Chapter One. Introduction

1.1 Overview

The absence of water mains and pressurized hydrant systems in rural areas has the potential to impose costly difficulties on the suppression of rural wildfires and structure fires.   However, the installation of "dry" fire hydrants (hereafter "dry hydrant") in rural areas can significantly reduce these difficulties. The USDA Forest Service (1993) defines a dry hydrant as "a non-pressurized pipe permanently installed in existing lakes, ponds, or streams that provides a means of suction supply of water to a tank truck" (pg 1-1). In Document 1142, Standard on Water Supplies for Suburban and Rural Fire Fighting, the National Fire Protection Association defines a dry hydrant as "an arrangement of pipe permanently connected to a water source other than a piped, pressurized water supply system that provides a ready means of water supply for fire-fighting purposes and that utilizes the drafting (suction) capability of fire department pumpers" (NFPA 1999, pg 1142-24). Although dry hydrants were traditionally constructed of metallic materials such as copper and iron, PVC is commonly used today. The intake fixture must be greater than 2 feet below the surface of the water to prevent a vortex from forming and the introduction of air into the system. However, the top of the hydrant at the hose connector cannot be greater than 20 feet higher than the surface of the water source; a hydraulic head exceeding 20 feet would prevent water from being lifted to the fire tanker truck at a sufficient rate. Ideally, the hydraulic head should be less than 10 feet.   Detailed specifications for designing, installing and maintaining dry hydrants can be found in USFS (1993) and NFPA (1999).   Although these hydrants are typically installed along existing water sources such as ponds (Figure 1.1), lakes, streams, or bays, new water sources, such as above below ground tanks, can be constructed to store the water supply where no other water sources are present.

Figure 1.1. A dry hydrant installed on a pond. Obtained from www.vdof.org.

To obtain water for rural fire suppression efforts, fire department tanker trucks are driven to a dry hydrant site to fill their internal water tanks. Once these tanks are filled, the water is transported to the scene of a fire. If these tanks are exhausted and additional water is required, the tanker truck crew returns to the hydrant location to refill the trucks' tanks. Hence, the distance or travel time to a hydrant can directly impact the degree to which rural fire suppression efforts are successful. The USFS (1993) notes that for a dry hydrant system, which includes the personnel and trucks as well as the hydrant to be successful, the dry hydrants must be strategically located. Although improving fire protection performance is the primary benefit of well- placed dry hydrants, their presence can reduce home-owners insurance premiums, conserve treated drinking water supplies and reduce fire suppression agencies' fuel expenditures.

Virginia Department of Forestry (VDOF) staff operating on a localized county level recently visited and inspected all of the known dry hydrants in their jurisdictions. The GPS point location data that they gathered show that there are an alarming number of regions of the state that lack hydrants. Because VDOF participates in most wildfire suppression activities occurring throughout the state and because this agency administers the dry hydrant grant program to which local fire departments can apply for funding to install new hydrants, they have a vested interest in ensuring that dry hydrants are well dispersed throughout the state in an efficient manner. One of the objectives of this thesis is to develop a geographic information system (GIS) decision support strategy that will assist VDOF in determining where to install future dry hydrants in the areas that currently lack hydrants. This objective, as well as others, is discussed in more detail in subsequent portions of this chapter.

1.2 Wildfires and the Wildland-Urban Interface

Wade et al (2000) provide an extensive, but succinct summary of fire history in the Southeast United States. The Pre-Euro-American southeast generally experienced a fire return interval of roughly thirteen years with growing season fires that could burn for weeks or months in the absence of precipitation. However, high nighttime humidity occurring in the mid-summer would typically prevent wildfires occurring in light fuels from surviving on a long-term basis (Wade et al 2000). But higher intensity fires subsisting on heavier fuels could overcome the mid-summer humidity and continue to burn until precipitation occurred or all of the fuel was consumed. In pre-Civil-War time, it was estimated that over 75 percent of the population were herdsman who brought fire-using practices from Western Europe. A law in North Carolina dating to 1731 reportedly required the annual burning of pastures and rangelands. (Wade et al 2000). Managed use of fire in the 20th century experienced a roller coaster of perspectives. Early in the century, the hazardous accumulation of fuels resulting from fire suppression was recognized and forest managers applied prescribed burning and generally allowed naturally or unintentionally ignited fires to burn. But by the 1920s, federal funding agencies encouraged states to suppress wildfires. As fuels accumulated as a result of this mindset, controlling wildfires that inevitably ignited became increasingly difficult.

Ball (1997) reports that less than 5 percent of the US Population lived in urban areas in 1790. But the 1940s, the proportion of those living in urban areas and those living in rural areas reached a 50/50 equilibrium. Roughly a decade later, urban areas begin spreading outward to form lower-density suburban developments. Although a discrete or indiscrete boundary between these more consolidated urban areas and the surrounding wildlands must have existed, it is during this time of suburbanization that the term wildland-urban interface (WUI) was conceived. The USDA Forest Service (2000) defines the wild land urban interface as “those areas where flammable fuels are adjacent to homes and communities.” By 1987, more than 75 % of Americana were living in urban/suburban areas and this continued, spatial expansion of large cities increased the amount of wildland urban interface (Ball 1997). These growth patterns, coupled with the improved transportation and growing popularity of living in a more rural settings, resulted in a greater number of WUI areas that were also more spatially expansive.

The presence of humans at the WUI not only places more private property at risk of being damaged or destroyed by a wildfire, but also increases the probability of ignition. If easily ignitable or "flashy" fuels are present, human activities such as leaf/brush burning or barbequing can ignite a surface fire. If ladder fuels and larger, dry fuels are present, the surface fire can escalate to an intense canopy fire. Therefore, a number of homes abutting a small, isolated patch of forest could quickly become jeopardized by a wildfire. The recent history of devastating destruction to homes spans the entire US and other developed countries. In 1983, 2,528 homes were destroyed and 77 people were killed in a wildfire that occurred in southern Australia (Lavin 1997). In 1985, wildfires throughout the US burned an area the size of Maine, Vermont and New Hampshire combined, resulting in fire suppression expenses of nearly $400 million and approximately $500 million of property and natural resources were damaged or destroyed (Bailey 1991). In 1987, 24 homes were destroyed in a subdivision near Spokane and 200 homes were lost in a wildfire occurring in Michigan (Lavin 1997). Some wildfires engulf homes so quickly that it can be difficult for emergency workers and even residents to respond. In California's Oakland Hills, a wildfire occurring in 1991 destroyed 2,500 homes in less than 12 hours (Lavin 1997). In 1993, a Laguna Hills, CA fire destroyed 366 homes in nearly 5 hours (Cohen and Saveland 1997). In 2003 several large wildfires in Southern California, including the infamous Simi Valley, Paradise and Cedar fires, burned over 750,000 acres and destroyed over 4,000 homes (West 2004). Large wildfires in the Western United States tend to receive more attention than smaller wildfires occurring in the Eastern US. However, on an annual average, more homes are destroyed by wildfires in the Eastern US (Zedaker 2005, pers. comm.)

In the mid 1980s, WUI problems had become a part of public awareness and were receiving increased attention by government agencies (Cohen and Saveland 1997). This growing recognition of the WUI wildfire problem shifted a substantial portion of governmental wildfire suppression efforts from protecting the nation's natural resources to protecting citizen-owned property (Davis 1990 and Cortner et al. 1990). The 1987

"Wildfire Strikes Home" conference made general WUI management recommendations such as developing aesthetically pleasing methods of managing WUI hazards, further researching materials that do not easily ignite from convectively carried embers, also known as "fire brands", and developing techniques to assess hazards and then detailed plans on how to mitigate them (Cohen and Saveland 1997). Over the years, there was increased recognition that all levels of governments needed to address the growing WUI interface problems. In 1997, Mary Jo Lavin (1997) stated that "managing fire risk in the WUI is a shared responsibility". In her opinion, "the most prominent component [in a hazard mitigation plan] is the landowner; they must take the primary responsibility in protecting their homes." But she recognizes that homeowners cannot begin such a task until they are educated by those trained in recognizing WUI hazards and the action needed to reduce them.

1.3 Recent GIS-Related Wildfire Programs at the Virginia Department of Forestry

Between 1995 and 2001, over 10,000 wildfires were documented in Virginia, burning 41,500 acres and causing $28.4 million in property damages (unpublished wildfire data from VDOF, US Forest Service, and the National Park Service (Shenandoah National Park only)). In 2001, funding from the National Fire Plan provided the resources to launch several, interrelated wildfire mitigation programs. Members of VDOF's newly formed Wildfire Mitigation Team began mapping Virginia's WUI communities, referred to as Woodland Home Communities (WHCs) by VDOF, using GIS viewers. These personnel examined USGS digital orthophoto quarter quadrangles (DOQQs), US Census Bureau TIGER road networks (USCB 2000), forest cover and, where available, building footprint data to locate probable WHCs. Each WHC was entered into a database, along with an estimation of its number of homes, the name of its primary road, and its spatial coordinates. In their project, VDOF defined a WHC as a cluster of 10 or more homes that are in close proximity to wildland fuels and would be jeopardized in the event of a nearby wildfire. Typically, these WHCs are subdivisions or neighborhoods, but a cohesive cluster of homes along a through highway or at a cross roads could qualify as a WHC as well. This survey resulted in the identification of 4,704 WHCs throughout entire state. Figure 1.2 shows examples of these inventoried WHCs in Frederick County, Virginia.

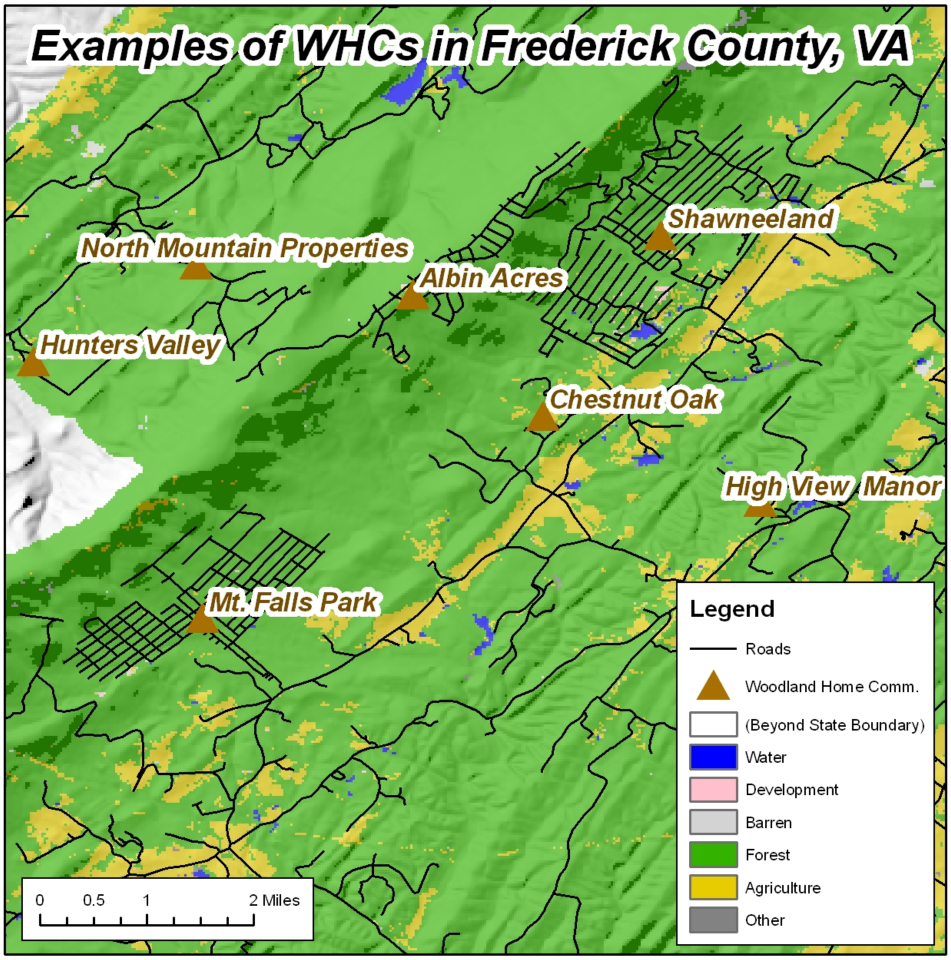

Figure 1.2. Examples of WHCs in Frederick County Virginia. Land cover adapted from National Landcover Dataset.

Currently, VDOF staff are traveling to these documented WHCs and gathering detailed data about their characteristics. These data include the general construction materials of the homes, fire truck accessibility, dominant vegetation, and fuel loads. These team members are also gathering GPS data to document the extent of each WHC. To date, however, detailed WHC assessments have taken place in only a handful of counties throughout the state.

The National Fire Plan grant also funded the Virginia Wildfire Risk Assessment GIS model. This weighted linear combination raster overlay model included many mappable factors including topography, wildfire history, land cover as a fuels surrogate, and demographics. The output of this model classified the entire Virginia landscape as high, moderate or low in wildfire risk. This GIS layer is used as one of the input layers in this thesis and the details of methodology used to produce it are discussed in Chapter Three of this thesis.

1.4 A Brief Description of Location-Allocation Models and Their Use in Planning the Location of Emergency Facilities

Location-allocation models (LAMs) are decision support tools that are designed to place optimally multiple supply or service facilities to serve geographically dispersed demand for these services. In the private sector, LAMs may be used to locate optimally warehouses in a spatial configuration that minimizes the aggregate distance between the warehouses (supply centers) and retail outlets (demand locations), thereby minimizing shipping costs. In the public sector, LAMs can be used to centrally place public facilities, such as libraries and recreation centers, in locations that are equally accessible to the general public. The “maximal covering” LAM is specifically designed to place a given number of emergency facilities in a configuration that will serve the maximum amount of demand within a specified travel time. For example, the maximal covering LAM may be used to place fire stations in locations that can reach the maximum number of buildings within an eight-minute travel time. Quantitative values can be assigned to demand locations based on the relative fire hazard found there; for example, higher weight can be assigned to manufacturing facilities that contain highly flammable materials and lower scores can be assigned to single-family dwellings.

1.5 Objectives

The four interdependent, but individual objectives of this thesis are to:

1) research the various LAMs to determine which is most appropriate in planning the location of dry hydrants,
2) investigate the effectiveness and reliability of the selected model to determine if it is capable of *optimally* serving hydrant demand,
3) investigate the flexibility of the selected model to determine if it is capable of responding to minor weighting adjustments made by fire managers to more effectively meet their individual needs and concerns,
4) develop an approach to guide fire managers in determining how many hydrants to allocate to multiple administrative regions, such as counties, in an objective and fair manner.

In meeting these objectives, the selected LAM will be applied to address the particular needs of VDOF's Resource Protection Team. These VDOF officials have stated that their primary concern is ensuring that hydrants are placed in locations where they can adequately serve the known and inventoried WHCs. However, they have also stated that high and moderate wildfire risk zones are also a concern. Hence, these two geographic factors will form the basis of the demand weighting schemes used in Chapter Three of this thesis. For example, if three candidate hydrant locations could effectively serve the same three WHCs but one of these candidate sites would simultaneously serve more high-risk areas, then it should be chosen as a more effective hydrant site.

1.6 Scope and Intent

This thesis is not an attempt to develop a universal methodology for determining where to place dry hydrants. Although the methods presented in this research are quite detailed, they reflect the general management needs of VDOF and as a result, the parameters used here were selected to meet their needs using the available data. Furthermore, this thesis does not aspire to recommend a final weighting scheme to be used by VDOF. Rather, its purpose is to determine if LAMs can meet the objectives that were stated above. If the LAMs are successful in meeting these objectives, then VDOF will have the freedom to weight these factors in a manner that reflects their management concerns and priorities.

Others who wish to apply these methods in another location are encouraged to consciously and actively consider whether these methods need to be modified to suit their particular case and if so, where the changes need to be made and how. For example, the weighting scheme used to distribute demand for hydrants across a given study area can be adjusted to suit individual needs. Additionally, the maximum allowable response time between a hydrant site and the locations to be protected can easily be modified.

One factor that should be considered when determining the level of necessary modification to the methods used in this thesis is scale or the geographic extent of a potential user's area of interest. One objective of this paper concerns determining how many hydrants to distribute across an entire state. If a reader of this thesis is wishing to distribute dry hydrants across one of four fire districts contained in a single county, then it is expected that the methods used here will require some significant modifications to more appropriately suit their particular management practices and needs.

1.7 Research Significance

As discussed in Chapter Two of this thesis, LAMs have been extensively used to plan the location of emergency facilities. However, the literature is apparently void of articles that address the use of LAMs in planning the location of dry hydrants. Additionally, this thesis explores methods of distributing resources in a manner that aims to ensure that discreet geographic units (e.g. counties or districts) receive a number of facilities that is proportional to each unit's need or demand for the resources. Hence, this thesis is a combination of applied and basic research.