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Integrating GIS into the management of vegetation along power line corridors

William E. Tedder
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Integrating GIS into the Management of Vegetation

Along Power Line Corridors

by

William E. Tedder, Jr.

B.S. Oklahoma State University, 1995

presented in partial fulfillment of the requirements

for the Degree of

Master of Science

The University of Montana

1998

Approved by:

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1-30-98

Date
The management of vegetation along power line corridors is a necessary function of utility companies in order to maintain a constant flow of power to the public. Depending upon the climate of the region, it is also important in the reduction of fire hazard. Utility companies are responsible for the management of vegetation by law in some states. The method by which vegetation is managed varies greatly between utility companies. This thesis demonstrates how GIS can be used as a tool in the management of vegetation along power line corridors, in particular, primary distribution lines.

The vegetation management programs of Montana Power Company and Pacific Gas & Electric are examined through personal interviews and work experience. A critical assessment of Montana Power’s program is given.

The process of data collection and integration of the data into the GIS are described. A vegetation and pole registration method is developed as well as coding schemes for relevant attributes. The more important analyses of the data are demonstrated with thematic map produced in ArcView. The types of thematic maps produced for vegetation are based on clearance codes, distance to the power line, and trim codes. In addition, thematic maps are produced showing the condition of utility poles and location of equipment. A time effort analysis for the collection of field data is produced. Also, guidelines for an effective vegetation management are recommended.
Acknowledgements

One day Dave Jackson asked me what I would get out of this when it was finished. The question was a surprise and at the time I did not have a definitive answer. That is how Dave is – asking a simple question that requires a thought provoking response. The answer came to me a few weeks later as I realized that my self-talk and habit pattern was to just do something and keep moving forward everyday. This is a real life exercise in positive self-discipline. The biggest challenge is to complete the task.

My sincere thanks and appreciation to my committee members Dr. David H. Jackson, Dr. Hans R. Zuuring, and Dr. Paul B. Wilson for their support and the freedom to develop this thesis topic. Special thanks to Dave Jackson for making attendance at the University of Montana possible. Also, thanks to the School of Forestry faculty and administration for their support and help throughout my journey.

My sincere thanks to all of the people at Montana Power Company that provided information and support material. Special thanks to Scott Bernhardt and Steve Yonce for the technical information, base maps, and most of all enthusiasm for the project.

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Dedication

This thesis is dedicated to the loving memory of my mother, Doris Belle Eck, whom would be proud of her son's achievements.
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Chapter One

INTRODUCTION

The management of vegetation to maintain adequate clearance between power lines and trees is a necessary and costly program for utility companies. Many companies use certified contractors that provide the necessary and hazardous services of trimming trees around power lines. Adequate clearance is vital to uninterrupted electrical service and reduced fire hazard. Some states enforce minimum clearances around power lines by law. The management of vegetation on a large scale is a complex and dynamic problem that varies by region due to vegetation types and climate as well as budget constraints. The use of a Geographic Information System (GIS) is ideally suited for the management of large volumes of data and associated spatial analyses necessary to maintain an efficient vegetation management program. This thesis is designed to demonstrate the application of GIS for maintaining vegetation clearance along primary distribution power line corridors and the maintenance of power line equipment.

Objectives

This study focuses on GIS applications for utility vegetation management and a discussion of its development. The application of GIS for vegetation management along primary distribution circuits is virtually untried. One reason may be due to lack of management support for new technology with unknown economic benefits. The application is based on data collected from demonstration areas representative of numerous power line corridors located throughout western Montana. It is used to determine vegetation status, trimming areas, manpower requirements, rotation cycles, equipment location and problems, and areas of special concern.
Study Areas

Two primary distribution power line corridors located in the Missoula, Montana municipal area were selected as study grids (Figure 1). They were selected based on circuit grids used by Montana Power Company (Yonce pers. comm.). The city grid is part of Montana Power grid number 876C404 (Yonce pers. comm.) and consists of 32 spans of power line covering about an eleven block area near the University of Montana campus.

Figure 1. Partial Municipal map of Missoula, Montana.
A span is the distance between two utility poles. The power line spans of varying lengths total approximately 4,195 feet or 0.8 miles. There are approximately 344 miles of power line in the Missoula area (Palmquist pers. comm.). The voltage of the power lines located in the city study area is 12,000 volts or 12 kV (Westman pers. comm.). This is a common voltage in residential areas.

The rural study grid extends seven spans east of the junction of Lupine Road and Pattee Canyon Drive and corresponds to Montana Power grid number 882C392 (Yonce pers. comm.). Voltage for the rural study area is 7.2 kV (Westman pers. Comm.). The power line spans of varying lengths total approximately 1,713 feet or 0.3 miles. Both study grids represent less than one third of one per cent of the power line corridors in the Missoula Municipal area.
Chapter Two

LITERATURE REVIEW

The Board of Directors of the Edison Electric Light Company, including Thomas Edison, gathered in the offices of J. Pierpont Morgan at 23 Wall Street in New York City on the afternoon of September 4, 1882 (Wyatt 1986). Promptly at 3:00 p.m., Edison flicked a switch; lights started to glow and steadily brighten as the dynamo at the Pearl Street Generating Station fed electric power into the World’s first electric distribution system (Wyatt 1986). The age of electricity had begun and since that time it has transformed the entire way of life in the industrialized world.

The demand for electricity was immediate. In 1910 a ceremony in the city of Berlin (now Kitchener, Ontario) brought about the “Illumination of the Streets and Buildings by Electricity” - electricity produced and purchased in Niagara Falls, ninety miles away, and transmitted on a 110 kV line (Gardner 1980). This was the first of many transmission lines and rights-of-way that would form a grid across North America. Today, the U.S.A. has the largest and most diverse electric utility system in the World with assets (at cost) of around US$400 billion -- worth considerably more at replacement value (Wyatt 1986).

Uninterrupted electrical service is important to all customers. Even a momentary interruption in the residential supply requires resetting of microwave ovens, videocassette recorders, clock radios, personal computers, and other devices with digital clocks connected to the main power supply (Wyatt 1986). From the inception of electric power systems, expansion and better service became pressing needs. However, with expansion came problems. Interruptions caused by vegetation were frequent: a
frequency that neither the customers would tolerate nor the utilities reduce without concerted effort (Gardner 1980). The foundation for utility vegetation management was in place.

**Distribution Systems**

The two basic types of electrical circuits are transmission and distribution. A circuit is the completed path for electric current from source to point of use and back (Moore 1989). The transmission and distribution systems carry electric power from the generating stations to the customer (Wyatt 1986). The transmission voltages in common use range from 44-500 kilovolts (kV) and are transmitted over tower lines to centrally located transmission substations (Moore 1989). The network of substations connects the transmission and distribution lines together and is where the first voltage reductions occur (Wyatt 1986). There is an extensive amount of literature concerning transmission line construction, maintenance, and management. However, the focus of this study concerns primary distribution circuits, although the concepts could be applied to transmission circuits as well.

The primary distribution circuits supply the transformers that reduce the voltage again so the customer (Moore 1989) can utilize the electricity. Distribution systems, which by their very nature are much closer to the myriad of end-users than the actual generation and bulk transmission facilities, consist of a large number of small substations, transformers, and overhead or underground lines (Wyatt 1986). Most primary distribution voltages range between 2.4-44 kV (Moore 1989). In older residential and urban areas the overhead wires and pole transformers are exposed both to the elements and impact by motor vehicles, cranes, and falling tree branches (Wyatt 1986).
Overhead distribution of electricity has a basic incompatibility with urban shade or ornamental trees and undesirable vegetation in rural areas (Gardner 1980). However, even where power lines are buried, they run the risk of accidental severance during excavation work (with accompanying hazards to the severer) and flood damage. Other disadvantages to underground power lines are: i) crossing streams, roads, and other buried services is more time consuming and costly; ii) locating lines in winter under snow; iii) splicing lines and tapping in branch lines is more difficult and takes longer; iv) when a line goes out, it goes out for longer times - this is offset by the lower frequency of outages; and v) washouts and landslides causing line breaks (Wyatt 1986). Underground lines are much more expensive to install than overhead lines and troubleshooting is much more difficult (Moore 1989).

Protection against vegetation-caused outages is a prime responsibility of the vegetation manager (Gardner 1980). The utilities have an operational and management responsibility for inspecting their lines (Moore 1989). Although vegetation management programs vary among utilities, the priority is the same. The utility company must maintain adequate clearance between the power line and vegetation.

**Utility Vegetation Management**

Vegetation management on rights-of-way once considered by some to be an “art” nevertheless has evolved to the stage where clear logic and detailed management are essential to meet the complexities and scale of most utilities (Gardner 1980). The electric utilities, both publicly and privately owned, are concerned with minimizing their legal liabilities and interruptions of service to their customers (Moore 1989). Moreover, the external pressure of public concern demands a comprehensive management style (Gardner 1980).
Accurate field inventories of right-of-way conditions and good records are fundamental requirements in any program before it is possible to plan and effectively manage or protect aesthetic, social and environmental values (Gardner 1980). Control of vegetation, whether by mechanical or chemical means, requires specialized knowledge, skills, and equipment thereby making it impractical for smaller utilities to do clearance maintenance work with their own employees (Moore 1989). In order to sustain a viable vegetation management program, it is necessary to establish an ongoing research and development capability (Gardner 1980). The vegetation management programs of two public utilities are examined to demonstrate common practices used throughout the industry.

Pacific Gas & Electric Company

Pacific Gas & Electric (PG&E) has the largest number of customers of any electric utility in the U.S.A. -- nearly 3.8 million, spread over its nearly 250,000 km² service area - that covers most of the northern two thirds of California (Wyatt 1986). Thousands of miles of primary distribution line are required to provide electric power to businesses and residences. This huge network of power lines demands a comprehensive vegetation management program. PG&E recently completed a vegetation inventory of 3 million trees under its management (Sweitzer pers. Comm.).

The two basic sources of labor and expertise for clearance work are contract and utilization of employees of the utilities (Moore 1989). PG&E manages vegetation through the use of several outside contractors for pre-inspection, post-auditing, and tree trimming of power line corridors. Area Utility Arborists (AUAs) are PG&E employees serving as vegetation managers for specific regions and are responsible for the coordination of outside contractors in their area. Currently, 250 inspectors (contract
utility foresters) schedule and audit tree trimming for 706 tree-trimming crews (Sweitzer pers. comm.). The majority of the tree-trimming crews work for the Asplundh Tree Expert Company. Contract utility foresters not employed by the tree trimming company typically do the pre-inspection and auditing of tree-trimming projects. PG&E's goal is to audit 27% of all tree and pole clearance work billed as completed by the tree trimming company (Sweitzer pers. comm.). Planning, supervision, and inspection of the maintenance work by management employees of the utility is essential in order to detect missed or sloppy work, code violations, potential civil liability, etc (Moore 1989). Without pre-inspection it is harder, if not impossible, to manage power line corridors considering the legal regulations, environmental issues, and customer concerns that exist in California (Sweitzer pers. comm.).

Montana Power Company

Montana Power Company (MPC) manages approximately 14,000 miles of power line in the state (Palmquist pers. comm.). The service area is divided into districts with each district being responsible for its vegetation management of that district (Bernhardt pers. comm.). A MPC employee in each district is responsible for assigning cutting areas to a contracting tree trimming company. The tree trimming company is usually assigned an area that runs from one substation to another substation (Westman pers. comm.). In other words, the tree trimming company is assigned a particular circuit to trim. The Asplundh Tree Expert Company is currently contracted with MPC to provide tree-trimming services. Asplundh provides 13 tree-trimming crews that cover the state except for the districts of Helena, Great Falls, and Havre (Bernhardt pers. comm.).

There is only one full-time tree crew in Missoula that averages trimming 10-15 trees per day (Westman pers. comm.). There is no pre-inspection program by MPC and
no policy regarding the audit of completed tree-trimming projects. Asplundh is responsible for contacting all customers prior to trimming trees on their property (Westman pers. comm.). MPC sets the tree trimming standards to be followed by the tree trimming companies (Bernhardt pers. comm.). However, the standards are common throughout the industry and are already in use by the tree trimming company. The standard employs a method known as natural target pruning (Shigo 1990). Although customers dictate the amount of trimming in many cases, an attempt is made to achieve at least enough clearance for a three-year rotation (Westman pers. comm.). Asplundh is very professional in their approach with customers and maintains a good working relationship with MPC (Bernhardt and Westman pers. comm.).

Tree Trimming Methods

It would be better for trees, electric lines, and customers if trees were not planted near electric lines (Shigo 1990). Many times trees exist before the power line is installed. While mechanical removal is the primary method used to obtain conductor clearance, the trimming of branches and felling of trees, without endangering personnel, the power lines or other property, can be difficult (Moore 1989). All persons pruning trees near electric utility lines must be qualified by training that includes pruning techniques, and an understanding of safety and line clearing requirements given by OSHA and ANSI Z 133.1-1988 (Shigo 1990).

The directional pruning method is the accepted industry pruning standard (www.asplundh.com/Links). Directional pruning requires the removal of branches at the nodes, where branches meet other branches or the trunk (Shigo 1990). Only those branches that conflict with the power lines are removed in a way that directs future tree growth away from the power line (www.asplundh.com/Links). Directional pruning
employs a method known as natural target pruning that requires a branch to be cut as close as possible to the branch collar without injury or removal of the collar (Shigo 1990) (Moore 1989). Directional pruning is endorsed by the National Arbor Day Foundation and promoted by the International Society of Arboriculture and the National Arborist Association as the preferred way to prune trees near power lines for their health, safety, and longevity (www.asplundh.com/Links).

**Legal Considerations**

Laws dictating guidelines for clearance distances to be maintained by utility companies do not exist in most states. Also, there are no such guidelines outlined in the Code of Federal Regulations (CFR). However, in California the laws are extensive and enforceable. The basic requirements for clearance distances around conductors (electrically charged wires) are set forth in Section 4293 of the Public Resources Code (Moore 1989). Additional laws and regulations are outlined in the Public Resources Code and Title 14 in the California Code of Regulations.

Section 4293 requires clearance of all vegetation for a specific radial distance from conductors based on the voltage carried by the conductors: four feet for voltages between 2,400 and 72,000 volts; six feet between 72,000 and 110,000 volts; and 10 feet over 110,000 volts (Moore 1989). These California standards could be applied to other regions of the country. Although not required by law, a good safe practice, as reflected in many easements and use permits as well as the internal policies of several utilities, calls for, a two foot radial clearance of all vegetation around any unprotected (without insulation) conductors energized at less than 2,400 volts (Moore 1989). As previously stated, the utility is responsible for maintaining adequate clearances. The California Department of Forestry and Fire Protection (CDF), United States Forest Service (USFS),
Bureau of Land Management (BLM), and other wildland protection agencies may initiate criminal actions to secure compliance with laws and ordinances as well as process civil actions for collection of fire suppression costs and damage to their resources (Moore 1989).

There are not specific legal guidelines for maintaining a certain minimum clearance of vegetation from power lines in Montana. The utilities may have internal guidelines that vary between companies, but research revealed no specific state laws. Presumably, damages could be collected for loss of property and fire suppression costs through civil courts if responsibility or negligence could be proven. This is not to imply utility companies are not regulated in Montana or elsewhere. However, the primary purpose of regulatory bodies today is to balance the rates charged to the consumers with a fair rate of return to the investor who puts up the money to pay for the required facilities (Wyatt 1986).

**GIS Applications**

The capability of GIS to analyze spatial and attribute data together primarily distinguishes it from automated mapping and computer-aided drafting systems (Arnoff 1995). The utility of GIS is as an organizing framework for more specialized modeling (Nyerges, Robkin, and Moore 1997). The range of markets utilizing GIS is expanding. Virtually all government forest management agencies in North America have acquired or are considering acquiring a GIS (Arnoff 1995). As the range of the market expands, so does the diversity of information contained in the databases. For example, the GIS for the Flathead National Forest in Montana includes digital terrain data, vegetation associations derived from Landsat satellite data, timber compartments, timber harvest history, land types, land ownership, administrative districts, precipitation, and the
drainage network (Arnoff 1995). Timber data is typically shown in polygon form with vegetation being grouped by species or other similar attributes. The polygon covers a specific geographic area.

Though computer use is common, the adoption of GISes by municipalities has been slow in part due to the high start-up costs of creating the GIS database (Arnoff 1995). This trend may change as the technology becomes more widely used. Many municipalities made substantial investments in GIS during the 1980s to support such functions as property management, property appraisal, permit and license issuing, subdivision planning, transportation analysis and planning, emergency vehicle routing and dispatching, engineering design, land use planning, and inventory of such facilities as water/sewer systems and electrical cabling (Arnoff 1995). The use of GIS in utility management is not new. However, the use of GIS is becoming much more extensive than for inventory or mapping purposes.

PG&E has had GIS capability for approximately ten years and use the technology for maintenance and installation of towers, poles and other power line equipment (Ciezlowski pers. comm.). Several other utilities have been using GIS for a number of years. In 1985, after Hurricane Kate wiped out major portions of Tallahassee, the City of Tallahassee Electric (COTE) utility recognized the need to overhaul an antiquated paper record-keeping system and develop a relational database (Cooper 1997). After investigating GIS technology for several years, COTE is now collecting field data about its electrical network that serves 90,000 customers over an area of 270 square miles (Cooper 1997). The data collection process uses high tech equipment designed for the task. The Mobile Data Collection System maps the location of poles, lines, and other electrical equipment using differential geographic positioning system (GPS) and laser
rangeproiever health (Cooper 1997). The new GIS has caught the interest of COTE management and increased the number of applications to be developed with the system. A few examples of applications under development are to improve the handling of network planning and design, load flow analysis, trouble calls, tree trimming, and the joint use of poles with other utilities (Cooper 1997).

In 1988, the city government of Wilson, North Carolina formed an executive committee to study methods for alleviating and managing its ever-increasing workload and the feasibility of adopting GIS (Hinton 1997). After two years of study, orders for hardware and software were placed for a GIS that would be utilized by several departments of the city. Since the electric division of the utilities department maintains 1,000 miles of primary distribution lines, creating an accurate base map for the city and all of the electrical service areas was a priority (Hinton 1997). In the process, map maintenance became less labor intensive and more accurate. As sophistication of the city’s system grew, so did its popularity and now all city departments use GIS for special projects (Hinton 1997).

The electric division uses GIS for several functions and projects. Examples of GIS projects at Wilson’s electric utilities include analyzing environmental impacts, studying streetlight saturation, scanning substation information, schematics, pole configurations, other diagrams, and performing electricity needs projections (Hinton 1997). The system is used heavily and new projects are limited only by the employee’s imagination. Although there is no mention of GIS being used for vegetation management, it is likely that records exist which could be used to build a spatial database. Since GIS has been around for several years, the technology is becoming more advanced as software improves to specifically address the utility industry.
Deregulation activity is making the utility market an open, volatile sea where companies now must wage business war to compete for consumer dollars (ESRI 1996). Pennsylvania Power & Light (PP&L) is using GIS technology to gain a competitive edge. PP&L serves 1.2 million customers throughout central eastern Pennsylvania (ESRI 1996). The company is going high tech and hopes to have its new system running for all regions by the end of 1997. The automated mapping/facilities management/geographic information system (AM/FM/GIS) is the latest in GIS technology that will jump-start customer service and facility management and keep PP&L at the forefront in utility operations (ESRI 1996). GIS technology is an important component as utilities strive to improve customer service and keep a competitive edge.

The growth of software revenue is another indicator that the utilities market is increasing its use of GIS technology. For the utility GIS market as a whole, the total revenues generated in GIS software sales grew from $38 million in 1992 to more than $55 million in 1996 (ESRI 1997). This is for software designed specifically for the utilities market. Although specific applications of GIS for vegetation management by utilities are not readily available, the technology to support it is. The growth of technology and sales of the software designed with utilities in mind leads to the conclusion that the systems are being used for more than just inventory and maintenance of power line equipment.

Summary

The use of electric power is a vital component to society, as we know it. The demand for electricity will only increase as the world population continues to grow and industrialization spreads to developing countries. The technology for managing electricity is developing as well.
Electric power is distributed primarily through overhead wires or cables. The voltage varies based on how the electricity is to be distributed. High voltage that has just been generated is transmitted to substations to be stepped down (reduced in voltage) prior to being transmitted through distribution lines for consumer use. Transformers reduce the voltage again just before use in homes and businesses.

Vegetation-caused outages have been a problem since the inception of electric power distribution. It is the responsibility of the utility company to keep the power lines free of contact with vegetation. Some states legally enforce minimum clearance distances, based on voltage. Vegetation contacting the power line can cause power disruptions as well as potentially devastating fires. Tree trimming around power lines is very dangerous and requires specialized training and equipment. Many utilities contract tree-trimming services with companies specializing in power line clearance work.

The tree trimming standard for the utility industry is natural target pruning. Limbs are cut at the nodes in a manner that encourages future vegetation to grow away from the power lines. This method is most effective for deciduous trees rather than conifers. Utilities typically attempt to achieve a minimum trim cycle of three years.

The use of GIS in utility management is increasing. Specialized software (AM/FM/GIS) designed for use by utility management is at the cutting edge. Utilities have used GIS for the maintenance and construction of power lines for several years. As deregulation of the utility industry takes effect, GIS is the tool utilities are looking toward to increase efficiency of operations and maintain a competitive edge. This fact is reflected in the growth of sales revenues for utility software by the industry. However, the application of GIS to vegetation management is not well documented. Although the technology may be in use by some utility companies for vegetation management or at
least in the research and development phase, extensive research at the University of Montana's library and the Internet provided no published documentation of the specific application. This thesis addresses that informational gap.
Chapter Three

METHODS

The first phase of this study actually began with meetings and interviews held with PG&E and MPC in an effort to obtain funding for the project. Proposals were presented to PG&E during January 1997 and to MPC during April 1997. Although funding was not obtained from either company, information obtained during the process was useful in comparing their vegetation management programs as well as defining goals and identifying steps to accomplish this study. The first tangible steps included the selection of a study area, inventory methods, and the selection of a GIS software package. The general scope of research and methods used in the study as well as the development of a GIS model is to:

- Evaluate different vegetation management systems through research and personal interviews with key personnel of utility companies.
- Inventory vegetation, poles and equipment of study area.
- Select GIS and digitize inventoried features of study area.
- Create databases for all relevant information to perform GIS analysis.
- Demonstrate various types of analysis using new program.
- Discuss implications of findings.
- Recommend a vegetation management program.

Selection of Study Area

An inventory large enough to demonstrate diversity and the benefits of a GIS was obtained from two different locations (Figure 1). One area is representative of a city residential setting and the second area of a rural residential area. The inventory consists
of the utility poles and associated equipment as well as the vegetation and its associated attributes.

MPC divides Missoula into grids covering a specific area. The paper maps for the corresponding grids are from aerial photography taken in 1973. They were useful for reference purposes only. MPC is in the process of converting their maps into digital form. The digital maps for the corresponding grids used in this study were provided by MPC for use as base maps in the GIS.

Several miles of power line were visually surveyed prior to the selection of the two grids comprising the study area. The search domain included the city of Missoula, the Rattlesnake area, Grant Creek area, Pattee Canyon, and the road to the Snow Bowl Ski area. The vegetation conditions in all of the areas surveyed are similar.

Data for approximately 100 trees were to be gathered with about an equal number of trees from each study grid. This would provide sufficient data to cover a diversity of situations and to make comparisons between the two grids. The extent of the grids would be determined by fulfilling the data requirements. The city grid would be inventoried first to build a spatial database containing approximately 50 trees. An additional 50 trees would be inventoried in the rural grid. The next step involved the development of inventory procedures.

**Inventory Methods**

The development of a data collection form went through several revisions. The data collection form would provide the information contained in the database. Each grid would have two different databases; one for poles and equipment and another for the vegetation. Also, the data collection sheet had to contain locational information so that the poles and vegetation could be digitized (as accurately as possible) at the same
geographic positions as on the ground. In addition, the final version of the data collection sheet (Appendix A) contained information about the length of time required to inventory each span.

Most of the attributes listed on the data collection sheet are self-explanatory, however, exact definitions are given in Appendix B - Attribute Definitions. The attributes represent three aspects of data collection; 1) the location and condition of power poles with corresponding equipment; 2) the location and status of trees growing along the power line corridor; and 3) the amount of time taken to collect data for each span. A schematic diagram in Appendix C illustrates the vegetation and pole registration method.

The instruments used to collect data include a Suunto clinometer (for measuring tree heights), Silva Ranger compass (bearing readings to the next pole), 100-foot tape measure (for measurement of X, Y-right and Y-left), a d-tape (tree diameter measurements), various stakes and eye-screws, 300 feet of nylon cord (centerline), and two dendrology books. The dendrology books were used for tree identification and the scientific names of each species (Farrer 1995), (Harlow, Harrar, Hardin, and White 1991).

The first pole inventoried in each study grid was located in an easily identifiable geographic location such as a street corner or intersection. From that point, the distance and bearing to the next pole were taken as well as the pole attribute and equipment data. Each tree was registered in relation to the power line span it was located on by a series of x and y measurements along the centerline (Appendix C). The centerline is an imaginary line (X) extending between the poles of each span. The distance along the centerline to the leading edge of the trunk is denoted as X. A tree located to the right of the centerline
is measured at a 90-degree angle to the center of the trunk and denoted as Y-right. The same method applies for trees located to the left of the centerline. Each pole and tree in the study areas was recorded using these methods.

GIS Software Selection

At the time the inventory was conducted, the GIS software had not been selected, but would be a choice between PAMAP and ArcView. Data was collected that would be compatible for either software. It was a question of how much digitizing would need to be done and whether the trees would be depicted as points or polygons. The decision was made after all the fieldwork had been completed. This created some problems that would manifest themselves later in the study.

The base maps were obtained from MPC. A computer aided drawing (CAD) system is used by MPC to reproduce the maps obtained from Missoula County (Yonce pers. comm.). The maps are redrawn to match the MPC grids for Missoula. During the process of redrawing, the map projection is lost because each map is registered at a 0,0 point. However, the scale of the maps is fairly accurate except for the road width in Pattee Canyon. The CAD maps are compatible with ArcView and easily imported. Since useable base maps for the city grid (Appendix D) and rural grid (Appendix E) had been located, the only digitizing to be done was for the poles, power line, and trees. For this reason, as well as its interface capability with Arc/Info, graphic display, and user friendliness, ArcView was chosen as the GIS software for this study.

Digitizing Process and Database Construction

The grid in Pattee Canyon was chosen as the first area to be digitized. The poles were digitized first and then the trees. As previously stated, the first pole of each area was located in an easily identifiable geographic location. The first pole was digitized, as
a point theme, and subsequent poles were digitized based on the distance measurement to the next pole and its bearing. The poles were symbolized by a circle with a cross hair that extends past the circumference of the circle.

There was a slight problem digitizing the poles because the bearing reflects a straight line, but when digitized the poles were not in a straight line. This is because the base map for the grid in Pattee Canyon is not accurate in terms of the road widths. The digitized road is wider than on the ground. The measuring tool showed the road to be 100 feet wide in some areas when in reality it is no more than 25-30 feet wide. However, the poles reflect their location on the ground according to their proximity to the road, the distance between poles, and a hand-drawn map from the field.

A line was drawn between the centers of each pole to represent the power line. Actually, the line represents the centerline between poles to be used for the X measurement for locating trees in the correct position. A zoom-in on each pole at a scale of around 1:250 permitted a line to be placed as close as possible to the center.

The next step involved digitizing each tree for each span in the correct location based on the X and Y-right or left measurements taken in the field. This was a very time-consuming process that could have been accomplished much easier using the proper equipment and the base maps being linked to a coordinate system. However, this was not the case, so each tree was located as a point theme as closely as possible to its geographic location on the ground for each span. On the second span one of the points fell in the middle of the road because the CAD map was not accurate in its depiction of rural road widths. This was not a major problem since only four out of sixty trees did not maintain their positional integrity after all trees had been digitized. The analysis
capability of the study was not affected because the feature attributes were not changed. The graphic display was affected, but is practically unnoticeable to a casual observer.

The next step after digitizing the poles and trees was creating the attribute databases. At this point, there was only a shapefile for the points representing the poles and trees. ArcView shapefiles are a simple, non-topological format for storing the geometric location and attribute information of geographic features. A shapefile is one of the spatial data formats that you can work with in ArcView. Spatial data stores the geometric location of geographic features, along with attribute information describing what these features represent. Previously, the attribute data for poles and trees had been stored as four separate excel worksheets for the Missoula and Pattee Canyon. The worksheets were converted into delimited ASCII text files and imported as tables into ArcView. The tables were joined to their respective shape files. In order to do this, the shape file had to be edited and a common attribute field added that matched the new table. The table and shape file were 'joined' to create the databases for poles and trees. Since the reader is assumed to have some knowledge about these GIS processes, all of the detailed steps are not included. The process was completed for the Pattee Canyon grid first and various thematic maps were produced.

The same procedures were repeated for the city grid. There were not as many problems for several reasons. The primary reasons were that the process had been completed once successfully and the city streets are in a grid that runs north/south and east/west, at least for the area inventoried. Also, the street widths in the CAD map for the Missoula grid are more accurate than those for the Pattee Canyon grid. The completed process for the city grid contained no trees or poles that were not in the correct geographic position.
Chapter Four

RESULTS

GISes are used for the management of vegetation on a variety of scales. Perhaps the most common use is the mapping of vegetation using polygons to depict similar tree species or common vegetation attributes. This study used point data to represent map features such as poles and trees. The features are not be linked together as polygons, but are illustrated as thematic maps produced from common attributes. The analyses illustrated are not all inclusive but only a fraction of the total. Only the database and the user’s imagination (guided by the spatial problem being solved) limit the number of different analysis that can be illustrated. The following illustrations are some that would be considered among the most important for a utility company.

Analysis of Vegetation

The first thematic map shows the inventoried vegetation as a unique value based on the clearance codes. This quickly shows the vegetation manager where hot spots are and the overall status of the vegetation in one map. The study area is in two different locations comprised of a residential grid in Missoula (Figure 2) and a rural residential grid on Pattee Canyon Drive (Figure 3).

There is a vast amount of non-spatial information available that can be accessed in the GIS. For example, the Missoula grid in figure two is based on the unique value of the clearance classes for the vegetation. The maps show the locations of poles and trees. For locations where a cluster of red dots appears the zoom tool can be used for a more detailed view. There are 63 trees in the Missoula grid. By opening the database table, the clearance class field can be summarized and the total number of trees for each
category can be displayed (Table 1). Using this information, it is easy to calculate that fifty-nine per cent of the trees (0-2 foot clearance class + 2-4 foot clearance class) are 4 feet or less from the power line for the city study area.

Figure 2. Thematic map of tree clearance classes for the Missoula grid.

The rural study area reveals different results than the city area. There are four clearance classes instead of three. The fourth clearance class is for dead, diseased, or leaning trees (hazard trees) that are in danger of falling into the power line. Hazard trees are more likely to occur in forested areas than in city areas. There is only one tree in this clearance class out of 60 trees (1.7 per cent) in the rural study area. Although the percentage of hazard trees is small, the damage to power lines and equipment can be
extensive if a tree falls across power lines. Hazard trees should be removed as soon as possible.

![Pattee Canyon Grid Diagram](image_url)

Figure 3. Thematic map of tree clearance classes for Pattee Canyon grid.

Similar to the Missoula grid, the Pattee Canyon grid contains 33 trees (0-2 foot clearance class + 2-4 foot clearance class) or 55 percent of the total that are within 4 feet of the power line. The Missoula and Pattee Canyon grids contain 70 out of 123 trees with 4 feet or less clearance. This represents 57 percent of the trees that are 4 feet or closer to the power line. This is a strong indicator of future service problems from power outages caused by vegetation as well as increased fire hazard by tree/power line contact.

The vegetation manager can use these data to schedule tree crews for clearance work in specific locations. The exact location for each tree is listed in the database as...
well as specific tree attributes. The spatial distribution of other vegetation conditions can be displayed by creating a layer using tree type as a theme. This will display the trees graphically as deciduous or coniferous (Figure 4).

Table 1. Number of trees by dot color and clearance class for Missoula and Pattee Canyon grids.

<table>
<thead>
<tr>
<th>DOT COLOR</th>
<th>CLEARANCE CLASS (FT.)</th>
<th>NUMBER OF TREES (PERCENT) IN GRID</th>
<th>Missoula Grid</th>
<th>Pattee Canyon Grid</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0-2</td>
<td>24 (38.1)</td>
<td>19 (31.7)</td>
<td>43 (34.96)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>2-4</td>
<td>13 (20.6)</td>
<td>14 (23.3)</td>
<td>27 (21.95)</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>4-8</td>
<td>26 (41.3)</td>
<td>26 (43.3)</td>
<td>52 (42.28)</td>
<td></td>
</tr>
<tr>
<td>Purple</td>
<td>Hazard</td>
<td>0 (0.0)</td>
<td>1 (1.7)</td>
<td>1 (0.81)</td>
<td></td>
</tr>
</tbody>
</table>

There are more coniferous than deciduous trees in the Pattee Canyon grid. This is confirmed numerically by performing a query of the databases for each area. The results indicate there are 26 conifers (41 percent) for the city area and 53 conifers (88 percent) for the rural area. This is important for the vegetation manager to know because there are different trimming methods used on conifers than deciduous trees and the rotation length between trims is longer for conifers as well.

The thematic map depicting clearance classes indicates a large number of trees near the power line (Figures 2 and 3). Querying tree type by vegetation distance from the power line (Figures 4 and 5) provides additional insight to the vegetation manager that may be critical, especially during a high fire danger season. The vegetation distance to the power line can be summarized by 1-foot classes for all trees (Table 2) or a single tree record can be displayed via an interactive query using the identify tool (Figure 4).

Query results are displayed graphically in red (yellow is the default color, however, the color is user defined) for each feature that satisfies the selection criteria. The query results displayed in Figures 4 and 5 show all trees with a vegetation distance
of less than or equal to one foot from the power line. This query revealed that there are 15 trees (24 per cent) in the Missoula grid within one foot of the power line of which eight trees are in direct contact (Table 2). This condition provides a high degree of fire danger during hot and dry seasons, especially when windy conditions are present.

![Thematic map of Missoula grid showing vegetation by tree type within a 1-foot clearance distance of the power line and an example of a single interactive query using the Identify Tool.](image)

Figure 4. Thematic map of Missoula grid showing vegetation by tree type within a 1-foot clearance distance of the power line and an example of a single interactive query using the Identify Tool.

Direct contact with the power line by vegetation in city areas is not as dangerous as in rural areas. The main problem resulting from tree/power line contact in the city is power outages. The problem is minimized by the use of switches that isolate the outage when vegetation or anything else makes contact. Fire hazard is minimized because of the larger number of people in the city that will report the problem and yards are
typically well maintained and watered during the dry summer months. However, this is not the case in rural areas where tree/power line contact is much more dangerous.

Figure 5. Thematic map of Pattee Canyon grid showing vegetation by tree type within a 1-foot clearance distance of the power line and zoom-in views of two areas.

The analysis of the rural area by tree type and vegetation distance reveal there are twelve trees out of sixty (20 per cent) within one foot of the power line. More importantly is the fact that three trees (5 per cent) are in direct contact with the power line (Table 2). This is less than the city area contains, but the length of the rural study area is much shorter and the consequences of a tree caused fire ignition are much greater. In rural areas, fire may erupt without anyone's knowledge and substantial damage may occur due to slower response by fire fighting agencies.
Table 2. Summary of number of trees by vegetation distance field for Missoula and Pattee Canyon grids.

<table>
<thead>
<tr>
<th>Distance from Power Line (ft.)</th>
<th>Number of Trees (percent) in Grid</th>
</tr>
</thead>
</table>
|                               | Missoula Grid | Pattee Canyon Grid | Combined  
| 0                             | 8 (12.7) | 3 (5.0) | 11 (8.94)  
| 1                             | 7 (11.1) | 9 (15.0) | 16 (13.01)  
| 2                             | 9 (14.3) | 8 (13.3) | 17 (13.82)  
| 3                             | 5 (7.9) | 6 (10.0) | 11 (8.94)  
| 4                             | 8 (12.7) | 8 (13.3) | 16 (13.01)  
| 5                             | 4 (6.3) | 8 (13.3) | 12 (9.76)  
| 6                             | 7 (11.1) | 3 (5.0) | 10 (8.13)  
| 7                             | 6 (9.5) | 4 (6.7) | 10 (8.13)  
| 8                             | 9 (14.3) | 11 (18.3) | 20 (16.26)  
| Total                         | 63 (100.0) | 60 (100.0) | 123 (100.0)  

There are many other types of analyses that could be conducted to address specific questions or problems dealing with the vegetation. The examples shown are among the most important for a utility company that is trying to manage the vegetation and develop a trimming schedule. GIS gives the vegetation manager an overview of the conditions in the field and a method for tracking progress. Additional analyses can be performed and are limited only by the information contained in the database. It is important for the database to be updated on a consistent basis to insure accuracy with conditions in the field. Vegetation management of power line corridors is accomplished more efficiently using GIS.

**Analysis of Poles and Equipment**

Although the focus of this study as on vegetation management, many utility companies use GIS to maintain and manage poles and equipment. While collecting field data for the vegetation, attributes for poles and equipment were collected as well. Several poles were observed with large checks so a method of categorization (Appendix
B) was developed. Each pole's condition was classified as either good, fair, or poor and their spatial distributions are displayed in Figures 6 and 7.

![Thematic map of pole condition classes for Missoula grid.](image)

Figure 6. Thematic map of pole condition classes for Missoula grid.

The Missoula grid has a large number of poles in poor condition. Poor condition means that the pole contains one or more checks or cracks that is approximately half as deep as the pole diameter and extends for several feet up the pole. The thematic map displays pole conditions with a colored symbol. The pole conditions for both grids are summarized in Table 3. There are 17 poles (52 per cent) in poor condition. A query of the database revealed that of the 17 poles in poor condition there are 8 that support equipment such as transformers. The Missoula grid contains 12 poles (36 per cent) with some type of equipment such as transformers, capacitors, or streetlights. The extra
weight of equipment increases stress to the pole and the likelihood of failure, especially for poles in poor condition.

Figure 7. Thematic map of pole condition classes for Pattee Canyon grid.

Table 3. Number of poles by condition class for Missoula and Pattee Canyon grids.

<table>
<thead>
<tr>
<th>SYMBOL COLOR</th>
<th>POLE CONDITION</th>
<th>NUMBER OF POLES BY CONDITION (PERCENT) IN GRID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Good</td>
<td>Missoula Grid (8 (24.3)) Pattee Canyon Grid (5 (62.5)) Combined (13 (86.8))</td>
</tr>
<tr>
<td>Blue</td>
<td>Fair</td>
<td>8 (24.2) 1 (12.5) 9 (36.7)</td>
</tr>
<tr>
<td>Red</td>
<td>Poor</td>
<td>17 (51.5) 2 (25.0) 19 (46.34)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>33 (100.0) 8 (100.0) 41 (100.0)</td>
</tr>
</tbody>
</table>

The Pattee Canyon grid contains two poles (25 per cent) in poor condition. However, unlike the Missoula grid the poles in poor condition do not have equipment on
There is equipment on two poles (25 percent) in the Pattee Canyon grid. The density of poles with equipment is greater in the city area than the rural area.

**Analysis of Time Effort**

The total inventory time for both study areas 20.75 hours. This is pure work time without allowances for travel time or breaks. The length of inventory time varies between spans (Table 4) depending upon the amount of vegetation, length of span, and field conditions. The total length of both study areas is approximately 1.1 miles. This is equivalent to 18.9 hours per mile to inventory vegetation, poles, and equipment. Multiplying 344 miles (miles of power line in Missoula grid) by 18.9 hours per mile yields 6,501.6 hours. Using 2,080 as the standard number of hours worked per year by a single employee, it would take 3.1 years to do a complete inventory. The initial inventory would require more time than subsequent inventories. However, it is unknown what the ratio of city to rural area is for the Missoula municipal area. It is unlikely that the ratio is 2.67 miles of city area to one mile of rural area. The sample size of the inventory was too small to determine these ratios accurately. In addition, MPC has useable data for poles and equipment that would not require inventory time.

A breakdown of the inventory time by spans (Table 4) for the two grids is a more useful summary because a range can be calculated. The Missoula grid required 11.5 hours to inventory 0.8 miles. Converting this to an hourly rate and expanding this rate to an annual basis yields 2.4 years for one person to inventory the Missoula municipal area. The Pattee Canyon grid required 9.3 hours to inventory 0.3 miles. This equates to 5.1 years of inventory time. Using the two values, a range of 2.4 to 5.1 years of inventory time is required. This time range can be reduced substantially by streamlining the data
collection method, using existing pole and equipment data, and utilizing GPS receivers with differential corrections.

Table 4. Inventory time per span in minutes and number of trees per span for Missoula and Pattee Canyon grids.

<table>
<thead>
<tr>
<th>SPAN</th>
<th>AREA</th>
<th>TIME</th>
<th>TREES</th>
<th>SPAN</th>
<th>AREA</th>
<th>TIME</th>
<th>TREES</th>
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<tbody>
<tr>
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<td>105</td>
<td>11</td>
<td>21</td>
<td>City</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>City</td>
<td>90</td>
<td>4</td>
<td>22</td>
<td>City</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
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<td>1</td>
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<td>3</td>
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<tr>
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<td>1</td>
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<td>26</td>
<td>3</td>
</tr>
<tr>
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<td>City</td>
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<td>1</td>
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<td>Rural</td>
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<td>1</td>
</tr>
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<td>City</td>
<td>18</td>
<td>2</td>
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<td>19</td>
</tr>
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<td>1</td>
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<td>Rural</td>
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<tr>
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<td>1</td>
<td>38</td>
<td>Rural</td>
<td>95</td>
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</tr>
<tr>
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<td>City</td>
<td>18</td>
<td>2</td>
<td>39</td>
<td>Rural</td>
<td>73</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>City</td>
<td>8</td>
<td>1</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>Na</td>
</tr>
</tbody>
</table>

Time for Missoula grid: 689 minutes
Average per span: 21.5 minutes
Time for Pattee Canyon grid: 556 minutes
Average per span: 79.4 minutes
Total time: 1245 minutes
Total average: 31.9 minutes
Converted to hours: 20.75 hours

The same type of calculations can be applied to tree trimming. The range of 10-
15 trees trimmed per day (50-75 per week) by one tree crew is a reasonable estimate for
most areas. This is an average number over an extended period of time. For simplicity,
62.5 trees per week will be used as an average. There are 24 trees per 0.8 miles of power
line in the city study area in which the vegetation is 2 feet or closer. This is equivalent to 30 trees per mile. Multiplying 30 trees per mile by 344 miles yields 10,320 trees. Dividing 10,320 trees by 62.5 trees per week yields 165.12 weeks or 3.2 years of trimming work for a single crew. This is based on conditions in the city study area. Applying the same method of calculation to conditions of the rural study area, the work time for a single crew expands to over 7 years (22,933 trees/62.5 trees per week). A range of 3.2 to 7 years for a single tree crew to provide 2 feet of clearance around the power line is unacceptable. Obviously, more than 2 feet of clearance is needed to achieve a sustainable rotation and it will require more than one tree crew to do it.
Chapter Five

DISCUSSION AND MANAGEMENT IMPLICATIONS

The experience gained as a utility forester for PG&E and the completion of a graduate-level GIS course led to the inspiration of using GIS to predict the scheduling of vegetation trimming around power lines. An understanding of the scope of the problem existed prior to the interviews with PG&E and MPC. Vegetation management is a complex problem for utilities at any scale. The objective was to find a simple solution to a complex problem.

The challenge throughout the study was to keep the focus on the objective. The objective is to demonstrate the application of GIS for vegetation management along power line corridors, specifically primary distribution lines. At the beginning of the study, growth models were to be used to predict future trimming requirements. Later, as the study progressed and conditions of the inventory became known, the idea of using growth models was eliminated because it goes beyond the scope of applications being illustrated for this study. The use of growth models is something that needs to be developed for each specific area and would be very problematic for urban areas with the vast variety of vegetation and growing conditions. Each residential property is like a small ecosystem with its own microclimate. In addition, the short rotation period for trimming the power line corridor as well as the unknown growth rates of secondary or sucker growth makes the development and use of a growth model not feasible at this time, especially for city areas. Utility companies actually using GIS to predict trimming schedules should consider the use of tree growth models. This is a natural extension of this type of GIS application.
There are some limitations and improvements to the methods used that should be mentioned. Having completed the process once leads to new insights that can only come from experience. Although the data entry and data collection process was somewhat crude, it was still effective. However, the same outcome could have been accomplished in a much more efficient manner in one of two basic ways: 1) Selection of the GIS first, and then collection of tree data based on category codes or vegetation distances and tree types only. The individual tree attributes could be eliminated as well as the measurements of X, Y-right and Y-left. A grid system could have been used for each span and trees located in their relative positions that way; or 2) Using tools and equipment designed for this type work such as GPS receivers, hand-held data collection units with pre-programmed menus and data fields, and computer programs designed for organizing and summarizing utility vegetation management data. In retrospect, more vegetation data was collected than necessary to complete the study.

A critical component is the creation of a geographic database from which to work. Ideally, the location of the poles and trees would have been completed using a GPS unit with differential correcting. The attribute data collected in the field would have been entered into a portable data recorder and later downloaded into a computer. This unit could be part of the GPS unit or a separate piece of equipment. The base map should have been associated with a coordinate system. When the data is downloaded from the field, the location of the poles and trees with all attributes would go directly into a geographic database. The technology is available, but was not accessible at the time.

**Management Implications**

There are a very high percentage of trees too close to the power lines in the Missoula municipal area. Under California laws, MPC would be in danger of legal
prosecution for negligence and possible endangerment to the public. The close proximity of vegetation to power lines increases fire hazard and the likelihood of power outages. MPC is aware a problem exists, but does not have a solution. This may be due to budget constraints and the lack of an overall vegetation management program. The existing program is fragmented with each district responsible for its area. Tree trimming is contracted to an outside company with minimal supervision by MPC. Faith that the tree trimming company will take care of the problem is not enough. In addition, tree trimming based on the size of the budget is not the answer. A more active management role is needed at the ground level and upper management needs to support GIS technology and the development of an overall vegetation management program.

GIS is an excellent tool for vegetation management around power lines. It is being used by utilities for a variety of functions. Although documentation of the use of GIS in vegetation management by utilities is not prevalent due to trade secrets or possibly lack of publication funding, the technology is available and methods of implementation do not have to be elaborate. The methods used in this study were somewhat crude but effective. Developing a simpler process with or without additional technology could reduce time spent doing the inventory. The focus should be to develop a program that is evolving to fit the needs of the utility company. An inventory of the existing vegetation is essential as a first step in developing a tree-trimming schedule.

**Recommendations for a Vegetation Management Program**

Businesses keep track of their inventory to maintain efficiency and profitability. The same necessity exists for utilities regarding vegetation around power lines. How can management strategies be developed if what is being managed is unknown? Also, utilities must take responsibility for tree trimming activities because power outages
reduce profit, erode customer satisfaction, and ultimately the utility companies are liable for damages.

A system of pre-inspection prior to tree trimming and post-inspection after trimming is needed. The utility must know what it is getting for its money namely that there is adequate clearance around the power lines for a minimum of three years. Adequate clearance means that the vegetation will be outside a 4-foot radial zone of the power line for at least three years. Of course, the amount of trimming will vary according to tree species and growing conditions. However, all trees in an area should be trimmed for a 3-year rotation and not just those close to the power line. Removal of conifers directly under the power line should be encouraged as well as a tree replacement program implemented to compensate property owners. Public awareness and education of the utility company’s vegetation management program should be promoted.

GIS should be used to maintain the vegetation inventory, the history of tree trimming activities and billing records, unusual problems or circumstances for specific areas, and any other data relevant to the vegetation manager. A walkthrough inventory should be conducted every 2-3 years. Billing records should be monitored closely with tree trimming activity. Double billings, billings for the same trees within two years of the last trim, or billings for trees that do not exist should be prevented or minimized. These types of problems can be identified easily with GIS.
Chapter Six

CONCLUSIONS

Utility companies across the United States are using GIS and other computer programs to manage equipment and vegetation. The specific methods of use are confidential information closely guarded by the utilities. This became very apparent when PG&E approved the request for a partial inventory of approximately 100 trees and the corresponding power circuit if rights to this thesis were waived. Their legal department would not approve the release of the data without the signed waiver. The information was not vital to the completion this thesis and did not merit the waiver of such rights. However, the methods used for this study will work based on the collected attributes. In fact, there are no reasons why a utility should not utilize GIS as a vegetation management tool other than the lack of management support.

Cost is not a problem because the technology can be purchased incrementally. That is one reason ArcView was chosen because it is a user-friendly program that is not very expensive and the analysis capability can be expanded very easily. GIS is becoming readily available as the technology improves and access is increased. There are some free GIS software packages available that have limited spatial analysis capability and can be downloaded from the Internet. However, research was not conducted to ascertain if any of those programs would have worked for this study.

A variety of methods can be used to incorporate GIS into the management of vegetation along power line corridors. The challenge of each utility is the decision to commit to using the latest GIS technology for developing tree trimming schedules and maintaining an easily updateable inventory of poles, equipment and vegetation.
REFERENCES CITED:


APPENDIX A.

Data Collection Sheet
### Data Collection Sheet

- **Grid #**: 
- **Span #**: 
- **Pole #** to **Pole #**: 
- **Bearing**: 
- **Start Time**: 
- **Distance Between Poles**: 
- **Pole Height**: 
- **End Time**: 
- **Pole Equipment**: 
- **Pole Diameter**: 
- **Elapsed Time**: 
- **Pole Condition**: 

### Tree Data *

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<th>Location</th>
<th>Type</th>
<th>Species</th>
<th>DBH</th>
<th>Spread</th>
<th>Tree Ht</th>
<th>X</th>
<th>Y-Left</th>
<th>Y-Right</th>
<th>Category</th>
<th>Veg dist</th>
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* See attribute definitions for data collection categories.
APPENDIX B.

Attribute Definitions
**Attribute Definitions**

**Pole Condition Codes:**
- **Good** – No checks or other structural defects.
- **Fair** – Small checks in pole but appears structurally sound.
- **Poor** – Large checks at least 40% of diameter in depth as well as other structural defects present. Pole does not appear structurally sound.

**Location:**
- The nearest street address.

**Type:**
- Conifer or deciduous trees.

**Spread:**
- Crown width is radius in feet toward power line x 2.

**Distance:**
- The distance in feet between poles of a single span.

**X:**
- Linear distance in feet along centerline between spans.

**Y-left:**
- Linear distance of bole in feet 90 degrees left of centerline.

**Y-right:**
- Linear distance of bole in feet 90 degrees right of centerline.

**Clearance Classes:**
- Clearance classes are based on vegetation distance from the power line. Only one class per tree is used.
  - **Class 1** = 0-2 feet clearance from power line.
  - **Class 2** = 2-4 feet clearance from power line.
  - **Class 3** = 4-8 feet clearance from power line.
  - **Class 4** = Dead, diseased or leaning trees that may fall into the power line.

**Veg dist:**
- Distance in feet of vegetation.
APPENDIX C.

Schematic Diagram of Vegetation and Pole Registration Method
**Schematic Diagram of Vegetation and Pole Registration Method**

- **Centerline**
- **Power Line**
- **Utility Pole**
- **Bole**
- **Tree Crown**

- **Distance along centerline from edge of pole to edge of bole determines X.**
- **Distance of vegetation to power line determines clearance class.**
- **Distance from bole to centerline determines Y-right or Y-left.**
APPENDIX D.

Base Map for Missoula Grid
Base Map for Missoula Grid
APPENDIX E.

Base Map for Pattee Canyon Grid
Base Map for Pattee Canyon