ELECTRIC UTILITY CORRIDOR TREE MANAGEMENT STRATEGIES AND OPTIONS: A CASE STUDY FOR STILLWATER, OKLAHOMA

By

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Finished is a funny word. It actually has two completely different meanings. On the one hand it means a task is completed. On the other hand, it means that some task has exhausted you to completion. This is a good word for me. I'm finished. Whew!

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CHAPTER I

Introduction: What is Utility Forestry?

Aboveground utility lines and trees have never made a good combination. Trees and utilities provide necessary benefits to the lives of those who live in urban settings, but unfortunately both tend to occupy and need the same space. In the urban environment, trees are usually placed in inferior locations, usually on the fringe of properties or near fence lines or between parking spaces. Utilities are placed in similar areas, within easements between properties and near curbs. When a tree branch contacts electrically charged bare wires, the flow of electricity through the line stops and is redirected through the tree. The resulting electrical charge to the tree can cause the tree to burst into flames or can cause a branch to slowly smolder until it falls from the tree causing damage to property below. Tree branches can also damage or break the electrical line, leaving an electrical wire on the ground, which could easily electrocute anyone in close proximity. Any tree located too close to an aboveground electric line poses a threat to surrounding property, to the utility line repair personnel who must fix power outages, and also to the customers whose lives may be dependent on a reliable flow of electricity. To provide safe and reliable service to their customers, utility companies must continually remove and trim trees in their easements. Utility forestry is the management of forested areas within utility easements. Foresters are utilized by utility companies to maintain proper clearance of aboveground utility lines from woody vegetation using environmentally and arboriculturally sound practices. At the same time, utility foresters use their knowledge of tree characteristics, growth habits, and differences to provide the most efficient tree management techniques. Public relations and educational work are also a very large responsibility for utility foresters. Since utility easements are often concentrated in urban areas, it is necessary for foresters to educate people on the need to plant proper tree species under powerlines and on the necessity to properly trim trees already near the lines. Proper trimming practices are encouraged by utility foresters for the health and function of the tree in the harsh urban environment.

A major challenge in managing tree trimming operations throughout electric service areas is developing a strategy that will enable the fewest number of work crews to maintain the greatest length of utility line. Since trees are constantly growing back into the power lines, regular maintenance must be done along the entire network of lines. Utility easement widths vary for each location. Typical easement width range for distribution lines is between 3ft-20ft. Trees targeted for maintenance include those with any portion of their crown within the utility easement. Removal is the preferred maintenance method of large trees that have their trunks within the easement. This prevents the need for repeated trimming of the same tree. Trimming is done on large trees whose trunks do not exist in the easement but whose crowns are close to the electric line. Utilities have varied methods on how they determine which trees will be removed and which will be trimmed.

Programmed maintenance involves the management and creation of a trimming cycle. A trimming cycle is the time established to trim or remove all trees within a given area (Miller, 1997). For example, in a five year trimming cycle one fifth of the trees in a management area will be removed or trimmed every year. Unfortunately, this sort of management scheme is very hard to implement in areas that have not been heavily managed in the past. A trimming cycle must be carefully calibrated to the size of system being managed and the growth rate of the trees being trimmed. If the cycle is long the trees grow back into the lines faster than they can be trimmed. If it is too short then the trees are trimmed too often making the process inefficient. Trimming guidelines also affect the length of a trimming cycle. Trees trimmed to a minimum distance from the line will need to be trimmed more often, whereas trees trimmed further away will require less immediate attention. A truly effective trimming cycle and comprehensive trimming plan are implemented only after careful analysis has been done of trimming needs and practices in a particular service area.

Development of a comprehensive trimming plan is dependent on an inventory (Miller, 1997). A tree inventory was done as a part of this study to determine typical trimming densities and trimming obstacles in utility line corridors throughout Stillwater, Oklahoma. The data was gathered, organized, and analyzed with the use of a geographical information system (GIS). This information was then used to formulate a management plan that could be applied to the entire Stillwater electric service area. This study also addressed strategies that can be used to manage public relation needs related to trimming operations.

CHAPTER II

Literature Review: Creating a GIS Tree Inventory

Much of the software developed for tracking and inventorying individual tree maintenance in the past has been for municipal urban foresters. Street trees, park trees, and other publicly owned trees have been tracked and maintained with the help of database software such as Tree Manager ™ by ACRT, Tree Inventory System (TIS) by Utah State University, and Compu-Tree ™ by Systemics (Miller, 1997).

Database Inventories: In 1991, a street tree inventory was done in Stillwater, Oklahoma (Birchell, 1991). Trees were located using street addresses adjacent to each tree's position. A DbaseIV database format was used to evaluate all of the information gathered. Analysis of the data consisted of finding species distribution according to size, species conditions, and tree orientation to the right-of-way. All of the data was within one database file and queries were done individually for the analysis. An excerpt taken from the database is shown on Table 1. A total of 52 fields were used to describe each tree. Diameter, species code, address location, right-of-way location (true or false), and condition rating can all be seen in this example.

***Table 1**. Example Database Taken from the 1991 Stillwater Street Tree Survey*

TREE	DIA	BLOC	DIREC	STRT_NA	HOUSE	SPE	DIAM	COND	MAIN2	MAI3	MAI	SPA	ON_ROW
1	0	1	S-N	S. RIDGE	524	0	0	0	0	0	0	S	TRUE
2	0	1	S-N	S. RIDGE	502	0	0	0	0	0	0	S	TRUE
3	0	1	S-N	S. RIDGE	502	0	0	0	0	0	0	S	TRUE
4	0	1	S-N	S. RIDGE	502	0	0	0	0	0	0	S	TRUE
5	0	1	E-W	W. 5^{TH}	2205	20	35	90	0	0	0		FALSE
6	0	1	E-W	W. 5^{TH}	2209	20	29	80	0	0	0		FALSE

(Birchell, 1991)

From Table 1, it would be very difficult to find all of the elm trees within a ten block radius of a diseased elm. Also, grouping of trees by location, species, age, or condition in any particular area is impossible. Another way of indexing the same kind of data has been done in the past by city block number. Trees are labeled according to their corresponding block and can be grouped with other trees existing on the same block. Several database packages use this kind of tracking, such as Inventree (Ventura and Barry, 1997) and Tree Keeper (TM) by Davy Tree Company.

City foresters and arborists have used databases successfully in the past to keep track of great numbers of trees throughout large metropolitan areas. Each tree is labeled with an identification number and given attributes such as species, location, maintenance codes, and condition. In this way the forester knows what maintenance has been recently done to the tree and what future maintenance will be necessary according to its condition.

Strict database software, however, is limited. It is unable to demonstrate spatial patterns among tree inventory databases and to incorporate other information such as street location, neighborhood boundaries, political boundaries, and utilities. Traditionally, databases have not been utilized to manage utility line tree maintenance.

By not exploiting the spatial aspect of the data, very significant relationships can be missed. For example, the progression of a tree disease through a town could be unknown if not looked at spatially. In a traditional database a diseased condition might be spotted in a general area such as along a street or city block. However. projecting the effects of the disease over a very large area would be very difficult if not impossible. A GIS, however, can be used to locate all of the trees with the diseased condition. By knowing the rate of spread of the disease, a model could be used to project the effects of the disease over the entire tree population. Measures could then be taken to systematically control the disease.

Utility Line Management Systems: Utility line management has traditionally focused on the tracking of line repairs, system elements (such as transformers and poles), and system function (such as outage location). Utility line management is different from municipal urban forest management in that it has traditionally not been used to identify tree maintenance needs. Management systems for utility line maintenance include Automated Mapping and Facility Management (AM/FM) software. AM/FM is similar to Computer Aided Design and Drafting systems (CADD). The electrical system elements such as individual poles, lines, etc. are mapped as symbols on data layers. Attributes are then attached to each symbol and each attribute is assigned networking characteristics (Korte, 1997). This type of system is mainly used to locate infrastructure of the electrical system. This system does not allow input of data layers other than electrical system components, such as trees, and traditionally has not been used to do so.

GIS Systems: With the advent of more user friendly software and faster computers, GIS has become common for a variety of geographical analysis. GIS is defined as "…a system that has the capability to capture, store, retrieve, analyze, and display data in a spatial format" (Haring, , 1992, p. 115). By integrating tree maintenance data into electrical system infrastructure data, a GIS can allow the utility line manager to track where trimming has taken place, where it is needed most (by locating those areas not recently trimmed). At the same time, a GIS allows integration of other kinds of information into the system. Some of this data may include neighborhood boundaries, underground utilities, or other information that could be used to make management decisions.

Dane County Tree Inventory: An example of a GIS tree inventory in an urban area can be found in a study done during the spring of 1995 in Dane County, Wisconsin by the Dane County Tree Board. A GIS was used to inventory all major landscape trees within a selected portion of the University of Wisconsin-Madison campus. Researchers used a GIS made by Environmental Systems Research Institute, Inc. (ESRI) called ArcView™ to map and measure each of the trees. Orthophotos (aerial photos adjusted to a coordinate system with all spatial distortions removed) were used as basemaps to locate and identify individual trees (Ventura, 1997).

To facilitate the on-ground collection of the data, researchers created what was termed a "….hybridized system of collecting the information"(Ventura, 1997, p. 11). The hybrid system entailed enlarging the one-meter pixel orthophotos into 500-acre prints that fit on a two foot by two foot piece of paper. They then took these prints out to the field and used them to identify over 6000 individual trees that they delineated on the map with small dots. They only identified those trees above four inches in diameter at breast height

(4.5 ft. from the ground, also called DBH). Conversion of the maps into digital form was done with a digitizer.

The Ventura study utilized a GIS to integrate tree information into a current maintenance system. The system was later updated from its initial inventory to include the entire campus. In this way, maintenance personnel could track and maintain all of their trees using this system.

The Lindhult Study: Lindhult (1987) completed a study similar to Ventura's titled "A Microcomputer-Based Tree Management System." The study combined the use of AutoCAD™ (for graphical representation of individual trees) and Dbase III (for tabular representation of individual trees). The integration of these two programs was done through the use of a customized program that converted queried tabular data into AutoCAD™ spatial data. The concept is the similar to using a GIS to inventory and query tree data. The Lindhult study listed several reasons for an urban forester to use a computerized system for managing trees (Table 2).

***Table 2**. Reasons to Use a Computerized Tree Management System*

1. Locating trees that need removal and replacement.
2. Coordinating a multitude of tasks dealing with the management of individual trees.
3. Preparing budgets, reports, and work orders.
4. Answering specific requests by the general public.

(Lindhult, 1987)

There are several benefits of having graphic capabilities in a tree inventory database (Table 3). These benefits would also pertain to the use of a tree inventory GIS.

Table 3. *Benefits for having Graphic Capabilities over Tabular data*

1. A specific site or area can be zoomed to provide detail as required to check and answer questions about specific trees.
2. The forester can visually identify trends or patterns in tree conditions through the graphical representation of data.
3. Strategies can be mapped for work scheduling.
4. Any information contained within the database can be viewed spatially including specific species distributions, diameter distributions, etc.

(Lindhult, 1987)

The Lindhult study concluded that computerized tree management systems would soon play an important role in urban forestry. Lindhult suggested that a forester could focus more on the problems and challenges of managing a forest than on the manipulation of tree data. Lindhult used a combination of tabular (DbaseIII) and graphical (AutoCAD™) systems to manage the maintenance of trees throughout a management area. He also used the system to present reports and calculate budgets.

CITYgreen: GIS is being slowly integrated into urban forestry management. An example of this can be found in the GIS application called CITYgreen. CITYgreen is a software application developed by *American Forests* that has been used to map and analyze the environments surrounding street and neighborhood trees. Other uses of CITYgreen include the ability to track and model percent canopy coverage, water runoff and heat effects over neighborhood areas. The system combines the tools of ArcView™ GIS with modules designed to track and analyze ecological factors throughout a community.

GPS Accuracy in Locating Trees: The ability to locate individual trees and represent them spatially is a very important concept for an accurate and useful computer tree inventory. Many methods have been used in the past for locating individual trees. One method includes using hard copy orthophotos as maps to locate individual trees. Another method uses a grid system overlaid on a map to assign X and Y coordinates to each tree. A third method was explored in a study done by Kane and Ryan (1997). It tested the reliability of using a Global Positioning System (GPS) for locating trees. GPS is a positioning system that employs the use of 24 satellites (3 are spares), that continually orbit the earth, sending radio signals to receivers on the ground. The receivers use radio signals from at least four satellites at any time to locate a position on earth. GPS receivers can be used to find the position of a tree along with information describing that tree. Depending on the model of GPS receiver, information such as species, diameter, height, etc. can be tied to individual data points through a keypad.

Instead of searching for individual trees with aerial photos and digitizing the resulting maps, information can be input directly into digital form using a GPS. There is no tedious transcribing of data from written field notes into a database and then connecting this information to individual trees. All data input is done in the field as the data is collected. However, there are drawbacks and benefits to both methods. One of the biggest differences in using a GPS in lieu of aerial photos is that a clear signal must be received with a GPS to collect tree positions. Reducing interference caused by buildings, clouds, tree canopy, etc., is necessary to obtain accurate positioning data. Also, GPS requires that post-processing be carried out on the data points (in cases without a real-time differential correction GPS). Post processing is required because of selective availability and other errors introduced into the system. This error is very significant and can cause the reported position of points to be inaccurate with errors as large as 328 ft. Differential correction of these data points requires the use of a base station. A base station is a GPS receiver whose location is already known. After points are taken with a rover GPS receiver, the data is compared to that received by the base station and corrected according to the error measured from the base station's own position (Kane and Ryan, 1997). Other factors affecting the use of a GPS include the cost of training a person to use the GPS. Many GPS systems are fairly complex and will take some training to be able to use. The cost of GPS equipment is also fairly prohibitive if orthophotos are already available. Another consideration is in the additional time it takes to receive an adequate signal for accurate positioning data. Sometimes it takes a little longer to acquire a good signal for accurate data, making the inventory last longer than it would if the data was simply transcribed. Tree measurement equipment is cumbersome, but when GPS equipment is added to this load, it makes the process of measuring trees go much slower. These factors are being minimized every year due to better engineering of the GPS receivers, but for tree inventory purposes in urban areas the benefits do not outweigh the costs of using a GPS at the present time.

In the GPS study by Kane and Ryan, aerial photos (when available) were found to be significantly more accurate in locating individual trees than using a GPS. They found the GPS to be time consuming and unpredictable in consideration of the interference caused by previously mentioned factors. They did, however, appreciate the GPS when locating trees that were off the set path and required a great deal of hiking to find. They concluded that when accurate maps are available to locate trees, they should be used in place of the GPS, but when aerial photos are unavailable, then a GPS can be very helpful (Kane and Ryan, 1997).

Measuring Tree Relationships to Powerline Maintenance Costs: Abbott and Miller (1987) developed a system of predicting approximate person-hours needed to complete a tree maintenance task based on three factors. The three factors included: the size of the tree, the National Arborist Association (NAA) Standard Pruning Classes, and the variable factors surrounding the tree which would influence job time. The NAA Standard Pruning Classes were developed as standard descriptions for use in writing tree pruning contracts. The following summarizes the procedure used by Abbott and Miller to make estimates. Before making a tree care time estimate, a contract foreman would measure the tree's diameter at breast height (DBH) and pruning class. Pruning classes are based on the four NAA classes found in Table 4 (Grey, 1996).

***Table 4**. NAA Standard Pruning Classes*

Class I: Fine Pruning: Removal of dead, dying, diseased, interfering, objectionable, and weak branches on the main trunk and within the crown, allowing for an occasional branch up to .5 inch in diameter if not practical to remove.
Class II: Medium Pruning: Same as Class I, except for allowance for an occasional branch up to 1 inch in diameter if not practical to remove.
Class III: Coarse Pruning or Safety Pruning: Removal of all dead, diseased, or weak branches greater than 2 inches in diameter.
Class IV: Cutting Back or Drop Crotch Pruning: Reduction of tops, sides, under-branches, or individual limbs in situations of utility lines, unusual growth, excessive size, or severe root loss.

(Grey, 1996, pp. 89-90)

After measuring these two variables, the foreman could use a chart developed by ACRT Environmental Services Inc. to predict the baseline time needed to remove or trim the tree. For example, from past tree trimming, the estimated time for trimming a 30 inch DBH tree required 5.2 person-hours on the average for the same NAA pruning class. The foreman then adds variable times to the baseline time using a system also developed by ACRT. Variable times are those external factors that influence the time needed to complete a tree trimming or removal job. Variable times are summarized in Table 5.

Table 5. *Factors Directly Affecting Labor Hours Needed to Complete a Trimming or Removal Operation.*

	Factor	% Increase in person-hours
1.	Electric wires at outside edge of tree canopy	10
2.	Electric wires halfway between edge of canopy and tree trunk	20
3.	Electric wires near trunk of tree	40
4.	Tree within 25 feet of building	20
5.	Tree within 5 feet of building	40
6.	High Traffic –flag person necessary, part-time	25
7.	Medium Traffic –flag person necessary, full-time	50
8.	Brush and wood must be dragged from backyard for chipping	100
9.	Major decay affecting 30-50% of trunk area	20
10.	Extensive decay affecting 60-90% of trunk area	50
11.	Thick tree canopy	20
12.	Client desires firewood length logs (stacked)	10
13.	Deadwood in 25 to 50 percent of tree canopy	25
14.	Deadwood in more than 50 percent of tree canopy	60

Interpreted from Abbott and Miller (1986).

By taking the baseline person-hours and adding the percent difference from variable factors on Table 5, an estimate can be made of the time needed to do tree removals. Other factors that are added to a complete job estimate include job assignment time (fixed), travel time (which is variable dependent on location), and work site organization time (fixed).

Another study done by Churack et al. (1994) projected maintenance costs of street trees in Milwaukee based on their species and diameter growth. Several species were selected as representative of the street tree population including honeylocust (*Gleditsia triacanthos)*, green ash (*Fraxinus pennsylvanica*), little leaf linden (*Tilia cordata*), and

Norway maple (*Acer platanoides).* Maintenance times and growth rates were measured for each tree within each two-inch diameter class. Regression analysis was done to measure the relationships between pruning time versus diameter, waste wood stack time versus diameter, waste wood yield versus diameter, and average annual diameter growth versus diameter.

The regression showed that all of the selected species studied showed a predictable increase in time needed to maintain them as they got older and larger. All species averaged an increase of six minutes of maintenance time for each inch of diameter growth (r squared = .9997). The specific relationship found in the regression includes the following: Y=-15.12 +6 (X) where X equals the diameter in inches and Y equals the time needed to trim the tree in minutes. Of the species studied, honeylocust needed the most maintenance per year of growth with average times significantly higher than that of any other species. This was attributed to this specie's need for more corrective pruning and its higher specific gravity. Above the 8-inch class, the honeylocust pruning times increased more rapidly than the other species (Churack et al, 1994).

Creation of a Utility Line Tree Maintenance Plan: Simpson and Van Bossuyt (1997) reported on a study done by Environmental Consultants, Inc. (ECI) which combined the efforts of 14 utility companies in the United States and Canada to analyze tree related outages and determine their major cause. The Brockton territory of the Eastern Utilities Company in Brockton Massachusetts participated in the study, and consequentially changed some of their own management schemes according to the findings. The Simpson and Van Bossuyt study consisted of three different measurements

They grouped questions on the survey into several categories including the following: cause of the outage, characteristics of the tree surrounding environment, orientation of tree to electrical conductor, weather conditions at the time that the outage occurred, components and design of the electrical system at the site of the outage and also whether the outage was preventable or non-preventable (Simpson and Van Bossuyt, 1996). The authors concluded that preventable and non-preventable outages were mostly caused by the growth of tree limbs back into electric lines (25%), and preventable outages alone were caused mostly by tree failures (40%). After learning this, a four year trimming cycle was implemented in Brockton resulting in a tree outage decrease of 11%, making the outage rate equal to about 10%, which is the industry standard for acceptable number of outages caused by trees (Simpson and Van Bossuyt, 1996).

A tree inventory was conducted in an area of the Brockton territory of the Eastern Utilities system to provide additional information. The study area consisted of approximately 300 square miles. The objective was to locate trees with the characteristics that presented the greatest risk to distribution circuits. The results of the inventory indicated that almost 20% of the trees surveyed showed some significant potential for causing an outage (Simpson and Van Bossuyt, 1996).

The third measurement was an analysis of the outage history throughout the Brockton territory and examined the years between 1989 through 1994. The objective of this analysis was to find the circuits that were most prone to having outages. The results showed that seven of the circuits represented 40% of the outages experienced (Simpson and Van Bossuyt, 1996).

The Danger Tree Mitigation Project began in January 1995. This program focused on the Brockton Territory system. The program consisted of changing the current trimming regime to a four year trimming cycle. Some of the additional changes made to their system included less trimming of growth beneath the lines and more trimming from the side. This system was based on the belief that less outages are caused by underneath growth. Trimming practices were also changed as a result of the Simpson and Van Bossuyt study. Suckers (shoots from past trimming cuts) are now cut in half, instead of being completely removed. This method of trimming slows down shoot growth and prohibits new suckers from forming.

A large part of the Simpson and Van Bossuyt study also dealt with communication within the community. Goals and guidelines for communicating with neighborhoods that contained trees that were identified as dangerous to the electrical lines were established (Table 6).

Table 6. Guidelines for Communication with Communities

1.	No viable tree will be removed unless requested by its owner or the designated community representative.
2.	Structurally unsound trees are considered a potential hazard to a public roadway and a financial liability to the community and are considered for removal.
3.	Collaboration is preferred for mitigating mutual hazards to the powerlines and public roadways.
4.	Percentage of trees removed should always be very small portion of the total tree population.
5.	Storm-proof pruning is used to improve the health and aesthetics of a tree.
6.	Commitment to urban forest renewal through tree planting is necessary.

(Simpson and Van Bossuyt, 1995)

From the Simpson and Van Bossuyt study it is shown that surveying the conflict that exists between utility lines and trees can have a significant impact on how a system is managed.

Utility Line Trimming and Its Effects on Trees: Trimming often stimulates faster shoot and sprout growth in many species. Therefore, trimming practices have a direct effect on trimming frequency. Sprouting occurs when a branch stub is left to produce new smaller branches at the end portion of a stub. After trimming the end from a branch, dormant buds within the branch become active. Normally, hormones released from the apical bud (the terminal bud) of a branch suppress the dormant buds. By removing the apical bud, the dormant buds are released. Growth rates of sprouts is very rapid and in most cases will exceed the normal growth rate of a branch. If trimming is done correctly, sprouting on the ends of branches can be minimized.

Shigo (1990) suggests several methods for reducing shoot growth on trimming cuts, including not cutting into the branch collar (the bark ridge where the branch intersects the trunk). Causing damage to the branch collar or completely removing it will cause profuse sprouting. Another suggestion is to remove entire branches that grow toward powerlines instead of trimming them back leaving a long stub that will also readily sprout. When removing existing sprouts, Shigo suggests not cutting into the ring of living tissue surrounding the sprout base, but instead cutting the top portion of the sprouts which he calls "the elites." In this way sprouting will be suppressed because the sprouts themselves will loose apical dominance and be forced to either grow slowly or die.

<u>1995 PSO Study</u>: Sprouting is more predominant in some species than in others. In addition, growth rates of sprouts can also differ. Cassada (1995) conducted a study for the Public Service Company of Oklahoma (PSO) which focused on the growth rate of sprouts after an initial trimming of a tree. Characteristics in sprout growth along PSO powerlines were determined by species and also by the kind of trimming done. Cassada (1995) separated the regrowth of two different types of trimming and analyzed them separately. The first kind of trimming was identified as "top trimming" which is trimming of trees directly underneath a powerline. It is by far the most damaging type of trimming both physiologically and aesthetically to the tree. In most cases complete removal of the tree is preferred over this type of trimming. In the top trimming category Cassada found that species averaged over 145 inches (12.08 ft) of regrowth during a five-year period across all regions of their distribution system.

The second category of trimming was side trimming. Side trimming is the trimming done on the side of a tree next to the power line to encourage its growth away from the line. In this category they found that species averaged over 142 inches of regrowth during a five year period across all regions of their distribution system. Overall, they found that top trimming significantly increased regrowth of several species including silver maple, hackberry, and mulberry, which are all known to be very prolifically sprouting trees. In analyzing the data, regrowth was grouped by PSO divisions and surprisingly little difference in regrowth amounts between the different areas were found. Rainfall and site condition differences had little affect on the ability of the trees to grow back into the lines in a fairly uniform manner. Total species distribution was evaluated along with species distribution by diameter class. Four separate diameter classes all of which were measured in inches were used in the study including 0-4, 4-8, 8-24, 24+. Poor trimming was also noted and resulted in 5%-30% more growth than those trees of the same species which were properly trimmed after a four year cycle (Cassada, 1995). Based on Cassada's study, a list of guidelines were developed for PSO line maintenance contractors. Each species has a recommended trimming length within PSO guidelines. This was done to ensure that the minimum amount of trimming would be done for the maximum trimming effect.

The Debate Over Line Clearance Needs: Infrastructure has long been a word associated with streets, sidewalks, electric poles and lines, but really never used to describe trees. To do so would be to place a value on trees and make trees a necessary and essential urban structure. Currently, utility companies do not have this level of appreciation, putting them at odds with a growing number of people who find great value in trees. Carlinsky (1992) believes that extreme tree trimming is not necessary for the reliability of electric service. Mr. Carlinsky lives in Connecticut, and in 1992 he lost a large very healthy American elm in his back yard to a line clearance contractor. Mr. Carlinsky admired and valued the tree and subsequently sued for damages.

Many of the unhappy customers that have suffered some loss due to trimming and removal operations have one very common characteristic. They were not asked if they would like the tree to be removed, or presented with any options. When people are included in a decision process they become much more agreeable to the suggestions they are presented (Ehlen, 1998 personal communication).

Factors such as the overall aesthetic impact to neighborhoods should be projected and proposed before trimming is started. In this way public relations efforts such as planting neighborhood tree replacements (more suitable for under power lines) could be done. Meetings with neighborhoods could occur to inform and educate people about the need for trimming in their area before trimming starts. Information could then be presented to justify the necessity of the trimming.

Alternatives to Line Clearance: Burying aboveground lines would seem to be a reasonable alternative, but unfortunately conversion from aboveground lines to below-ground conduits is not that simple. Underground lines cost 10 times more than aboveground lines. The materials are more expensive, because they are designed to be able to stay underground for a very long time (Goodfellow, 1995). Also, since upgrading underground lines is very difficult, the lines are engineered to handle future electrical loads, unlike aboveground lines which are much easier to upgrade. Other issues which effect this type of conversion include the costs of widening existing easements, working with other utilities to coordinate underground conduit construction, and most notably the cost of "site restoration" after trenches have been dug through established trees, landscaping, and paving (Goodfellow, 1995).

Goodfellow (1995) describes some further alternatives to aboveground line construction to reduce the effects of tree-related disturbances on powerlines. Every time a tree touches an "energized conductor" or a line, it causes a short to occur because the tree is grounded. By reconfiguring where the lines are situated on open construction (bare wire and cross-arms) interaction can be decreased. For example, Goodfellow suggests that in some instances the alteration may be as simple as moving the neutral wire from the bottom of the cross arm to the top. Or, alley arms can be used, which are L-shaped in configuration and suspend all system lines fully on one side of the pole. Of course, this may also require the installation of additional guy lines for support.

"Compact construction framing" is another system configuration described by Goodfellow. It compacts all three lines into a smaller space around the pole. This could be helpful in shortening the clearance required to keep this line safe, but can also pose a hazard in causing phase to phase outages encouraged by small branches bridging the gap between conductors.

"Covered overhead primary" (COP) is another alternative. Although it poses no great difference in the amount of tree maintenance needed along a line, it does offer limited insulation capabilities not available in the bare wire systems. This insulation coating provides some amount of protection from outages, but not enough to guarantee them "tree proof."

"Spacer Systems" are another alternative method of line configuration. They are manufactured by Hendrix™ and are a combination of the "covered overhead primary" and "compact construction framing" systems. The insulated wire combined with the compact design offers increased benefits to tree trimming operations in both decreased clearance space and in thicker insulation covering than typical tree wire. The increased insulation properties can, however, cause problems to the power system in that utilities might not be able to tell that a wire has been downed and therefore the chances of having downed and energized lines are much greater than with typical bare wire lines.

The final alternative discussed by Goodfellow is the "aerial cable systems" which are made of the same materials as underground systems except they are placed aboveground. The costs associated with putting lines underground is negated, but the material costs of this type of line are still much greater than standard aboveground lines.

The Current Standard of Line Clearance work: Currently, there is one nationally accepted standard for line clearance of trees, but no nationally accepted trimming methods. The minimum required clearance for any electrical conductor is 10 feet (ANSI Z133.1-,1994). Specific standards dealing with the distance required for the amount of "work space" needed around an electric line are found in Appendix J. These are the

Another type of bidding is called unit price. It is defined as a contract which established fixed costs per production unit (Goodfellow, 1985, p. 116). The third variation of bidding is called fixed price bidding. It is defined as contract establishing a cost for the completion of an entire project. Fixed-price bidding has the effect of making operation run more efficiently. Cost savings have proven to be at least 20%-30% on fixed-price bids (Goodfellow, 1985, p. 116). With this type of bidding the contractor has complete control over the trimming operation, and it is to the contractor's advantage to make the project as short and efficient as possible. In the study done by Goodfellow (1985) the Wisconsin Public Service Corporation (WPS) went from supervising operations on a daily basis to periodic project reviews (Goodfellow, p.117, 1985). The task of writing specifications for a fixed price bid in an urban situation is difficult because it is very hard to quantify exactly how much work there is to be done. At the time of the bid there may be question as to how many of the trees are removals and how many are trims only. WPS suggests fixed bidding only those jobs where you know it is either all trimming or all removing in a particular area. They also suggest not doing fixed bids in areas where customer complaints are likely to require more on site supervision. This kind of situation defeats the purpose of having a fixed bid.

Public Relations Options: Utility line managers in Kansas found that an effective tree replacement program can be a very valuable tool in increasing public support, public awareness, and in reducing tree trimming needs. Twelve hundred trees were replaced in 23 communities with more suitable species introduced under powerlines (Reason, 1991). Average cost of individual tree trimming in Kansas is $18-$20 per tree with an average of $50 per tree spent to replace each tree removed. Costs for this program were initially expensive, but estimates indicate that they will recoup this expenditure within a 3.3 year period (McGillivary et al., 1996).

In 1997, the Stillwater Tree Board (a citizen advisory board for the City of Stillwater) began a Tree Replacement and Removal program. Removal of significantly sized trees (larger than 4" DBH) is encouraged through an incentive to have the tree replaced. The City of Stillwater gives program participants a $50.00 voucher for each tree removed from underneath a powerline (limited to 5 per resident). It has been a fairly successful program in reference to individual tree removals with a total of 61 vouchers being given since the beginning of the program. However, in reference to the overall tree-trimming problem, it has been mildly successful. Instead of doing replacement programs on an individual basis, a GIS could be used to locate large areas that would be suitable for this type of proposal. Instead of approaching individuals for replacements, the utility could approach whole neighborhoods with the incentive of planting several large trees within more suitable areas (neighborhood parks, tree lined streets etc.).

CHAPTER III.

Utility Tree Management in Stillwater, Oklahoma

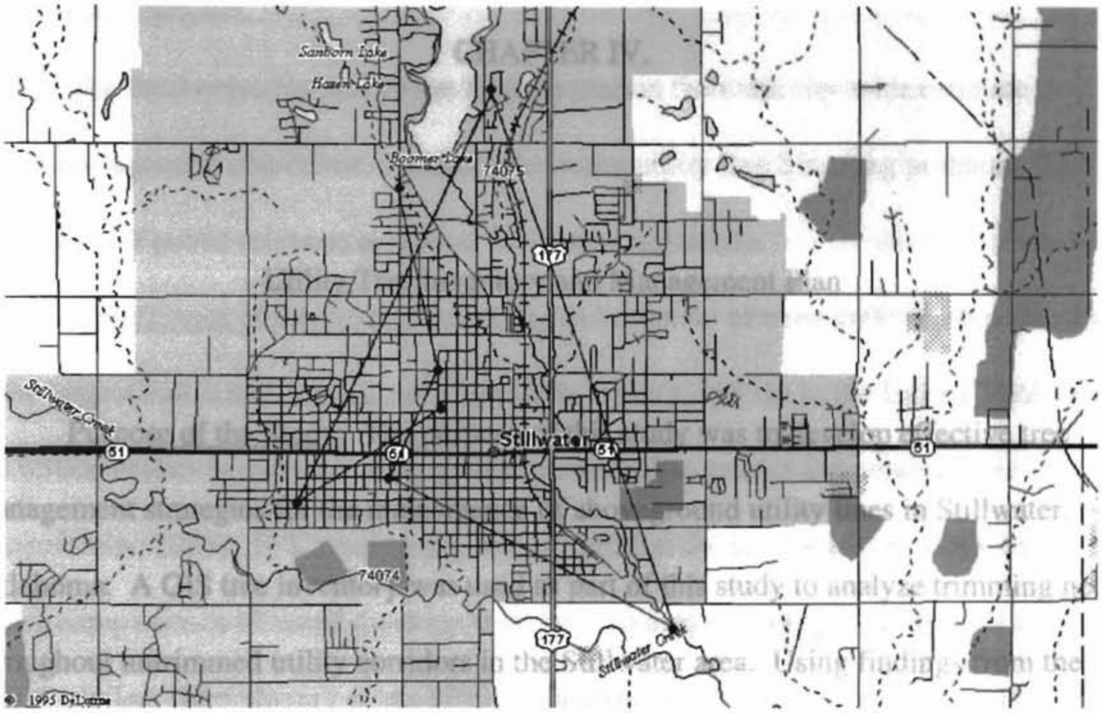
Stillwater Electric Utility (SEU) is a municipally owned electric company that provides electric service to over 38,000 people in Stillwater, Oklahoma. Approximately 250 miles of utility lines are managed and maintained by SEU. Gauging the level of tree /utility line conflict for SEU has been limited to visual estimates from clearance contractors. There is no established trimming cycle in Stillwater, and no long-term planning or inventory of these areas to project needs in terms of budget, or for measuring efficiency of current and future line clearance contracts. SEU currently spends $450,000 (1998 /1999 budget year) per year on trimming and removal costs. A majority of this is spent on "hot-spotting" methods of removal and trimming.

Hot-spotting is a term used to describe trimming and removal activities, that occur in specific areas having a particularly great need for trimming or removal. These areas usually have chronic outage problems or are due for pole or line replacements (Cassada, 1995). The crews that do this kind of trimming have no set trimming cycle and they are managed on an "as-needed" basis. This sort of management takes place to some degree in all management schemes because of emergency situations, and it is estimated that at least 20% of all normal utility line clearance operations deal solely in this type of activity

(Ehlen, 1998, personal communication). It is, however, a much more intensive style of management and increases costs in terms of transportation to different sites, and in overall effectiveness. Trimming operations which decrease hot-spotting actually increase efficiency (Ehlen, 1998). However, many operations currently do not have the option of changing their management because they are stuck in a "hot-spotting loop." Many times those operations who use a majority of hot-spotting to manage their entire system will suffer because the more they hot-spot, the more they have to trim. Control is never reached because the time spent going from one very needy situation to another is time that the trees will use to overgrow back into areas which have been neglected, thereby creating more outage problems. The more hot-spotting that is done, the more hot-spotting is needed. Unless additional management is used to change the crews from hot-spotters to cycle trimming, the problem intensifies.

Figure 1 shows the movement of one individual contract crew across Stillwater during a two-month period. This map demonstrates that SEU has no predetermined trimming cycle. Crews tend to move from place to place randomly as directed. This is because they are currently overwhelmed with trimming needs. They also have no way of knowing how much trimming there is to do at any particular time, and emergencies and line construction often demand most of their time.

Figure 1*. Single Crew Movements through Stillwater from 7/1/98 to 8/30/98*



CHAPTER IV.

Utility Tree Inventory and Management Plan

<u>Purpose of the Study:</u> The purpose of this study was to develop effective tree management strategies for the maintenance of aboveground utility lines in Stillwater, Oklahoma. A GIS tree inventory was used as part of this study to analyze trimming needs throughout untrimmed utility corridors in the Stillwater area. Using findings from the inventory, an estimate was made of trimming needs throughout Stillwater. Methods were also discussed for starting a trimming cycle in Stillwater. Other strategies addressed in this study focused on public relation aspects of utility line tree trimming, specifically along utility corridors adjacent to major roadways or very visible areas, including the replacement of suitable tree species after large tree removals.

<u>Objectives of the Study:</u> The first objective was to develop a method for evaluating the level of conflict between trees and SEU utility lines. There is currently no standard way of measuring the amount of conflict between a tree and a utility line. The method developed by this study is referred to as the Conflict Evaluation Model (CEM). It was used in combination with the tree inventory to determine how much time is necessary for trimming.

The second objective of this study was to take the information gathered from the inventory and use it as a model for predicting trimming needs throughout the untrimmed portions of Stillwater.

The third objective was to use the information from the city-wide estimate to create management objectives to address the entire utility line trimming problem. This also included public relations problems and marketing needs.

Significance of the Study: Trimming and removal of trees underneath powerlines is the largest individual cost incurred by utilities (Perry, 1977). In the United States, over 1.5 billion dollars is spent annually by utility companies to trim and remove trees (Goodfellow, 1995). In Kansas alone, over 13 million dollars is spent annually by six utility companies to trim and maintain trees with an average cost per utility over two million dollars (McGillivary et al., 1996). Maintenance of utility lines is essential to providing reliable service to urban areas. The present study provides alternatives to the current methods of tracking and monitoring trimming progress throughout a management area. It will help utility managers find the information they need about an area before they make trimming management decisions. It will also help in determining proper budget estimates, contractor selection, and public relations programs.

Using methods from this study, costs can be calculated for a particular area's trimming without using bid estimates as the baseline information for determining costs. Conversely, money budgeted to trimming can be spent more efficiently by choosing those trimming projects that will utilize a particular budget amount. Diagrams can be made to show estimated costs of trimming management zones, demonstrating exactly what must been done and what could be done with allocated funding.

Also, this study method could be used to locate areas with severe trimming needs and to devise an efficient scheme for maintaining those areas.

Conceptual Assumptions: To estimate the total costs for trimming or removal operations, assumptions had to be made about the way trimming is normally valued. The only trees being considered are those that are currently in conflict with the lines, not future conflicts or "hazard assessments." The possibility of a tree located out of the immediate utility line area falling into a powerline was not accounted for in this study.

The trees in this study are all "large trees" i.e., larger than four inches DBH. Small trees (which represent future conflict with the line) were not considered. The next assumption involved the contractor working with conflict trees and not yard trees. The current line clearance contractor does do tree removals in yards at the request of SEU along with brush removal and some other services. These costs were not considered.

Scope and Limitations: The valuation method used in this study will require continual improvement. Costs will change as contractors become more efficient and as equipment needs change. Baseline costs will be customized according to what SEU and the contractor deem is suitable. Additional costs pertaining to time needed for individual tasks, however, should remain constant, and therefore the model developed for predicting costs should remain valid as long as baseline data is kept accurately. For example, Abbott and Miller (1987) showed that some costs are fixed while others are variable (Table 7).

Table 7. Fixed and Variable Factors Used to Estimate Tree Care Jobs

Task	Fixed factor	Variable factor
1. Job assignment, pick up tools, gas up equipment	X	
2. Travel time to job site		X
3. Work site organization, tools, traffic signs	X	
4. Actual work operations climbing tree, cutting branches for a particular size tree and pruning class	X	
5. Presence or absence of, traffic, buildings, fences		X
6. Clean up of work site, chipping brush, cutting up wood for a particular pruning class or activity	X	
7. Disposal of debris at dump site		X
8. Travel time back to crew headquarters		X

(Abbott and Miller, 1987)

Variable costs are those which will change on a project by project basis. Fixed costs are those which will stay the same (assuming that all site variable stay consistent). All of the fixed costs and most of the variable costs in this table have been included in the CEM (Conflict Evaluation Model). The fixed costs are those that are input by the CEM from the inventory done of the study area. Individual trees have been measured along with other obstacles that will influence the time needed for the fixed variables. The variable costs are those that will need to be added to the model estimate based on a project by project basis. Table 8 lists an example of an estimate made for a particular trimming job, taken from the study done by Abbot and Miller, (1987).

Table 8. Example of Person-Hour Estimating

Task	Factor	Person hours	Crew members	Person hours
1. Job assignment, etc.	Fixed	.5	2	1.0
2. Travel time	Var.	.75	2	1.5
3. Work site organization	Fixed	.25	2	.5
4. Medium prune 16" oak	Fixed	2.1	1	2.1
5. Medium prune 30" maple	Fixed	5.2	1	5.2
6. Clean up	Var.	.5	2	1.0
7. Disposal of debris	Var.	1.0	2	2.0
8. Travel time, etc.	Var.	.75	2	1.5
Total project time				14.8

Another limitation to this study is in the implementation of this type of system within the management infrastructure of the City of Stillwater. SEU does not have the technology or expertise needed for this is kind of system, so it could be very difficult if not impossible to implement. The City of Stillwater has the hardware to handle the GIS software, but not the software itself or equipment needed to develop an improved utility line management system. It is hoped that information presented by this study could serve to present options for improving the current methods used to track and analyze SEU utility line maintenance.

The scope of the study could also be considered a limitation. The scope was limited to a pilot project area chosen by SEU. The area represented approximately 3% of the entire SEU service area.

The future use of this study would be dependent upon the constant upkeep and maintenance of the system itself. It is noted that such a task might pose a very large hindrance in its overall effectiveness. It is very possible that the maintenance of the GIS system itself would require the addition of at least one staff member. However, personnel costs are not taken into account for this study. Further analysis of a working system would have to be done to determine feasibility of adding additional staff member.

Future tree conflicts also posses an arguable limitation to this study. After areas are trimmed, their conflict level is returned to zero in the database. Removed trees are separated from the database and kept as a record for a particular year's trimming. A growth model could then be used to "grow" existing trees back into the line continually within the database. The database itself could track tree growth and alert managers to the current changes and updates to the management plan according to ongoing analysis of the tree data. Unfortunately, this study does not include a current growth model. However, if a suitable trimming cycle can be implemented then "growing" the trees within the software will become a non-issue because all of the trees will be trimmed on a set cycle.

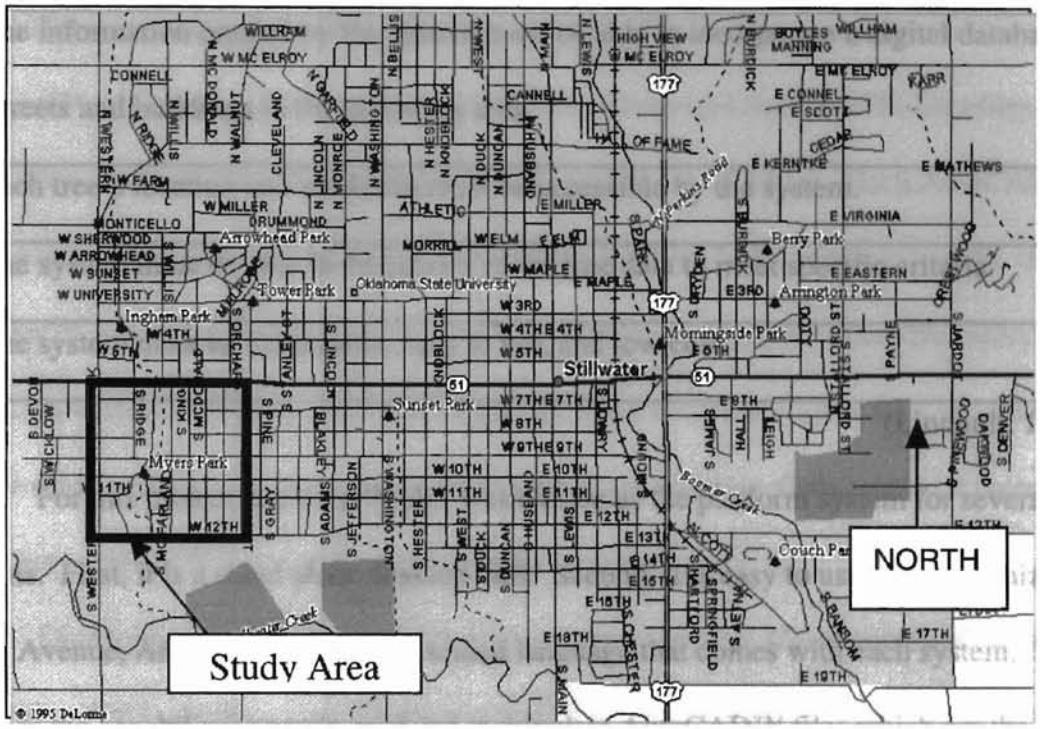
CHAPTER V.

Research Methodology

Selection of Study Area: The study area for this project was located in Stillwater, Oklahoma. Stillwater is a city in the north central area of Oklahoma approximately 65 miles north of Oklahoma City. Population for Stillwater is approximately 38,000 people. Land area for Stillwater is approximately 29 square miles. Stillwater is bordered by grasslands and plains to the north and west with more forested areas located to the east and southeast. The urban forest in Stillwater consists of very old elm, cottonwood, and hackberry trees planted in the 1930's along with many younger ornamental species such as silver maple, Bradford pear, crabapple, Chinese pistache, and lacebark elms. Oklahoma State University is located in Stillwater.

The inventory area for this study was located between Walnut St., N. Western Rd., 6^{th} Ave., and 12^{th} Ave. (Figure 2). It occupied one quarter section totaling 160 acres. SEU owns and maintains approximately 4.55 linear miles of overhead line through this area.

Figure 2. Map of Study Area



This area of town was selected because it is an older part of Stillwater and has some obvious tree / utility line conflicts. The study area was chosen with the help of SEU.

The GIS: To solve the problem of managing and tracking the trimming of the utility line corridors, several objectives for the system were created. Most of the criteria are very similar to those created in the Lindhult study. Table 9 summarizes the system objectives.

Table 9. Summary of System Objectives

1. The system must be able to identify trees that pose a serious threat to the utility lines.
2. The information created by the system must be able to incorporate a digital database of streets and buildings in the inventory area.
3. Each tree's location and attributes must be accessible by the system.
4. The system must be able to do queries of the tree data to meet specific criteria.
5. The system must be updateable, easy to use, and low cost.

(Lindhult, 1987).

For this project ArcView™ GIS was chosen as the platform system for several reasons. First, it is a stand alone desktop GIS. Second, it is easy to use and customize using Avenue, ArcView™'s object oriented language that comes with each system. It also has the capability to easily read and manipulate AutoCAD™ files which are the format for a majority of the basemap data used in this project.

Basemap Data: AutoCAD™ files were available for this study from the City of Stillwater GIS division. Each file consisted of one quarter section of Stillwater and contained layers of building footprints, streets, paved area outlines, section lines, lots, easement areas, land contours, tree group outlines, pole locations (power, lighting) and other important layers. These layers served as basemap data for locating houses, streets, electric poles, and individual trees in the study area (see Appendix F). The AutoCAD™ files did not, however, locate electric lines or electric easements, which were input separately into the GIS. Electric poles and easements were input using hardcopy easement maps supplied from SEU. Each line was drawn into ArcView™ by connecting the electric poles which already existed in the basemap data. A 60 ft buffer was then created for each line, representing the specific easement width. Buffers were created using the ArcView™ Spatial Analyst.

Transfer of Basemap Data into GIS: AutoCAD™ files were input into ArcView™ and converted from AutoCAD™ ".dwg" files into ArcView™ shapefiles or ".shp" files. AutoCAD™ files are layered very similarly to GIS files. Each AutoCAD™ file had to be separated and converted into a shapefile. This had a two-fold benefit. First ArcView™ stores and edits shapefiles much easier than AutoCAD™ files. Secondly, the AutoCAD™ files were very large in file size and came with more layers than were needed for this study including drainage areas, topography, and signage. Only pertinent layers were kept. Appendix A contains a listing of the data dictionary.

Development of the Conflict Model-Inventory Method: Components of the Abbot and Miller (1987) study and the Churack et al. (1994) study were combined to assist in determining approximate trimming times for the trees that were inventoried in the study area. The combination of these two methods compose the conflict evaluation model (CEM) for the present study. Costs were found by applying the contractor's trimming cost per hour to the time needed to trim each tree. Using the Churack et al. study as a reference, the diameter of each the tree was used in the following formula: $Y=-15.12 +6 (X)$ where X equals the diameter in inches and Y equals the time needed to trim the tree in minutes. The resulting time was used as the baseline maintenance time of each tree. Additional variables listed in the Abbot and Miller study were used to adjust the baseline time to account for additional site characteristics that would influence the tree trimming along with variables for removal. The additional variables can be found listed in Table 12.

The Tree Inventory: ArcView™ was used to find the trees which needed to be inventoried. A 50 foot buffer was created around each overhead line. The buffer was then overlaid on the tree line and individual tree layers which existed on the basemap data. Each tree that intersected the buffer was included in the area to be inventoried. Maps were printed of the selected trees, building footprints, streets, and lines. Each tree was measured for the characteristics listed in the table found in Appendix G with additional variables in Appendix H. The tree measurement data was written on inventory sheets and each tree was given a unique identifying number. An example inventory sheet can be found in Appendix B. The number was placed on the map of the inventory area symbolizing the approximate location of each tree.

Other Measurements: Along with tree measurements, other measurements were taken such as the existence of heavy brush and the exact location and type of powerlines that were situated around the trees. Also the date of measurement was input separately. This variable served as the temporal dimension within the GIS. Each year that the same tree in the inventory is trimmed, the same measurements will be taken of the tree. In this way the growth of the tree can be tracked, and specific amounts of trimming and removals can be evaluated on a yearly, monthly, or weekly basis. Using the query builder in Arcview, a list of trees can be found in the order that they were trimmed. Weekly, monthly, and yearly totals can be obtained by querying for those dates that correspond to the period in question. If a tree is removed, it will be separated from the current tree database and kept in a yearly removals shape file. A new removals shape file will begin after the start of a new fiscal year

In the same way, reports can be generated to list those trees which need to be trimmed. Using the query builder in ArcView™, the trees which have not been trimmed within a three year trimming cycle can be selected out of the data base and printed in a report and a map. To assist in locating trees addresses can also be attached to each tree based on its proximity to existing property lines. The inventory of the study area was done over a six-week period. A total of 799 trees were surveyed.

Transfer of Data Into the GIS: All of the inventory data was then transferred into ArcView™. Trees were represented by a point layer or "theme." A "theme" is the name given to the data layer format in ArcView™. Themes can be represented as polygons, points, bitmaps, lines, polylines, and others. Each tree was represented in its appropriate location and connected to tabular data describing all of the information taken in the inventory. Table 10 is an excerpt from the tabular data.

Table 10. *Tabular Data Excerpt from Tree Inventory*

TRE = Tree unique identifying number
DIA = Diameter of tree in inches
SPECIE = Species of tree
LINDIS = Trunk distance from line (ft)
CONF% = Percent of Crown under line

HT = Height of tree in feet
IN_OUT = Tree exists in or out of fenceline
LINTYP = The kind of powerline next to tree
CONFLev = Conflict level
COND = Description of tree condition

TRE	DIA	SPECIE	HT	IN_OUT	LINTYP	LINDIS	CONFLev	CONF%	COND
1	6.0	cedar	15	in	3	4.5	0	0	
2	6.0	cedar	15	in	3	4.0	0	0	
3	6.0	cedar	15	in	3	4.5	0	0	
4	6.0	cedar	15	in	3	4.5	0	0	
5	18.5	pine	40	in	3	15.0	1	1	
6	14.0	pecan	30	in	3	10.0	2	25	
7	6.0	plum	20	in	3	2.0	0	35	dead/dieing
8	22.5	ash	30	out	3	22.0	0	50	
9	10.5	pine	30	out	3	5.0	0	1	
10	34.0	oak	50	in	3	15.0	1	5	
11	6.0	hackberry	25	out	3	0.0	3	100	
12	34.0	oak	50	in	3	15.0	0	0	dehorned

Additional Site Variables Added: Using the buffering capabilities of the GIS, three individual layers (themes) were created to locate those trees within close proximity to buildings. An important variable in determining time needed to remove or trim a tree is found in the tree's proximity to any building. Trees were selected from the tabular data that were between 0.0- 5.0 ft. and 5.1-25.0 ft. of a building. The next additional variable added was the brush layer. Removal of brush adds a great deal of time to the trimming or removal process. To add this factor into the model, the brush areas, which were located during the inventory, were given a 10-foot buffer. The buffer was then used to select those trees affected by the brush. The final additional variable added to the GIS was a traffic count layer. This layer was added using the "Street Centerline Layer." Traffic counts were added to account for the additional time necessary for a crew member to direct traffic around the chipper truck and work area. Traffic counts under 3,000 vehicles per 24 hours (V/24hrs) were given a "low" designation. Those under 10,000 (V/24hrs) but over 3,000 (V/24hrs) were given a "medium" designation. Those over 10,000 (V/24hrs) were given a "high" designation. Trees were again selected and given the designation of "high," "medium," or "low" using a 100 ft buffer around the centerlines of each road. Another derived variable was the delineation of fast, medium, and slow growing tree species. This variable assigned a value to each tree based on its categorization as a fast, medium, or slow growing species of tree. Using this variable, trimming precautions can be taken to ensure that fast growing species of tree are trimmed carefully to ensure adequate clearance in consideration of their faster growing rate. Also, removal and replacement efforts can be concentrated in area with high numbers of fast growing species of tree.

The Implemented CEM: Measurements from the inventory corresponded with variables used in the CEM. Table 11 shows each measurement and its corresponding variable. Approximate tree removal and trimming times were calculated using the coefficients assigned to the variables in Table 11. Most coefficients were derived from the study done by Abbott and Miller (1987). Coefficients were used to adjust the baseline trimming time based on the site characteristics measured during the inventory. They were multiplied times the baseline time as percentage increases, thereby increasing the overall trimming time for each tree.

Table 11. *Variable Description Table Derived from Abbot and Miller (1987)*

Measurements taken during inventory = measurement which were taken from the study area
Variable Derivation = the range at which each measurement was used
Coefficient = the number which is multiplied times the baseline trimming time to adjust it for the additional variable measured in the field

Measurement Taken During Inventory (partially derived from the Abbott and Miller Study)	Variable Derivation	Coefficient
Electric wires at outside edge of tree canopy	Conflict percent 30% or less	.10
Electric wires halfway between edge of canopy and tree trunk	Conflict percent 31%-60%	.20
Electric wires near trunk of tree	Conflict percent 61%-100%	.40
Tree within 25 feet of building	Trees selected through the calculated Buildings buffer	.20
Tree within 5 feet of building	Trees selected through the calculated Buildings buffer	.40
High Traffic –flag person necessary, full-time	Trees selected through the calculated Centerline buffer	.5

Medium Traffic –flag person necessary, part-time	Trees selected through the calculated Centerline buffer	.25
Brush and wood must be dragged from backyard (fences in or out counted here also)	Trees selected through the calculated Brush buffer	1.00
Deadwood in 25 to 50 percent of tree canopy	Condition of "almost dead" or "topped"	.25
Deadwood in more than 50 percent of tree canopy	Condition of "dead"	.60
Designated tree removal	If the condition = "dead" and conflict percent is greater than 1 – or input as a removal after the removal is done	.00
Travel Time	Variable input as job site is defined	variable
Conflict level 0	NAA defined pruning class = I	..25
Conflict level 1	NAA defined pruning class = II	.5
Conflict level 2	NAA defined pruning class = III	.75
Conflict level 3	NAA defined pruning class = IV	1.00
Growth Rate 1	If the tree is a slow growing species, it is given a 1	0
Growth Rate 2	If the tree is a medium growing species, it is given a 2	.10
Growth Rate 3	If the tree is a fast growing species, it is given a 3	.20

Time of Measurement	Date variable input for each time a tree is measured or maintained	no coefficient
Client desires firewood length logs (stacked)	Input after trimming is done as a "yes" or "no"	1.00

To determine the total amount of time needed to remove or trim any tree in the inventory, all of the coefficients are combined and applied to a the baseline time. The basic formula for deriving trimming time is found below.

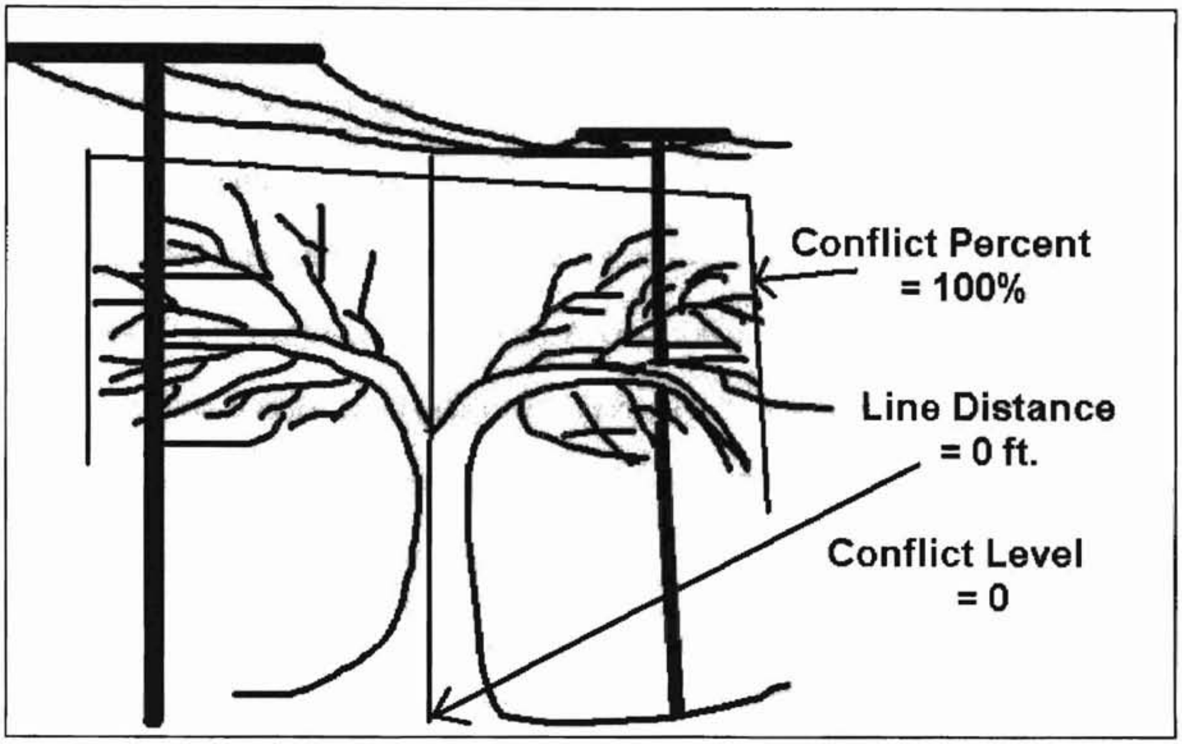
Formula for Trimming time = (-15.12) + ((diameter of trunk in inches) x (6 minutes of trimming time per inch diameter))* x (the tallied coefficients + 1) = (the number of minutes needed to complete the trimming of the tree) / (60 minutes per hour) = (hours to complete tree maintenance).

* = Formula from Churack (1987).

Example of Formula Use = ((-15.12) + (10 in. diameter tree) x (6 min./ in.)) x ((.10 (conflict% = 30) + (.40 (tree within 5 ft of building)+1) =67.32 min / 60 min per hour = 1.12 hours.

Research Design Considerations: Conflict, as it is used in this study, can be defined by several factors surrounding each tree. Size, height, and distance to the line do not necessarily determine the conflict level of the tree. If a tree is properly pruned so that it grows away from the line, it is possible to have a very large tree next to the line and pose no conflict. This means that the tree in Figure 3 posses no conflict with the line (assuming it is a healthy and live tree). It is, however, possible for the tree to eventually grow back into the line at a future date. Percent conflict, line distance, and conflict level are unique measurements designed to simulate the characteristics important to tree trimming near utility lines. See Figure 3 for additional information.

Figure 3. *Measurements used to Simulate Characteristics Critical to Tree Trimming*

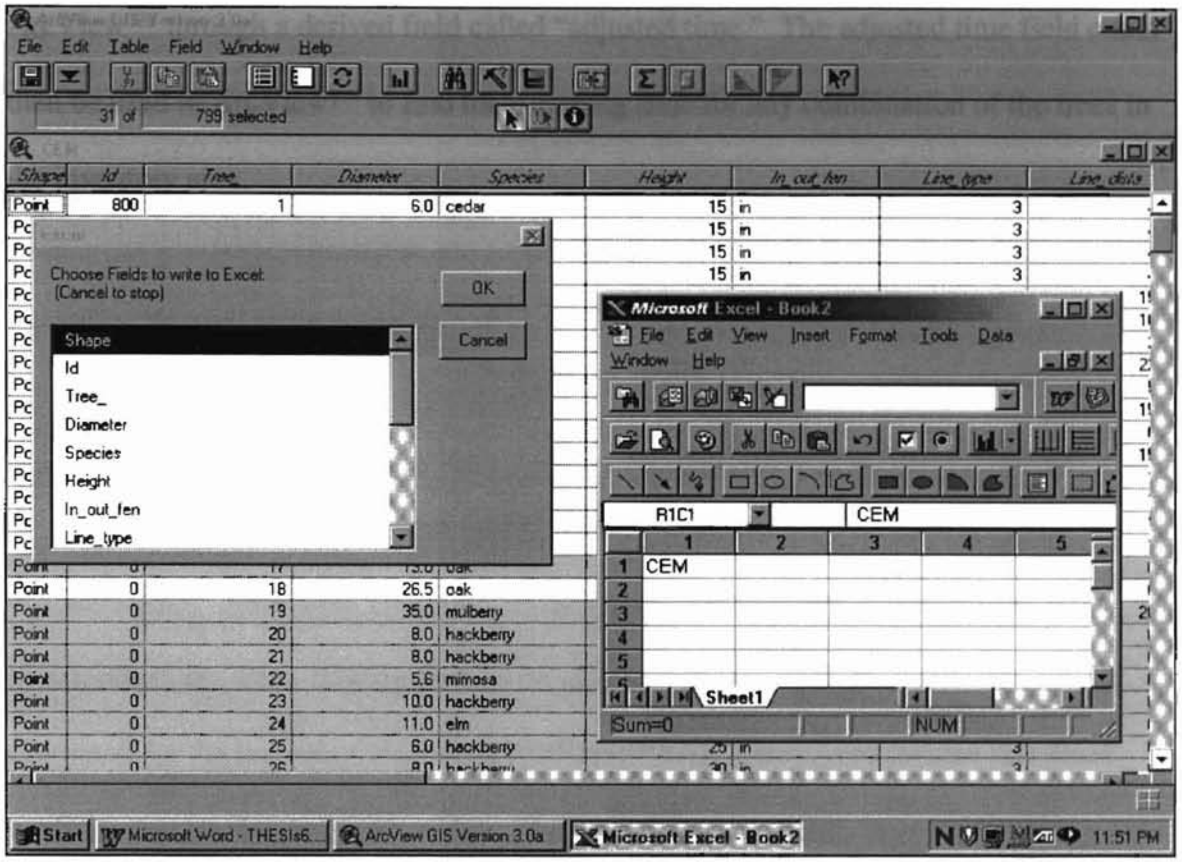


<u>Using the GIS to Implement the CEM</u>: After the tree measurements were found, they were input into the GIS. A point layer was created in ArcView called "combined." It represented the trees in conflict with the utility line. Points were drawn into the "combined" layer from the inventory maps locating each tree. A tree ID attribute was added to each point as it was drawn. The tree ID corresponded to the unique identification number used during the inventory to locate each tree individually. The other tree measurements were input into a separate Excel spreadsheet. This was done to make input of the data go faster. It is difficult to draw the points and input the data accurately at the same time. Once the CEM layer was finished and the separate

spreadsheet was done, the two were joined using the tree ID field as a common link. The system was then capable of being queried for any measurement attribute. Next, the CEM was applied by linking an Excel spreadsheet to the GIS application.

Making the GIS user-friendly was a priority for this system. In general, ArcView™ is a very easy to use GIS, but implementing the CEM in the GIS required the invention of an easier interface. Avenue is the object oriented program (OOP) language that is included with ArcView. Its purpose is specifically for the creation of tools and interfaces for different tasks. In this study Avenue was utilized to create a link to an Excel spreadsheet which could calculate the maintenance time needed for each tree from the variables which were input into ArcView. Figure 4 illustrates an example of the interface found in the GIS-CEM combination.

***Figure 4**. GIS and CEM interface in ArcView™*



The CEM was implemented by using a series of nested "IF" statements within the Excel spreadsheet. The CEM uses measurement ranges and coefficient combinations to generate maintenance times needed for each tree. For example, if a tree is between 0.0-5.0 ft of a building the coefficient used to correct trimming time is 1.4. If the tree is within 5.1-25.0 ft of the building the coefficient is 1.2, and if the tree is more than 25.1 ft away from the building, the coefficient is 1. The nested IF statements test the data ranges for each variable and then they assign the appropriate coefficient. An example nested IF statement follows: "=(IF(RC[-8]=0,0,IF(RC[-8]=1,0.25,IF(RC[-8]=2,0.6))))" This is an example statement used in Excel to determine the coefficient needed for the condition measurement. Once the coefficients have been applied to the baseline trimming time in the Excel spreadsheet, the corrected trimming times were automatically updated in ArcView™ through a derived field called "adjusted time." The adjusted time field could then be used in ArcView™ to find the trimming time for any combination of the trees in the inventory area.

CHAPTER VI

Analysis of Study

Analysis of Species Composition: Different species demonstrate different characteristics. Some trees are prone to disease and die (creating a hazard around the lines), others are weak causing them to break under stress. Species distributions were examined for the inventory area using ArcView™ GIS. They were divided into small, medium, and large species shapefiles. The overall species distribution is found in Appendix C. Only trees that presented a conflict with the line were measured in the inventory

Analysis of Fast Growing Species: Fast growing species of trees were found and also grouped using the GIS. Fast growing species tend to grow back quickly into the lines after trimming. They also have brittle wood that tends to break readily under stress. This combination of traits makes them prone to causing utility line problems. Location of these trees is important to having long-term planned line maintenance. Fast growing species were delineated and summed using ArcView™ GIS.

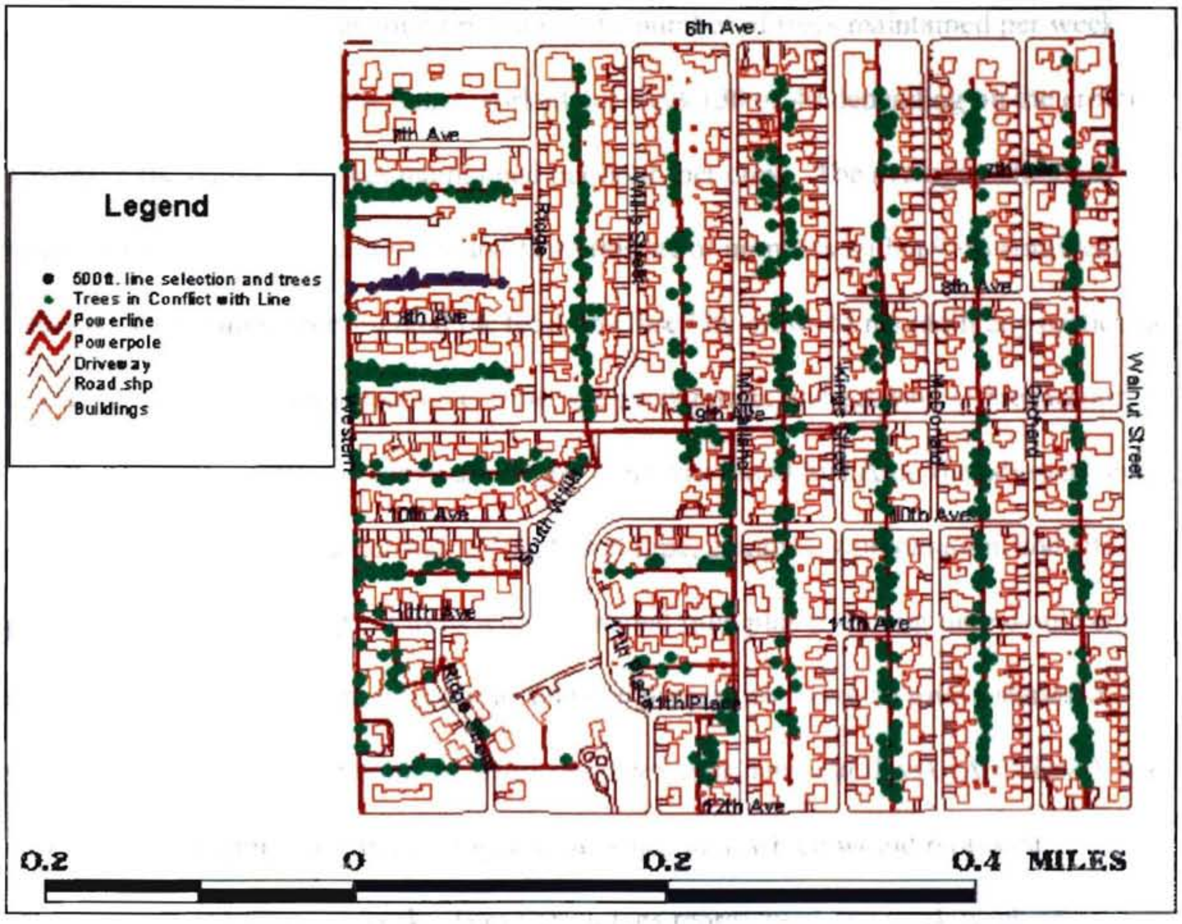
Analysis of Dead Tree Location: The analysis of tree conditions began with the mapping of all tree condition attributes from the inventory. Dead and dying trees were selected out of the database and made into their own shapefiles so they could be accessed easily.

Analysis of Conflict Levels: Conflict levels were also analyzed spatially. Each level was selected out of the tree theme and converted to individual shapefiles. The conflict levels begin at zero (minimal trimming necessary) and go up to three for the most severe.

Analysis of Diameter Distribution: Tree diameters play a critical role in the evaluation of trimming time and line conflict. The diameter measurement determines all other size variables of the tree. The larger the tree diameter is the larger the height, spread, and branch diameters the tree will have. Diameters were measured during the inventory and attached as attributes onto the tree point layer for the ArcView™ GIS. Diameter distributions were found using the theme query function in ArcView™.

Tree Density Along the Line: Average trimming time for a particular stretch of powerline can be found by taking average tree density along the powerline multiplied times the average time needed to trim a tree. Usually contractors have a good feel for their own trimming rate. By looking at the tree density along a powerline, contractors are able to come up with a trimming time estimate. In this study, the average tree density was found by taking a random sample of 500 ft. lengths of powerline throughout the study area and finding the number of trees in conflict with the line. The sampling process and evaluation were all done with the help of a GIS. Figure 5 illustrates the powerline sampling. The lighter dots indicate the selection of a 500 ft section of line with the adjacent trees selected. A total of 35 sections were sampled for approximately 3.31 miles of density measurement. The utility lines were broken into 500 ft sections and labeled as individual entities. Then a buffer was placed around each section to find all of the trees adjacent to the line. Mean tree density on a 500 foot section of powerline was analyzed for a 95% confidence interval by using the formula for variance.

***Figure 5**. Selection of 500ft Powerline for Determination of Tree Density*



Analysis of SEU Work Task Sheets: Comparisons of the CEM tree maintenance times to actual trimming times were done using task sheets kept by the SEU line clearance contractor. All work by the line clearance contractor for the City of Stillwater is documented on task sheets. Task sheets record the work done by a crew during a one-week period (40 hours). Contract crews work 10 hours per day for 4 days during the week. The task sheets used for this study are a random sample of 25 sheets from the SEU 1996-1998 budget years. An example task sheet can be found in Appendix E. The line clearance contractors currently do not track the diameters of trees removed. The only information given about the trees on the sheets is the total number of trees trimmed and removed in one workday. Since time is not delineated between trimmed and removed, the two categories were grouped into a "total maintained" category. The average trimming rate per week was found by taking the number of trees maintained per week and dividing that by the crew hours worked per week (30 or 40 depending on the crew). This gave the number of trees maintained per hour, per crew. The average number of trees removed per hour was then found from this set of numbers with a 95% confidence interval. This number represented the total time used by crews to maintain any particular tree along the line. It included travel time, site preparation, and equipment preparation.

The CEM's average removal rate per hour was found by taking the adjusted times already found from the model and adding travel time, equipment preparation, and site preparation hours to groups of trees whose removal time plus trimming time would equal one week. Site preparation, travel time, and equipment time were all give a standard weekly allowance of eight hours (2 hours per day x four, ten hour days). ArcView™ was used to find groupings of trees throughout the study area which would represent approximately 32 hours of work. These groupings represented one work week of trimming. To delineate between removals and trimming, only dead trees were designated as removals and their times were adjusted accordingly.

Feasibility Analysis: The feasibility of using this type of system to track and maintain a utility line maintenance system depends on several factors including: the cost of doing an inventory of the utility area, the cost of buying the GIS system, the cost of maintaining the system, and the returns from using the system. These costs were totaled and compared in the findings.

CHAPTER VII

Findings

Species Composition: Cedar has the highest population of trees in conflict with the line in the study area. It represented 14.0% of the total tree population with pecan trees second at 12.4%. Tables 12-14 and Figure 6 show the species distribution by size class and species size (large, medium, and small)..

Table 12. *Large Trees Representing Conflict with Aboveground Lines*

SPECIES	COUNT	SPECIES	COUNT
cedar	112	poplar	4
pecan	99	pistache	4
elm	80	boxelder	2
hackberry	65	birch	2
oak	62	catalpa	2
mulberry	53	honeylocust	2
maple	48	holly	1
sycamore	36	hickory	1
pine	33	buckthorn	1
magnolia	16	white poplar	1
walnut	13	beech	1
locust	12	willow oak	1
sweetgum	11	spruce	2
ash	10	coffee tree	1
cypress	5	**Total**	**688**
cottonwood	4		
willow	4		

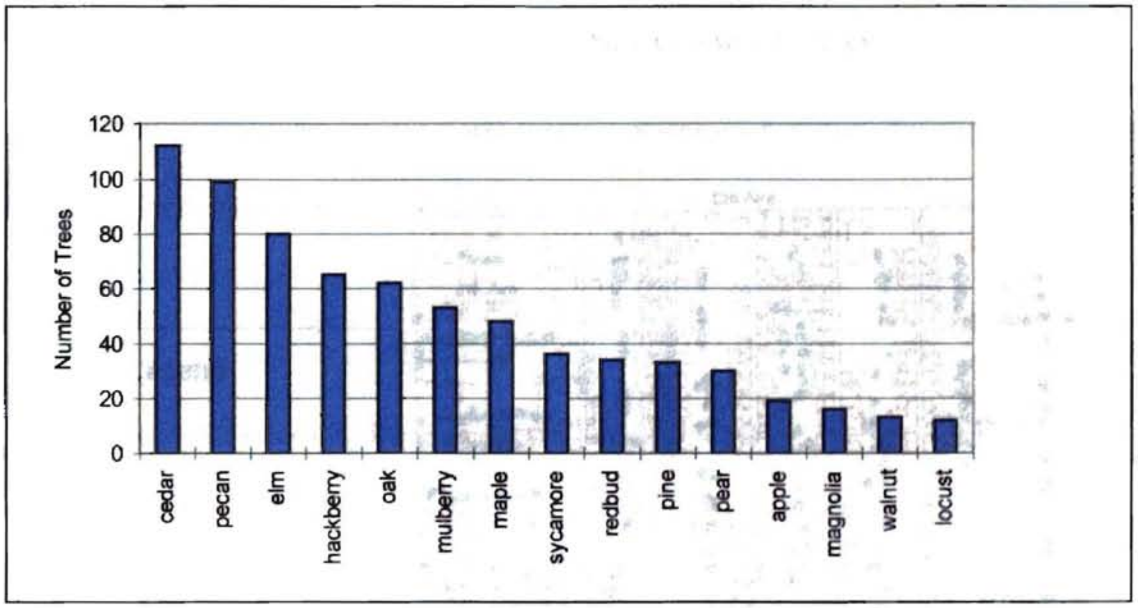
Table 13. *Medium Trees Representing Conflict with Aboveground Lines*

SPECIES	COUNT
pear	30
mimosa	9
soapberry	5
winterberry	1
Total	45

Table 14. *Small Trees Representing Conflict with Aboveground Lines*

SPECIES	COUNT
redbud	34
apple	19
plum	5
apricot	2
arborvitae	2
peach	2
cherry	1
alder	1
Total	66

Figure 6. *Top 15 Species in the Inventory Representing Conflict with Aboveground Lines*



Forty-three species were counted within the 799 trees inventoried. The utility line conflict in this area is represented mostly by large species of trees. Large species totaled 688 trees while the smaller and medium species both totaled only 111. Since the inventory found only those trees that represented a current conflict with the line, it is logical that the smaller species would be excluded from this survey. The smaller species of trees represent a small portion of the total conflict in the study area. Only three trees in the small tree category have a conflict level greater than zero.

<u>Fast Growing Species Compared to Slow:</u> Table 15 shows the fast growing species found in the study area. Fast growing species represented 33% of the total number of trees in the study area. These trees will consequentially need more pruning and should be considered for removal and replacement. The presence of fast growing trees across an area to be managed will slow a trimming crew. Finding groupings of these trees is helpful in determining the amount of regrowth that will be present after trimming in done. The spatial distribution of fast growing trees in the study area is shown in Figure 7. The black dots represent the locations of fast growing tree species locations and the white dots are the medium and slow growing trees.

***Figure 7.** Locations of Fast Growing Species*

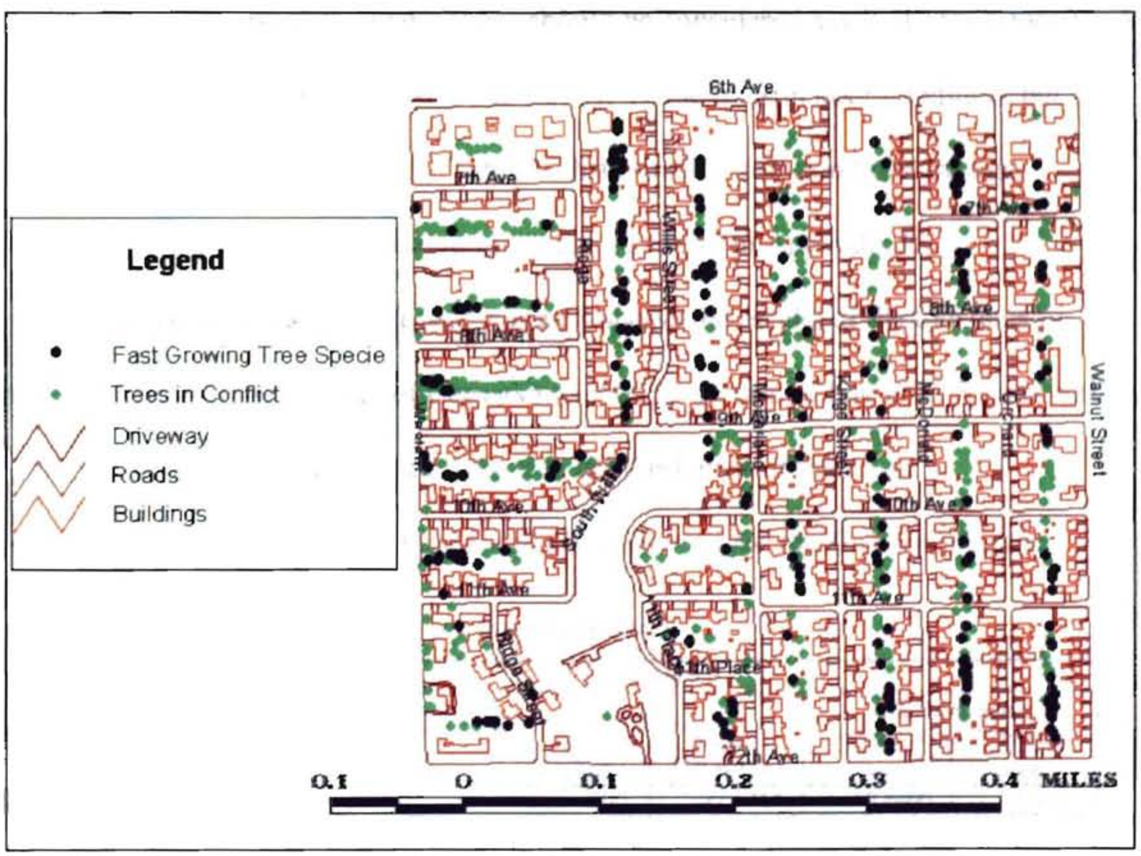


***Table 15**. Fast Growing Species Representing Conflict with Aboveground Lines*

SPECIES	COUNT
elm	80
mulberry	53
maple	48
sycamore	36
locust	12
sweetgum	11
ash	10
cottonwood	4
willow	4
poplar	5
boxelder	2
catalpa	2
Total	267

Dead Tree Location: The darker colored dots in Figure 9 represent dead trees which are located next to the line. These should be considered a priority for removal. A total of 34 dead trees were located in the survey. Those trees in poor condition, but not dead totaled 88 (11% of the total). Table 16 lists specific tree condition ratings. Definitions for the specific condition terms can be found in Appendix I.

Tree Density Along the Line: Figure 8 shows the results of the tree density analysis. The average number of trees along a 500 ft. section of line is 22.5 trees with a 10.86 tree standard deviation and a 1.83 tree standard error of the mean.

***Figure 8**. Derivation of the Confidence Interval for the Density Samples*

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
VAR00001	12.295	34	.000	22.5714	18.8406	26.3023

Figure 9. *Location of Dead Trees in Study Area in Conflict with Aboveground Lines*

Dead trees represented by black dots. Green dots represent trees in conflict with the lines.

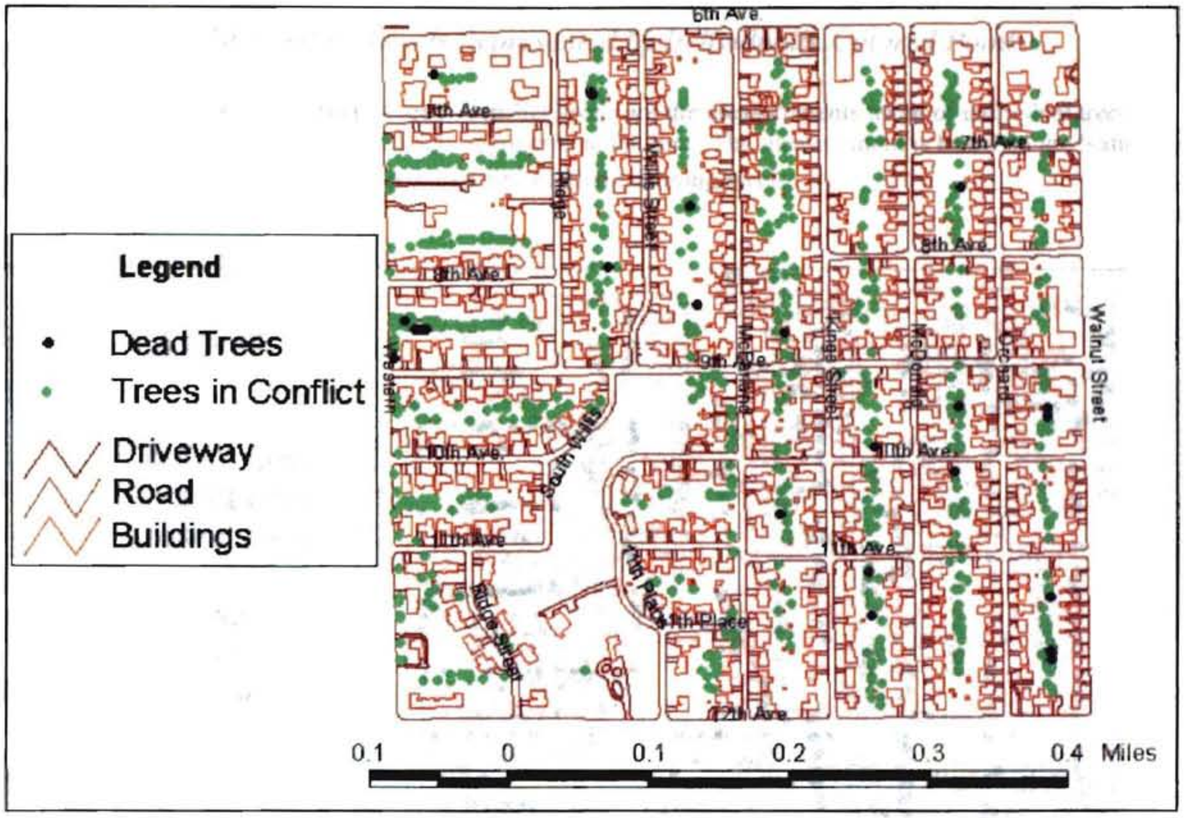


Table 16. *Totals for Specified Tree Conditions*

Definitions for tree conditions found in Appendix I

CONDITION	COUNT
Dead	34
Dehorned	10
Leaning	5
Diseased	3
Old trim	26
On line	4
V cut	6
Total	88

Mapping Tree Conflict Levels: Tree conflict levels are shown in Figure 10 with the totals per level listed in Table 17. The darker colored dots represent a higher conflict level whereas the lighter colored circles with dots in the middle represent a lower conflict level.

Figure 10. *Conflict Levels Represented by Individually Colored Points*

Definition of Conflict Levels: Conflict levels are the measurements taken of individual trees to represent the amount of contlict each tree represents to the line. The measurement is based on the National Arborist Association trimming levels.

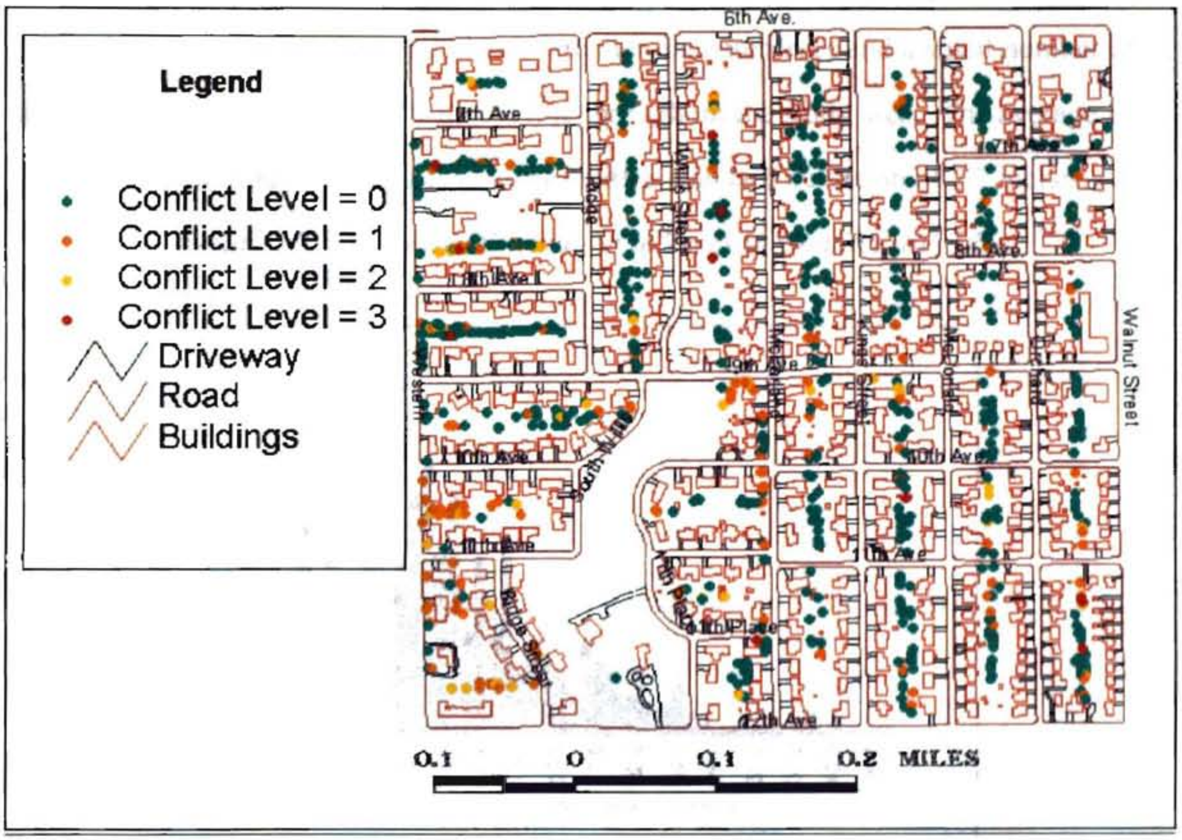


Table 17. *Total Tree Counts Per Conflict Level*

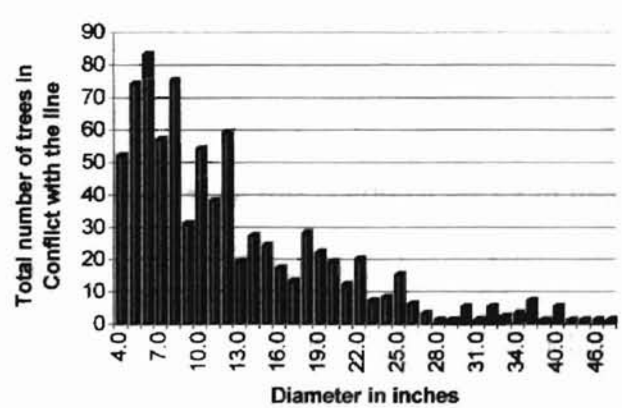
Definition of Conflict Levels: Conflict levels are the measurements taken of individual trees to represent the amount of contlict each tree represents to the line. The measurement is based on the National Arborist Association trimming levels

CONFLICT	TREE COUNT
level 0	591
level 1	138
level 2	57
level 3	13
Total	799

Level 0 is by far the largest category. This is probably an indication of some previous trimming activity in this area combined with the "hotspotting" that takes place to trim the most severe areas first. The conflict measurement only measures the relative severity of the way a tree is situated around the line. It is the most subjective of the measurements taken. Example illustration of the different levels can be found in Appendix D.

Diameter Distribution: The diameter distribution from the study area is shown in Figure 10. There were a large number of smaller diameter trees and a small number of large diameter trees in conflict with the line throughout the study area. The average diameter for the study area was 12.2 inches with a standard deviation of 7.7 inches.

Figure 11. *Diameter Distribution of Trees in Conflict with Line*



Comparison of CEM to SEU contractor: Values from the task sheets were input into an Excel spreadsheet for analysis. The totals for the number of trees removed and trimmed per workday were added. Then these sums were used to create a field for the total number of trees maintained per crew work hour per day (the tree maintenance work rate). The mean rate for tree maintenance according to a random selection of task sheets is .6 trees per crew hour or 23.9 trees per week. This value includes all trees counted by the clearance contractor, and does not necessarily mean that these trees were of significant size. The trees counted as part of the task sheets could be as small as an inch in diameter. Using this rate for tree maintenance, the study area trimming time equals 133 work days (10 hour work days). The maintenance rate of .6 trees per crew hour included travel time, equipment setup, and project organization. The CEM did not include these times as a part of the model, so they were added separately. For every 8 hours of tree trimming time in the model an addition two hours were added. The total number of hours calculated from the CEM to trim the study area was 1746.5 model hours + 436.6 additional hours = 2183.1 hours. The mean maintenance rate for the CEM confidence interval was 2.7 hours per tree or .4 trees maintained per crew hour. All of the trees included in this rate are over four inches in diameter and the average tree is 12.2 inches in diameter. Using this rate for tree maintenance trimming time equaled 218 work days (10 hour work days) for the study area. See Table 18 for comparison data.

***Table 18**. Comparison of trimming rates between the CEM and SEU Task Sheets*

	Total crew hours to complete the trimming	Trees/Hour	Average Diameter	Total Work Days
CEM	2183.1	.4	12.2 inches	218 work days
SEU TASK SHEETS	1334.8	.6	not available	133 work days

Model Calibration: The model will become more accurate as the baseline times are calibrated with actual removal times. Overall, both the CEM and SEU task sheets show that the quarter section study area can be completely trimmed within a five to seven month period. The difference between the CEM and SEU task sheets can be attributed to several factors. First, the CEM is based on trees whose diameter is greater that 4 inches. Secondly, the CEM uses very large coefficients for correcting the baseline trimming time for site factors that would influence the trimming time. These coefficients were based on rough percentage time differences, and they would need to be fine-tuned to show accurate trimming times. Also, the baseline trimming times were found using a formula developed for street tree trimming. This could've added additional time to the baseline times due to a more thorough trimming job done for street tree trimming.

Managing Tree Maintenance using the GIS: The previous analysis showed some general and fairly simple analytic uses for the GIS. The next analysis involves full use of the CEM and GIS capabilities. Specific area cost evaluation involves selecting an area, which is either going to be trimmed or has been trimmed to measure the predicted time and costs needed to complete a trimming job. For example, within a selected management area (the study area) a manager wants to schedule his/her crew to work on the most needy trimming area for the next couple of weeks, and he/she wants to set a high goal for their crew. Using the selection pointer in ArcView™ the manager can select trees, equal to the amount of work in a week period. An example is shown in Figure 12.

Figure 12. Management Zone Selection from Study Area

The whole area is the management zone, and the lighter area is the trimming zone or work zone. Inside of the work zone all trees are selected. The table for the combined trees is then opened and the selected trees are summarized using the summary function. Total hours are then found for removal. The area selected results in 73.36 hours, which would be enough to keep a 3 person crew busy for almost two weeks.

Application of CEM to Stillwater Service Area: Using the average tree density along a 500 foot section of powerline, a projection can be made at how much trimming is needed for all of the SEU service area. The density average equals 22.57 trees. Stillwater's total service area is estimated to have approximately 250 miles of line (estimate from SEU). At least 20% of this line is transmission line or is not heavily wooded, leaving 47,667 trees in conflict with the lines. If a three year trimming cycle were implemented this would mean 14,300 trees would need to be trimmed yearly. The trimming rate by the current line clearance contractor is approximately 6.1 significantly sized trees trimmed or removed daily. Applying this number to the number of 10 hour days worked per year (52 weeks times 4 days per week) equals 1262.56 significantly sized trees trimmed or removed per year per crew. To implement a three year trimming cycle a total of seven crews would be needed at an increased removal and maintenance rate of 10.91 per day. See Figure 13 for more information. The cost of doing hotspotting to trim the entire system on a 3 year cycle amounts to $35.15 per tree or $558,508.90 per year for the entire system.

***Figure 13**. Summary of CEM application to Stillwater*

Miles of Line =250
Feet of Line = 1,320,000
Feet of Forested Line = 1,056,000
Number of 500 foot sections = 2,112
Trees per 500 foot section = 22.6
Total number of trees = 47,667.8
Trees to trim for a 3 year cycle = 15,889.3

Hotspotting verses Trimming cycle rate	Trees trimmed	Trees removed /year/crew	Crews needed	Costs per year	Trimming rate possible (trees/day)	Cost per tree
Hotspotting	6,312.8	1,262.56	5	$500,000	6.07	$79.20
Trimming Cycle	15,889.28	2,269.89	7	$700,000	10.91	$44.05

Feasibility Analysis Findings: The cost associated with the inventory and data input was fairly inexpensive. The inventory work was done with two students over a 6-

week period. The students were paid $7.00 per hour. The students worked approximately 243.25 hours making the total spent on the inventory and data input $1,702.75. The GIS system (ArcView™ with the Spatial Analyst Extension) cost approximately $2,900, and the computer that ran the system cost $2,100. The only other costs involved was the time spent by the researcher in implementing and coordinating the program and some equipment costs, making the total cost of the project around $9,200 or $11.51 per tree. After this initial investment, it will take inventorying the rest of SEU's aboveground lines to implement a full-scale management program with this system. The whole system is estimated to be approximately 30 times the size of the pilot project study area, making the cost of inventorying this area approximately $51,060.00.

Returns from the system will be realized from the increased efficiency and management of the trimming crews themselves. In this study it was found that trimming the entire study area could take five months using the old trimming management system and seven months under the CEM system. However, with the CEM system pre-notification and planning for trimming could be done in advance of need. Optimum routes could be developed and justification could be made to change some of the current trimming strategy to a systematic method. With the new system a crew could be working on the study area would have the benefit of knowing exactly what they needed to get done for that week. They would have production goals set for them based on the conflict evaluation model. In this way crew efficiency can be tracked and measured, and the CEM model can be used to ensure consistency during trimming operations and also provide work and budget goals.

Findings Concerning the Model Implementation: Developing a method of predicting the amount of trimming needed in any particular area is a difficult task. The best method would be to use extensive, long-term time and motion studies from crews to develop more accurate and predictable baseline times to input into the model. The current baseline times derived from the formula in the study done by Churack is good for general observations and estimates, but is not good enough to predict exact costs. If baseline costs for tree removals could be tracked and measured for SEU, then those variables could be added to the system to make it more accurate. Until this happens, this system should be used strictly for tracking and not modeling.

Summary of Findings:

- Cedar has the highest population of trees in conflict with the line in the study area (representing 14.0% of the tree population).
- Large species trees represented a majority of the conflict with the line in the study area (688 large species).
- Fast growing species of tree represented 33% of the total number of trees in conflict with the line in the study area.
- Eleven percent of the trees in conflict with the line were dead.
- The average tree density along a 500 ft section of line in the study area is 22.6 trees (with DBH larger than 4 inches).
- A majority of the trees exhibited a very slight to no conflict with the line (591 trees were designated a zero conflict level).

- The CEM predictions were significantly higher in trimming time than the recorded average maintenance rate (trimming and removing) for the SEU line clearance contractor.
- The maintenance rate for the SEU line clearance contractor is approximately 6 trees per day.
- The CEM-GIS combination provides a useful tool for creating work schedules based on the amount of trimming to be done.
- The CEM needs to be properly calibrated with actual trimming times before it can be used to accurately predict trimming needs in any area.

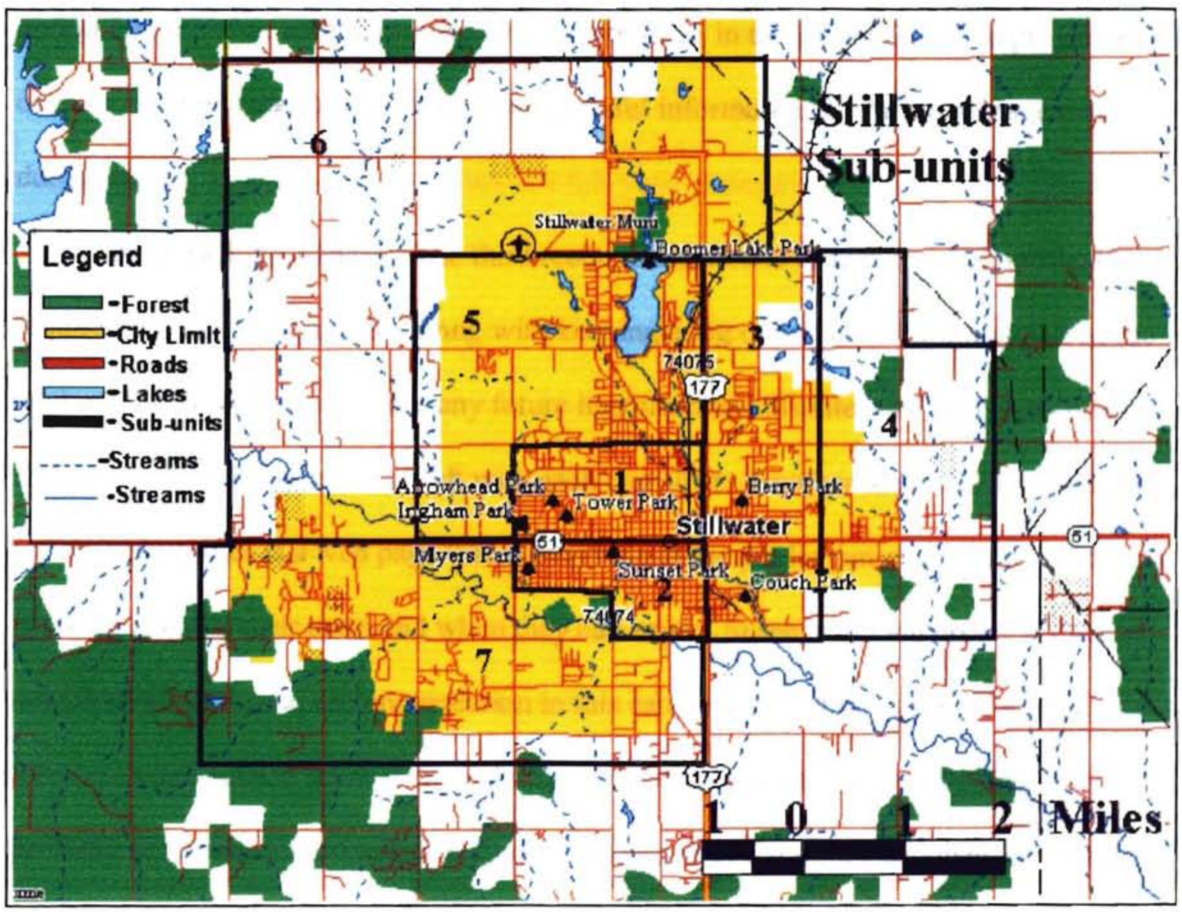
CHAPTER VIII.

Recommendations and Conclusions

Recommendations for the Study Area: Based on the findings of the inventory, there are some immediate maintenance concerns in the study area. One concern involves the dead trees found in the utility corridors. Having crews work on the study area in particular would lesson the likelihood of having an outage due to one of these trees. Secondly, since this area has already been inventoried it would be an ideal place to begin a set trimming cycle. In this way adjustment of the model through the analysis of real baseline trimming times could be done to accurately predict future trimming activity.

Recommendations for the SEU Service Area: The first recommendation is to break the entire SEU service area into management sub-units. The area of the sub-units in dense tree covered areas with overhead lines will be approximately .5 to 1 square miles. In each square mile of dense overhead lines there are approximately 20 linear miles of line to maintain in Stillwater. The inventory showed that it is possible to complete the trimming of this kind of area within a period of approximately five months with one crew. There are approximately five square miles of dense powerlines in Stillwater. Three crews could focus on this concentrated area and finish it within a three year cycle, assuming there are no large setbacks (storms, etc.) or major line replacement activities. The rest of the SEU service area consists of more rural areas and has a light density of overhead line distribution. These lines could occupy separate management sub-units and could be focused on by at least two other crews. This leaves only emergency and "as needed" situations. Initially two crews would probably be needed to handle emergency situations, but eventually at least one of these crews could be phased out. The total number of crews for this type of management scenario is seven. See the diagram below for a description of possible management sub-units. These sub-units are based on the density of line distribution in the area.

Figure 14. Possible Management Sub-Units for Stillwater



The sub- units are grouped so that three crews could focus on the dense portion of the SEU service area and four crews focus on the less dense portions. Sub-units 1 and 2 are both 2.5 square miles, allocating five months per quarter section to each crew (as found in the inventory). Each crew would have three years to complete all trimming necessary in each sub unit.

Tracking of Projects: The second recommendation is to introduce some form of tracking into the current contractor's regime. Currently SEU tracks by memory what has been done and what needs to be done in terms of trimming. This is not a reliable system. By simply tracking the work done, improvements can be made throughout the system. Modeling using the CEM and implementation of a trimming cycle may not be a current option for SEU, but tracking of ongoing maintenance in the form of detailed project areas or more detailed task sheets could provide useful information for future management decisions.

Notification Changes: The third recommendation is to make verbal notification a requirement for the contractor along with keeping a log of this notification as part of the contract. This will help sort out any future line clearance disputes and will also ensure that every effort is taken to consult with each customer. Another idea which has worked for several utilities is a web page that is available to the public that states where trimming is taking place in their town and when they can expect to see trimming crews in their neighborhood. A final recommendation in this category would be to use a foreman or forester to contact and work with clearance crews and with the public. Having a professional tree expert to talk to the public on behalf of the utility company creates a customer friendly image in contrast to having exposure only to work crew personnel.

Establish and Set Clearance Requirements: Trimming specifications should be customized to allow for less clearance on stronger wooded, slower-growing trees and more clearance on faster-growing, weaker wooden ones. Further specification should use terms such as directional pruning and natural target pruning (NTP). Clearance specifications should only be modified through approval by SEU. The consequences of these recommendations should increase trimming crew efficiency by decreasing the amount of trimming that is done in the field. Another consequence of this type of action will be a "tree-friendlier" public perception to those customers who know each tree is carefully examined before it is trimmed.

Consider Doing Some Projects on Fixed-Price Biding: SEU currently uses a time and materials type of bidding system. The bidding is usually done yearly or bi-yearly (every other year). Once the bidding procedures are completed, the contractor knows that employment is guaranteed for at least one full year. Amounts of trimming and areas of trimming are not specified in the bid. Fixed bidding would require a project area to be specified and planned in advance. It would also require bid specifications to be customized for each individual project. Using fixed bids is a more intensive style of management, but it allows for better control over the contractor and increased trimming efficiency. Although many large tree-trimming companies do not usually bid on a fixed bid type of system, it is possible to keep specifications suitable for many of the smaller tree trimming companies to participate in these kinds of bids.

Conclusion: One of the most needy areas of urban forestry study is in utility forestry. Through research done in utility and urban forestry, a better understanding will be gained about opportunities to integrate and explore new technologies and options within current management systems. GIS is a very useful tool, which combines the spatial element of data with analytical capability. It allows researchers and managers to analyze the very complex and interactive realm of the urban environment. In Stillwater, the use of a GIS combined with a tree inventory provided a base of knowledge that may lead to the improvement of utility line tree maintenance in the future. However, the present study is only a beginning. Further research is needed in the area of GIS based utility line management and urban forestry. Both fields have a great deal to gain from the use of the GIS technology.

The Next Step in the Research: This study found that a GIS is a useful tool to locate and measure tree conflict with overhead utility lines. However, to accurately model the trimming and removal times it is necessary to have an extensive knowledge of trimming and removal rates. Further research in this area should focus on modeling the removal rates based on those variables used by this study to measure tree conflict. Another area of study for this type of research is in the use of a GIS to model conflict predictions based solely on orthophotos. If the variables listed in this study can be delineated from orthophotos, then conflict measurements could be done strictly using the GIS. Other areas of research might focus on the application of this type of system within an electric utility or line clearance company.

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APPENDIX A.

DATA DICTIONARY OF LAYERS USED IN THE GIS

Data Dictionary

Layer	Feature	Class	Attributes	Value	Description
Roads	ROADS	Polyline	None	none	-None
Trees	SINGLE TREES	Points	Conflict Levels	0 1 2 3	No conflict -slight conflict -considerable conflict -severe conflict
			Conflict %	0%-100%	Area of crown in immediate distance of powerline
			Line Distance	0-100ft	Distance from trunk to edge of powerline
			Species	name	-species of the tree
			Height	0-100ft	-height of tree
			Diameter	4-62 in	-DBH in inches
			Brush	0% or 100%	Specifies the % time added to trimming due to proximity to brush
			Tree Number	I.D.# 1-800	-Unique tree identifying number
			Condition	0%,25 %,or 60%	Specifies the % time added to trimming due dead condition of tree
			Buildings	0%,20 %,40%	-Specifies the % time added to trimming due to proximity to buildings
			Traffic%	0%,25 %,50%	Specifies the % time added to trimming due to proximity to traffic
			Line Type	1 or 3	Specifies if line is single or triple phase
			Conflict Percent	0%,10 %,20%, 40%	Specifies the % time added to trimming due to conflict %
			In/Out Fence	"in" or "out"	Specifies tree in or out of fence
			Remove %	0% or 200%	--Indicates the addition of time due to the removal of the tree-
			Traffic	"High, Med, Low"	Specifies traffic count level

			Combined	any #	The sum of all the % time added variables
			Averaged	any #	The multiplication of all of the % time added variables to the baseline trimming cost
			Corrected	Number of minutes needed to trim the tree	The Averaged level divided by 60 minutes per hour.
Tree Line	TREE LINE	Polylines	None	None	None
Detwalk	DETWALK	Polyline	None	None	None
Lightpole	LIGHTPOLE	Polylines	None	None	None
New Fence	FENC	Line	None	None	None
Roads	ROAD	Polylines	None	None	None
Driveways	DRIVEWAY	Polylines	None	None	None
Management Zone	NON-TRIMMED AREA	Polygon	Area	Square feet of area	The area of a management zone that has not yet been trimmed
Curbs	CURBS	Polylines	None	None	None
Remove Tree	MISSING TREE	Points	None	None	None
Remove fence	MISSING FENCE	Line	None	None	None
Fence	OLD FENCE	Polylines	None	None	None
Centerline	CENTER OF ROAD	Line	Traffic Count	0 1 2	Low Medium High
Trimmed	TRIMMED AREA	Polygon	Area	Square feet of area	The area of a management zone that has been trimmed
Powerline	POWERLINE	Lines	None	none	None
Poles	POLES	Points	None	none	None
Buildings	BUILDINGS	Polylines	N/A	N/A	N/A
Easement	EASEMENTS	Polylines	None	none	none

APPENDIX B.

EXAMPLE EVALUATION SHEET

Tree Evaluation Sheet for
Quadrant 1
Tree Survey for the City of
Stillwater
6/11/98

Number	Diameter	Species	Height (ft)	Distance from line	in fence or out	Conflict level	percent conflict	Triple, single, etc.

APPENDIX C.

SPECIES DISTRIBUTION

SPECIES DISTRIBUTION

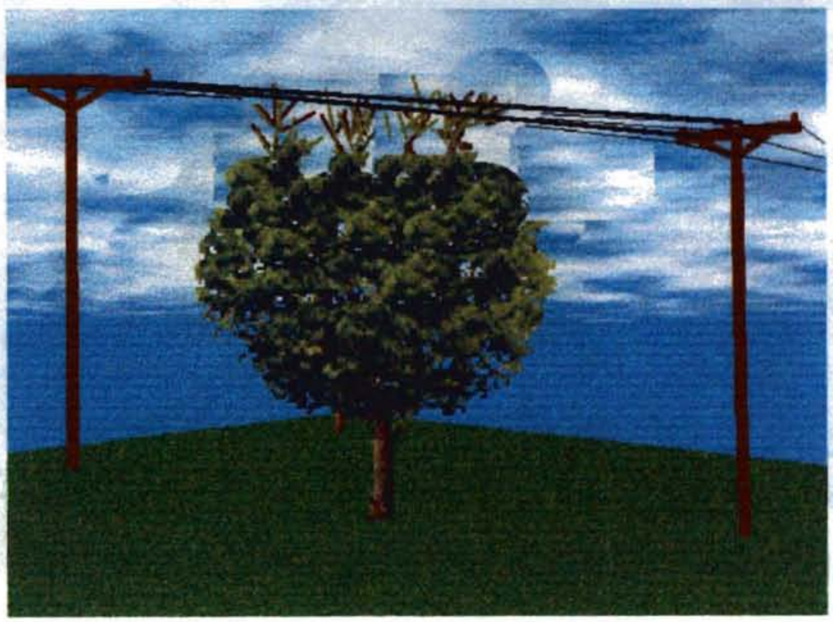
SPECIES	COUNT
cedar	112
pecan	99
elm	80
hackberry	65
oak	62
mulberry	53
maple	48
sycamore	36
redbud	34
pine	33
pear	30
apple	19
magnolia	16
walnut	13
locust	12
sweetgum	11
ash	10
mimosa	9
cypress	5
plum	5
soapberry	5
cottonwood	4
pistache	4
poplar	4
willow	4
apricot	2
arborvitae	2
birch	2
boxelder	2
catalpa	2
honeylocust	2
peach	2
spruce	2
alder	1
beech	1
buckthorn	1

cherry	1
coffee tree	1
hickory	1
holly	1
white poplar	1
willow oak	1
winterberry	1
Total	799

APPENDIX D.

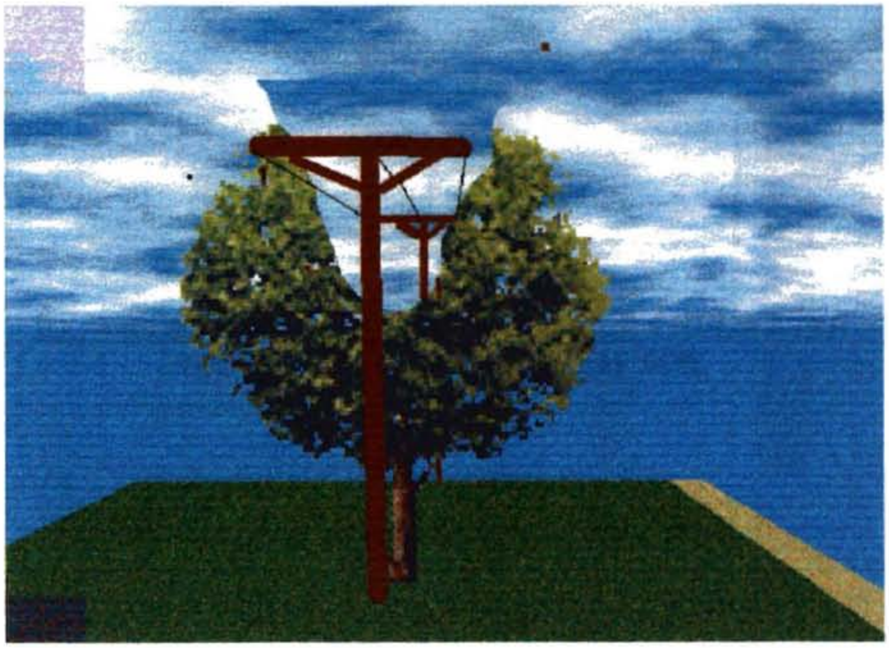
ILLUSTRATION OF CONFLICT LEVELS

CONFLICT LEVEL 0

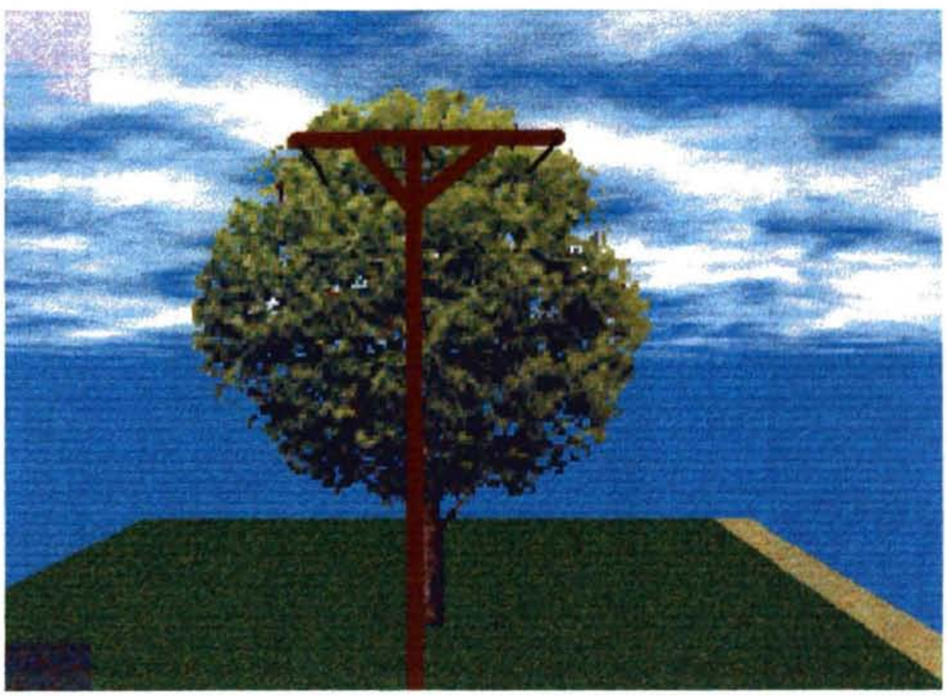


CONFLICT LEVEL 1

CONFLICT LEVEL 2



CONFLICT LEVEL 3



APPENDIX E.

EXAMPLE INVENTORY SHEET FOR THE STILLWATER ELECTRIC UTILITY CONTRACTOR

[illegible] 1449 Stillwater OK. 74074
Mrs. Fern Broyles (IDENTIFY AS REQUIRED ON INVOICE)
[illegible] Remove
Stillwater

OK

FOREMAN / ACTING FOREMAN: R. Buzze[ll]
GENERAL FOREMAN NAME: M. O'Berne?
V.P. / MANAGER NAME: D. Thurston

	SUN ACCT NO	MONDAY ACCOUNT NO	TUESDAY ACCOUNT NO	WEDNESDAY ACCOUNT NO	THURSDAY ACCOUNT NO	FRIDAY ACCOUNT NO	SAT ACCT NO
Account		615 S Hester / 617 S Hester	620 S Standlee? / 615 S Hester	11d chips / 617 S Hester	11d chips / 723 S M Fork?	11d -	

EMPLOYEE NAME	CUST CLASS	CO CLASS	T	PAY RATE	SUN	MON	TUE	WED	THU	FRI	SAT	SUMMARY OF LABOR: ST	OT	DT	TOTAL CREW HOURS	HOL
24 R. Buzzell	F	01				10	10	10	10			40			40	
18 B. Willis	T	46				10	10	10	10			40			40	
91 R. Maldonado	T	46				10						10			10	
49 M. Friend	T	46					10	10	10			30			30	
4 R. Buzzell	F	01														
N - NEW R - REHIRED T - TRANSFER IN — TOTAL CREW HOURS						30	30	30	30			120			120	

ENTER PROPER CODE IN DAY OF WEEK & EXPLAIN A - ABSENT T - TRANSFER V - VAC. H - HOL. X - TERMINATED

EQUIPMENT NAME	EQUIPMENT NO.	SUB	SUN	MON	TUE	WED	THU	FRI	SAT	TOTAL	REMARKS BILL E[…]
Lift	860-1262			10	10	10	10			40	
Chipper	434-4144			10	10	10	10			40	Truck + C[…]
	521			10	10	10	10			40	wash ot[…]
	61			10	10	10	10			40	G.F.
TOTAL EQUIPMENT HOURS				40	40	40	40			160	

BILLABLE EXP[…]
DESCRIPTION

	SUN	MON	TUE	WED	THU	FRI	SAT
TREES TRIMMED		2	3	4	9		
CREW HOURS TRIMMING							
TREES REMOVED		9	11	2	-		
CREW HOURS REMOVING							
SHOW ACRES SQ. FT. OR SPANS							
SHOW ACRES SQ. FT. OR UNITS							

TOTAL

START TIME	QUITTING TIME	I WORKED AN ACCIDENT FREE WEEK: (SI[GNATURE])
7:00 Am	5:30 Pm	[signature]
7:00 Am	5:30 Pm	Robert Maldonado
7:00 Am	5:30 Pm	Bryan Willis
7:00 Am	5:30 Pm	[signature]

APPENDIX F.

EXAMPLE BASEMAP DATA

BASEMAP

APPENDIX G

LIST OF TREE MEASURMENTS

LIST OF TREE MEASUREMENTS

Species – Tree species will determine how fast a tree grows, if it is more likely to split apart during a wind storm and cause an outage, and also its sprouting characteristics after it has been trimmed.

Diameter - Measured with a diameter tape 4.5 feet from the ground (DBH).

Height - Measured using an ocular estimate comparing the height of the electric line, which was approximately 30 feet from the ground to the height of the tree.

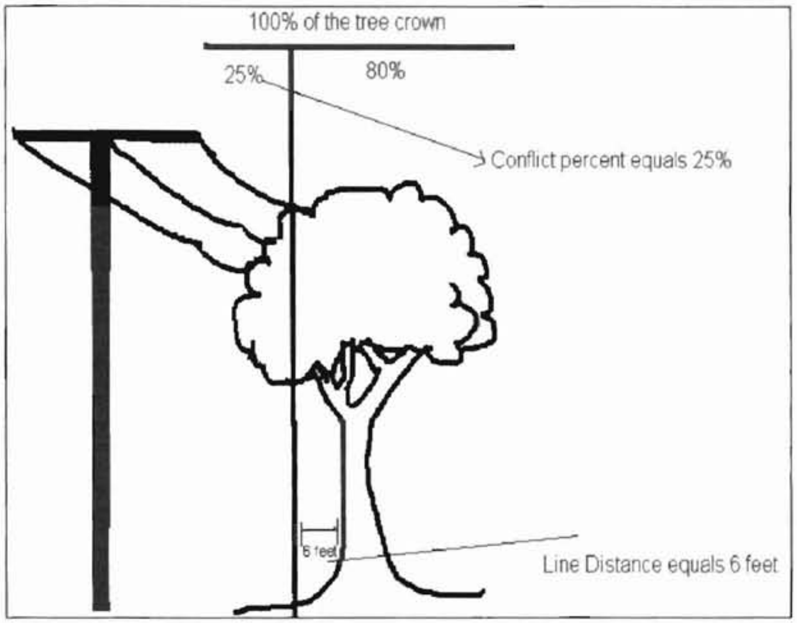
Line distance - Line distance is the distance from the nearest electric line to the trunk of the tree. This helps in determining where the tree is located relative to the line. An example of this measurement can be seen on Figure 14.

Conflict Percent- This measurement is determined from the percentage of crown than is under or around the powerline. The measurement is determined by examining the percentage of crown that is dissected from a straight-line distance down to the ground taken from the nearest powerline to the tree Condition- The overall condition of the tree is noted such as "dead," "partially dead," or "topped." These measures are later used as additional variables to determine the time needed to trim or remove the tree.

Fence Line Location- Fence lines pose a very significant obstacle to the trimming of a trees. This measurement takes note of the tree's location either inside or outside of a fence line.

Conflict Level- Categorized from a trimming class based on the National Arborist Associations trimming class standards. The categories are listed in Appendix H..

Figure 14. Percent Conflict Diagram



APPENDIX H.

CONFLICT LEVEL CATEGORIES

CONFLICT LEVELS

0- No conflict- either the tree has been sufficiently trimmed away from the line to a distance of 10ft or, the tree is growing far enough away from the line to pose very little to no threat. This can also be a tree which has a very minimal amount of pruning needed (branches less than five inches in diameter) and has not grown large enough underneath a line to pose a serious threat. This category is based on the NAA standard Class I - for Fine Trimming.

1- Slight conflict- the tree has small sized limbs (limbs less than one inch in diameter) that are in conflict with the electrical lines. Typically the tree is easy to reach and would require less than 30 minutes to trim back to a conflict level 0. It could also be a previously trimmed tree that has sprouted significantly back into the line. This category is based on the NAA standard Class II – for Medium Pruning.

2- Moderate conflict – this tree can have some major limbs (greater than two inches in diameter) in conflict with the line, but it could still be trimmed back away from the line in less than four hours. This category is based on the NAA standard class III – Coarse or Safety Pruning.

3- Major conflict – this tree has more than 3 major limbs in conflict with the line and would take at least a full day or more to trim. The category is typified by unusual growth, under branches, excessive size, or severe root loss (Grey, 1996). This category is based on the NAA standard class IV – Cutting back, or drop crotch pruning.

APPENDIX I.

CONDITION RATING DEFINITIONS

CONDITION RATING DEFINITIONS

Dead – the tree is 100% non-living tissue

Dehorned- the tree has been topped, all major branches and limbs have been removed.

Leaning- the tree shows a significant lean that could pose a significant threat to surrounding property

Diseased- the tree is showing significant die-back due to a disease

Old trim- the tree has been previously trimmed for utility clearance and could be in decline due to the past trimming.

On line- the tree has branches making contact with a live electric wire.

V cut- the tree has been directionally pruned in the past and may be in slight decline because of the past trimming.

Total- Total number of trees showing a significant condition rating

APPENDIX J.

MINIMUM-WORKING DISTANCES FROM ENERGIZED CONDUCTORS

Minimum-Working Distances from Energized Conductors for Qualified Line-Clearance Tree Trimmers and Qualified Line-Clearance Tree Trimmer Trainees.

	Minimum Working Distance (in feet)		
Nominal	+190.269	+190.269	+190.269
Voltage Range (kV phase to phase)	elev. factor, sea level to 5000 ft.	elev. factor, sea level to 5001-10,000 ft.	elev. factor, sea level to 10,000-14,000 ft.
0.05-1.0	Avoid contact	Avoid contact	Avoid contact
1.1-15.0	2 ft 4 in	2 ft 8 in	2 ft 10 in
15.1 to 36.0	2 ft 9 in	3 ft 2 in	3 ft 5 in
36.1 to 46.0	3 ft 0 in	3 ft 5 in	3 ft 9 in
46.1 to 72.5	3 ft 9 in	4 ft 3 in	4 ft 7 in
72.6 to 121.0	4 ft 6 in	5 ft 2 in	5 ft 7 in
138.0 to 145.0	5 ft 2 in	5 ft 11 in	6 ft 5 in
161.0 to 169.0	6 ft 0 in	6 ft 10 in	7 ft 5 in
230.0 to 242.0	7 ft 11 in	9 ft 0 in	9 ft 9 in
345.0 to 362.0	13 ft 2 in	15 ft 0 in	16 ft 3 in
500.0 to 550.0	19 ft 0 in	21 ft 9 in	23 ft 6 in
765.0 to 800.0	24 ft 4 in	31 ft 3 in	33 ft 10 in

(ANSI Z133.1-1994)

VITA

Carrie Tomlinson

Candidate for the Degree of

Master of Science

Thesis: ELECTRIC UTILITY CORRIDOR TREE MANAGEMENT STRATEGIES AND OPTIONS: A CASE STUDY FOR STILLWATER, OKLAHOMA

Major Field Forest Resources

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Professional Memberships: International Society of Arboriculture, Society of American Foresters