	30% Change Area (h)	Ideal Conditions Area (h)
Grass/Herbaceous	50.4	45.2	40.3	35.1	87.2
Impervious	36.9	36.9	36.9	36.9	81.2
Soil/Bare Ground	7.1	7.1	7.1	7.1	3.9
Tree/Shrub	28.5	33.7	38.6	43.8	43.6
Water	0	0	0	0	0
Total	122.9	122.9	122.9	122.9	216.0

Table 6. Percentage of survey points per cover class based on hydrology status. Survey points were changed in 10% intervals in 'Hydrologic Concern' Grass/Herbaceous cover to Tree/Shrub cover until equal to or greater than 'Ideal Conditions' area.

Cover Class	Hydrologic Concern % Cover	10% Change % Cover	20% Change % Cover	30% Change % Cover	Ideal Conditions % Cover
Grass/Herbaceous	41.0	36.8	32.8	28.6	40.4
Impervious	30.0	30.0	30.0	30.0	37.6
Soil/Bare Ground	5.8	5.8	5.8	5.8	1.8
Tree/Shrub	23.2	27.4	31.4	35.6	20.2
Water	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0

Table 7. Value (T) of carbon tree benefit estimates in Priority Area 1. Ten percent change intervals in 'Hydrologic Concern' Grass/Herbaceous cover to Tree/Shrub cover until equal to or greater than 'Ideal Conditions' area.

Carbon	'Hydrologic Concern'	'Hydrologic Concern' with 10% change	'Hydrologic Concern' with 20% change	'Hydrologic Concern' with 30% change	'Ideal Conditions'
Sequestered annually in trees	96.17	113.58	130.16	147.57	147.23 T
Stored in trees (per h)	2,415.15	2,852.37	3,268.78	3,706.00	3,679.59

Table 8. Hydrological tree benefit estimates. Ten percent change intervals in 'Hydrologic Concern' Grass/Herbaceous cover to Tree/Shrub cover until equal to or greater than 'Ideal Conditions' area.

Abbreviation	Description	Hydrologic Concern Amount (gal)	10% Change - Amount (gal)	20% Change - Amount (gal)	30% Change - Amount (gal)	Ideal Conditions Amount (gal)
AVRO	Avoided Runoff	36.4	43.0	49.3	55.9	55.8
E	Evaporation	3,007.83	3,552.35	4,070.94	4,615.46	4,604.97
I	Interception	3,024.66	3,572.23	4,093.72	4,641.29	4,630.74
T	Transpiration	4,070.05	4,806.87	5,508.60	6,245.42	6,231.24
PE	Potential Evaporation	22,791.61	26,917.68	30,847.27	34,973.34	34,893.90
PET	Potential Evapotranspiration	18,596.05	21,962.57	25,168.79	28,535.32	28,470.51
Total	-	51,526.63	60,854.73	69,738.63	79,066.73	78,887.14

Table 9. Value (USD) of carbon tree benefit estimates in Priority Area 1. Ten percent change intervals in 'Hydrologic Concern' Grass/Herbaceous cover to Tree/Shrub cover until equal to or greater than 'Ideal Conditions' area.

Carbon	'Hydrologic Concern'	'Hydrologic Concern' with 10% change	'Hydrologic Concern' with 20% change	'Hydrologic Concern' with 30% change	'Ideal Conditions'
Sequestered annually in trees	$16,402	$19,371	$22,199	$25,168	$25,111
Stored in trees (per h)	$411,905	$486,474	$557,493	$632,062	$630,626

3.4 Discussion

Natural resource managers can use i-Tree Canopy as an initial look into possible hydrology issues in their management zone. Increased water volume and wastewater pollutants can be particularly damaging in areas where soil hydrologic groups have poor filtration and high runoff rates. HR was identified as a target to mitigate these stormwater issues as it has multiple areas of hydrological problems. Excess water in urban areas can contain more pollutants than rural areas due to increases in gas, oil, and waste (Li et al. 2018). Poor filtration and high runoff can waterlog and affect urban vegetation. As seen through results from i-Tree Canopy, both

‘Ideal Conditions’ and ‘Hydrologic Concern’ areas have a large amount of land cover in the form of grass or herbaceous plants. Planting trees or vegetation in 30% of the areas with land cover class Grass/Herbaceous can help mitigate hydrology issues. Adding vegetation and trees to ‘Hydrology Concern’ would provide the same tree benefit estimates as the ‘Ideal Conditions’ area. Bioswales or rain gardens can be placed in the ‘Hydrologic Concern’ area to combat stormwater problems while adding native vegetation back to the landscape. Ideally, green infrastructure could also be implemented in these areas along roads and parking lots as the impervious surfaces impact water direction and flow throughout the Priority Area.

In addition to stormwater and filtration control, green infrastructure can also reduce toxicity and contamination by water filtration through vegetation and trees planted within them (Anderson et al. 2016). Tree species such as those in the *Fraxinus*, *Ulmus*, and *Quercus* genera with high stomatal conductance, large form when mature, and high-water tolerance were found to be best for placement within green infrastructure (Scharenbroch et al. 2016). Species with high stress tolerance particularly towards water and pollution would work best in the ‘Hydrologic Concern’ area (Caplan et al. 2019). From the urban forestry inventory conducted at RSA, abundant tree species were found to be crape myrtle (*Lagerstroemia indica*), willow oak (*Quercus phellos*), red maple (*Acer rubrum)*, Virginia pine (*Pinus taeda),* eastern redbud (*Cercis canadensis,* loblolly pine (*Pinus virginiana),* and Bradford pear (*Pyrus calleryana).* Native species are recommended for use in green infrastructure as adding invasive species could add more issues to these urban areas. Enhancement of the ‘Hydrologic Concern’ area may also be as simple as removing invasive species such as Bradford pear (*Pyrus calleryana)* while putting native trees back on the landscape.

3.5 Conclusion

Understanding the hydrology of an urban area can help natural resource managers create stormwater management plans and incorporate green infrastructure to mitigate the issue. Through the soil hydrologic group and runoff data, and the i-Tree Canopy Program, areas in Priority Area 1 of hydrologic concern were identified. Planting trees/vegetation in 30% of the areas with land cover class Grass/Herbaceous can help mitigate hydrology issues in the 'Hydrologic Concern' area. These grass spaces can be transformed using green infrastructure along with trees to value approximately $632,000 at RSA.

Chapter 4: Conclusion

The urban forest inventory at RSA provided insight into the measurements, condition, risk, and species of urban trees in the Housing and Recreation (Priority Area 1 - HR), Administration (Priority Area 2 - ADM), and Golf Course (Priority Area 3 - GC) areas. Urban trees in each Priority Area exhibited strengths and weaknesses when it came to condition and risk. The use of i-Tree programs can help quantify the benefits of trees currently on Post, and ones that may be added in the future. The area of this study was limited to areas under US Army jurisdiction; to fully understand the impacts of urban trees at RSA more areas would need to be surveyed. Further research can be done to determine what new plantings can be added to these areas to improve urban natural resources on Post.

One prevalent issue across all Priority Areas were high-risk trees as well as the prevalence of Bradford pear (*Pyrus calleryana)*. It is recommended that high-risk trees should be properly removed within the next year. These removals will prevent damage to infrastructure and possible danger to people. Removing Bradford pear will necessary to prevent this invasive species from overtaking the area from native species. Further research can be done at RSA to understand how wildlife is moving invasive species, such as Bradford pear, across on Post. Bradford Pear is also an ornamental and often planted for aesthetic purposes. Resident education programs can be used in the future at RSA to help residents on Post understand the effects of invasive trees. Incentivization programs can also be used to encourage residents to plant native tree species.

Urban trees can play a role in mitigating other environmental issues at RSA. Hydrological impacts at RSA can influence the future of trees in residential and recreational areas on Post. Excess stormwater at RSA can bring increased water volume, runoff, and pollutants to urban areas. Through the soil hydrologic group and runoff data, and the i-Tree Canopy Program, areas in Priority Area 1 of hydrologic concern were identified. The ‘Hydrologic Concern’ area consisted of hydrology containing poor soil infiltration groups and areas defined as having high runoff classes. The ‘Ideal Condition’ area survey points covered approximately 216 hectares. While ‘Ideal Conditions’ was larger than the ‘Hydrologic Concern’ area which covered approximately 123 hectares, adding trees to this area can match benefits of the ‘Ideal Conditions’ area. Planting trees/vegetation in 30% of the areas with land cover class Grass/Herbaceous can help mitigate hydrology issues in the ‘Hydrologic Concern’ area. Areas changing from Grass/Herbaceous to Tree/Shrub can also change tree benefit estimates of hydrology in areas of concern saving approximately 79,000 gallons of water and avoided runoff. Monetary benefits of the change from Grass/Herbaceous cover to Tree/Shrub went from approximately $411,000 in carbon storage to $632,000 in Priority Area 1. These green spaces can be transformed using green infrastructure along with trees. Further research of this area would be to evaluate other areas on Post that may have hydrology issues. The i-Tree Canopy program is a free tool that many other military posts and installations could use to estimate tree benefits in term of carbon and hydrology.

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Appendix A

Tree Species in Urban Forest Inventory at RSA

This table contains info on the common and scientific name of all species inventoried at Redstone Arsenal for the urban forest inventory. Location of these species is listed under Priority Area. The following numbers are in relation to their Priority Areas: 1) Housing and Recreation (HR), 2) Administration (ADM), and 3) Golf Course (GC).

Common Name	Scientific Name	Priority Area
American Elm	*Ulmus americana*	2,3
American Holly	*Ilex opaca*	1,3
Bald Cypress	*Taxodium distichum*	1,3
Black Cherry	*Prunus serotina*	1,3
Black Gum	*Nyssa sylvatica*	1,3
Black Oak	*Quercus velutina*	3
Black Walnut	*Juglans nigra*	3
Bradford Pear	*Pyrus calleryana*	1,3
Carolina Cherry Laurel	*Prunus caroliniana*	3
Chinese Crab Apple	*Malus spectabilis*	3
Chinquapin Oak	*Quercus muehlenbergii*	3
Common Hackberry	*Celtis occidentalis*	1,3
Common Serviceberry	*Amelanchier arborea*	1
Crape Myrtle	*Lagerstroemia indica*	1,2,3
Cucumber Tree	*Magnolia acuminata*	1
Deodar Cedar	*Cedrus deodara*	3
Eastern Cottonwood	*Populus deltoides*	3
Eastern Redbud	*Cercis canadensis*	2
Eastern Red Cedar	*Juniperus virginiana*	1,3
Flowering Dogwood	*Cornus florida*	3
Gingko/Maidenhair Tree	*Ginkgo biloba*	1
Golden Raintree	*Koelreuteria paniculata*	3
Honey Locust	*Gleditsia triacanthos*	1
Japanese Maple	*Acer palmatum*	1,2
Kousa Dogwood	*Cornus kousa*	1
Loblolly Pine	*Pinus taeda*	1,2,3
Mockernut Hickory	*Carya tomentosa*	3
Northern Red Oak	*Quercus rubra*	1,2
Norway Maple	*Acer platanoides*	1

Ohio Buckeye	*Aesculus glabra*	3
Overcup Oak	*Quercus lyrate*	1,2
Paradise Apple	*Malus pumila*	3
Pecan	*Carya illinoinensis*	3
Persimmon	*Diospyros virginiana*	3
Pignut Hickory	*Carya glabra*	1
Pin Oak	*Quercus palustris*	1,2,3
Post Oak	*Quercus stellata*	2,3
Red Maple	*Acer rubrum*	1,2
River Birch	*Salix nigra*	1,2
Sassafras	*Sassafras albidum*	1
Sawtooth Hickory	*Quercus acutissima*	3
Scarlet Oak	*Quercus coccinea*	1
Shumard Oak	*Quercus shumardii*	1,2
Silver Maple	*Acer saccharinum*	1
Southern Live Oak	*Quercus virginiana*	3
Southern Magnolia	*Magnolia grandiflora*	1,3
Southern Red Oak	*Quercus falcata*	1,3
Sugar Maple	*Acer saccharum*	1,3
Sweetgum	*Liquidambar styraciflua*	1,3
Sycamore	*Platanus occidentalis*	3
Tulip Tree	*Liriodendron tulipifera*	1,2,3
Virginia Pine	*Pinus virginiana*	1,2
Water Oak	*Quercus nigra*	1,3
Western Hemlock	*Tsuga heterophylla*	3
White Ash	*Fraxinus americana*	2
White Oak	*Quercus alba*	3
Willow Oak	*Quercus phellos*	1,2,3
Winged Elm	*Ulmus alata*	3