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Security Vulnerability Trends Related to Electric Power Supplied at Military Installations

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SECURITY VULNERABILITY TRENDS RELATED TO ELECTRIC POWER SUPPLIED AT MILITARY INSTALLATIONS

THESIS

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AFIT/GEM/ENV/10-M11

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AFIT/GEM/ENV/10-M11

SECURITY VULNERABILTIY TRENDS RELATED TO ELECTRIC POWER SUPPLIED AT MILITARY INSTALLATIONS

THESIS

Presented to the Faculty

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Abstract

The United States (U.S.) electric grid is considered one of the greatest inventions of the twentieth century, yet it become apparent over the past few decades that it is not without its own set of problems. The deregulation of the U.S. electric system in the late 1990s eliminated monopolies and resulted in the nation's generation, transmission, and distribution systems becoming separate entities owned and operated by multiple companies. This created a market economy in which many electric companies failed to plan for the future, did not invest in maintenance and upgrades, and began to push the aggregate system to its maximum capacity. A number of cascading power outages in the late 1990s, culminated by the complete blackout of the northeastern U.S. in 2003, have subsequently caused the federal government to question the reliability of the nation's deregulated electric grid and take action to remedy current issues.

Therefore, the objective of this study was to leverage the trend and spatial analysis capabilities embedded in typical geographic information system (GIS) platforms to examine power outage data from the Energy Information Administration (EIA). Utilizing the industry standard for GIS, ArcGIS, interpolation using the inverse distance weighted approach was used to calculate preliminary vulnerability levels at military installations based on EIA's power outage database from 2000 to 2009. The results of the study offer insight that will help key stakeholders better understand the state of the nation's electric grid and identify areas of concern. This allows stakeholders to be in a better position to address associated vulnerabilities by making appropriate plans for either system upgrades or mitigation efforts.

Acknowledgements

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I would also like to thank my advisor, Dr. Al Thal, for his guidance on through this thesis effort and keeping me on track to completion. Last but not least, I would like to thank Lt. Col William Sitzabee for his guiding hand for using ArcGIS and for bringing to light the IDW methodology. Without this, I would be simply putting numerical points on maps and discussing their proximity affects on Air Force installations. I would also like to thank my other committee members, Dr. Michael Grimaila and Capt. Bryan Cooper, for their technical expertise in this subject matter.

Peter A. Sabatowski

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SECURITY VULNERABILITY TRENDS RELATED TO ELECTRIC POWER SUPPLIED AT MILITARY INSTALLATIONS

Chapter 1. Introduction

Vulnerability and security concerns with the electric grid are increasing as the United States (U.S.) continues to "operate critical infrastructure systems closer to their stability or capacity limits" (Mili, Qiu, & Phadkey, 2004). Compounding this concern is the overall effect on the nation's power grid by significant events within the past decade, to include deregulation, terrorist attacks, and natural disasters (Mili et al., 2004; Lerner, 2003; Masse, O'Neill, & Rollins, 2007). Questions have also arisen regarding power companies' abilities to deliver reliable power to U.S. consumers. These concerns have sparked the creation of regulations aimed at mitigating power failures. However, with regulation efforts still in the early stages, it is unclear if vulnerability and security concerns with the electric grid will be resolved or if historical trends are an indicator of future regional power reliability problems.

Researchers who have investigated the underlying causes of reported power failures have observed an inverse relationship between power consumption and power system maintenance (Rietz, 2008). This is partially due to the failure of the Federal Energy Regulatory Commission (FERC) to adequately regulate the nation's power system (Ayres, Ayres, & Pokrovsky, 2005). The FERC regulates the nation's power system without sufficient manning to effectively manage and create reliability standards. As a result, the North American Electric Reliability Council (NERC) was created in 1968 as an “informal, voluntary organization of operating personnel to facilitate coordination of the bulk power system” (NERC, 2008; About FERC, 2009). It was anticipated that by combining the FERC’s regulatory power and the NERC’s technical expertise, the power grid should improve in overall reliability and quality. However, prior to the passing of the Energy Policy Act of 2005 (EPAct 2005), the NERC lacked sufficient authority to enforce their own standards.

Rising concerns with the current status of the power grid is not limited to consumers and has the potential to significantly impact the Department of Defense (DoD). The increasing frequency of power failures within the national grid (Mili et al., 2004) is a concern among base commanders, yet instances of prolonged outages raise the largest concern since mission capability can be seriously jeopardized (Defense Science Board Task Force, 2008). Vulnerabilities within the electric grid have raised interest among military installations as they come to the realization that they are more vulnerable to power issues as they have become increasingly dependent on commercial power. Each incident reinforces the notion that bases must be able to adequately supply power to their critical infrastructure to maintain mission capability. Unfortunately, no tool exists to determine overall vulnerability to future power outages at military installations. Therefore, this research attempts to fill that void by utilizing geographic information systems (GIS) to determine the associated vulnerability to future outages. Utilizing historical power outage information and interpolation tools within GIS, it is possible to develop detailed maps showing historical vulnerability levels across the U.S.

Background

The need for reliable power is an increasing concern for consumers as the dependence on electricity to perform routine activities has increased. This is also true for military installations as the need for consistent power to critical infrastructure and facilities has become a requirement for continual mission operations. However, recent widespread power failures have identified several weaknesses within the nation's power grid (Mili et al., 2004). Weaknesses ranging from deteriorated equipment to lack of physical security amplify the grid's vulnerability to not only a terrorist attack but also to human errors that result in catastrophic failures (Cieslewicz, 2004). These areas have been the basis for the increased concerns regarding power reliability and the focus of both the NERC and FERC to help mitigate rising concerns.

The FERC was initially intended to "regulate the sale and transportation of electricity" (History of FERC, 2009). Over the years though, the FERC gained additional responsibilities such that the sale and transportation of electricity was no longer its main focus. In 1962, the electric industry created the NERC, an informal voluntary organization of operating personnel, to facilitate coordination of the power system in the U.S. and Canada in an effort to manage the grid's increasing complexity and size. Unfortunately, the policies created by the NERC included voluntary compliance that were not mandated until EPAct 2005 (Abshier, 2007; McDonald, 2008). The power wielded by the FERC was limited to regulating existing standards, whereas the NERC was responsible for creating standards but lacked regulatory authority (Mili et al., 2004). Basically, the NERC is aware of problems within the electric grid and creates policies to correct the situation yet lacks adequate authority to mandate compliance.

The FERC-mandated deregulation of the electric industry created additional problems with the electric grid as the dynamics of transmission and distribution were altered. Deregulation attempted to create a market economy and provide open access for any electricity supplier. However, it essentially forced inter-reliance on existing transmission and distribution power lines. Although not initially anticipated, deregulation minimized direct government involvement in ensuring the system was being managed and maintained adequately (McDonald, 2008). Prior to deregulation, power was supplied to users through geographically separated electric companies who maintained their own power generation and transmission capabilities. Therefore, companies had a vested interest in maintaining their assets to ensure not only adequate supply capability but also future growth capability. Following deregulation in 1996 though, no single electric company could own multiple components of the electric grid's generation, transmission, and distribution lines. This aided in the elimination of any monopolies and created a market economy in which electricity began to be traded as a commodity (Arrillaga, Bollen, & Watson, 2000). Unfortunately, as these components became separate entities, owned and operated by multiple companies, companies failed to plan for the future and began to push existing lines to maximum capacity (Lerner, 2003). It became evident during a rash of power outages in 1996, 1998, and 1999 that deregulation did not solve the problems with widespread outages; instead, it put additional stress on the electric grid as systems were operated closer to their maximum capacity and little money was invested in maintenance and upgrades (Arrillaga et al., 2000; Lerner, 2003).

The consequences from the failed attempt of deregulation ultimately raised concerns with consumers as they became increasingly reliant on power and the responsiveness of electric companies during outages and emergencies (McDonald, 2008). This essentially resulted in a blind dependence on financially motivated companies supplying a service critical to nearly all aspects of modern-day life. In fact, power outages are not only inconvenient but can cost consumers significant amounts of money. Assigning a monetary value to power outages has sparked multiple studies intended to investigate the costs associated with power outages within residential, commercial, and industrial consumers (Eto & LaCommare, 2008). The studies estimate that power interruptions within the U.S. cost consumers anywhere from $22 to $135 billion each year (LaCommare & Eto, 2004). Although this financial burden felt by most consumers is quite high, it does not necessarily compare with Air Force installations and the possible impact on critical missions and national security.

The decreasing reliability of the national power grid has also received attention within the DoD and Air Force regarding how to address the deteriorating power grid and efforts to mitigate its risks (Aimone, 2009; Defense Science Board Task Force, 2008). Part of the concern for the Air Force is that existing manning levels have limited the service's capabilities to provide backup power to critical infrastructure assets which are tested only for intermittent power outages (HQ AFCESA/CEOA, 2009; HQ AFCESA/CES, 2005). In fact, Air Force installations have become so dependent on reliable power that manning for internal power generation and electrical support has steadily decreased. One of the main reasons for this decrease has been a need to commit more funds to the replacement of deteriorating airframes (Scully, 2008). The manning and associated funding cuts were justified based on the assumption that the local grid is capable of supplying reliable power needed for the base to operate. There is a downside to this increased reliance though, which is the resulting lack of organic base capability to provide sufficient power to counter the increasing number of power failures in both duration and magnitude (Mili et al., 2004).

According to Air Force policy, “it is important to identify and protect those (critical) infrastructures that are truly critical to the Air Force so it can accomplish its worldwide mission” (Dix, 2006). However, problems exist within each base in determining the critical assets necessary to sustain mission operations since each base organization feels they constitute a critical function. This in turn creates confusion about which facilities to support during power outages and makes apparent the inability to support a large volume of requests. In conjunction with the Air Force Civil Engineer’s lack of adequate capabilities and manning, the backup capability on Air Force installations cannot be adequately determined (Defense Science Board Task Force, 2008). Air Force guidance regarding emergency generator management sparsely mentions prolonged power outages and focuses mainly on intermittent power failures (HQ AFCESA/CEOA, 2009). This lack of planning for a worst-case scenario compounds electricity concerns if power failures persist beyond the planned duration of generator fuel and manning capabilities.

The intention of this research was to demonstrate an approach to assessing vulnerabilities to certain types of power outages. Although the findings are specific to Air Force installations, they are considered generalizable to other non-DoD agencies as well. Additionally, many private organizations share the Air Force’s concerns regarding the reliability of the power grid, yet their motivation lies mainly with minimizing financial losses due to the loss of worker productivity. This analysis of power outages surrounding Air Force installations will address associated vulnerabilities while proposing ways to help mitigate concerns for future outages.

Problem Statement

As a whole, the nation has become increasingly dependent on reliable power to perform daily operations. However, it is not until power is lost that individuals realize how dependent society has become on the availability of consistent, reliable electricity. Herein lies the problem with which this study is focused: increased dependence on electricity has made people and organizations more vulnerable to the effects of prolonged commercial power outages. To address this problem, this research relied on the Air Force as a case study.

Problems with reliable power will not go away anytime soon and will continue to have a significant impact on consumers until they are addressed. With the concerns over forced deregulation and changes within the power grid, it is no longer realistic to simply rely on supplied power. Power supplied over the electric grid tends to be at the mercy of old technology operating outside its suggested life expectancy. As a result, deteriorated equipment has spiked a large increase in blackouts in recent years and has brought to the forefront the issue of the nation's electric grid (Abshier, 2007). Although efforts by the FERC and the NERC are underway to standardize security measures across the electric grid, efforts will require time to be completely developed and implemented. Meanwhile, the electric grid is still failing to provide uninterrupted power to consumers. This will continue to be problematic to DoD installations and their ability to sustain operations during prolonged power outages.

Research Questions

There were two main research objectives for this study. The first question: "what vulnerabilities exist at Air Force installations for future power outages?" The calculated level at each installation provides a score based on different components of historical power outages. These vulnerability scores serve as the basis to address the second question: "how can these vulnerabilities be reduced at the installations?" These research questions focused on the individual components of power outages and their implications to Air Force installations. The findings will help installations address concerns with supplied power and provide a basis for the Air Force to assess their available generation assets and power generation strategy.

Methodology

This study focuses on trend analysis of power outages throughout the U.S. based on reported power outage data from the Energy Information Administration (EIA). Data for this study was collected from the EIA's major disturbances and unusual occurrences database which contains information about reported power outages from January 2000 to September 2009. Of particular interest in this database is information regarding power outages relating to the responsible power company, duration, location, power loss, cause, and number of people affected. The database was initially reviewed for errors and then geographic orientation was added to each data point for use within GIS. The software being utilized, ArcGIS, is offered by the Environmental Systems Research Institute, Inc. (ESRI). ArcGIS contains the Spatial Analyst Tools necessary to perform the analysis.

The EIA's power outage database was inputted into ArcGIS and analyzed using the inverse distance weighted (IDW) approach to interpolate the values between known points based on distance and weighted values. IDW was performed for each of the components identified above, resulting in separate maps for power outage duration, power loss, and number of people affected. Utilizing the raster calculator in ArcGIS, the three maps were consolidated into a single output showing overall vulnerability levels. From this map, assessments can be made regarding which bases are more vulnerable to power outages caused by failing transmission equipment.

Assumptions

There were four primary assumptions that needed to be made in order to perform the analysis for this research. First, it is assumed that the EIA power outage data could be generalized within each region. Since the EIA data lacked exact coordinates of the power failure or the specifics regarding the customers affected, it was assumed that power outages were central to each power company's service area and uniformly affected customers from the center of the service area outwards. Second, it is assumed that the past trends of power failures are in fact good predictors of future occurrences, even considering the major improvements being made to the electric grid. Third, it is assumed that all power companies provide reports on identical types of power outages, making the data collected uniform across the U.S. Last, despite inherent differences between environmental conditions, operating conditions, and missions at bases across the Air

Force, the findings and recommendations developed during this study were assumed applicable to all installations.

Limitations

The primary limitation affecting the research was the fact that all of the data being utilized is second-hand from government agencies. As a result, there are a limited number of data points which can be used with no opportunity to get additional data. In particular, the exact origin of and exact customers affected by power outages is lacking within the databases, so each data point must be generalized to each utility company region and the affected customers. This is not only an assumption but also a limitation since the EIA requires this information to be reported immediately following an outage, yet the information is not available to the public. This limitation affects the overall IDW calculations since the analysis uses distances; with data points overlapping, the output is slightly skewed towards areas with higher numbers of outages. The final limitation is the lack of previous research using IDW and the raster calculator in ArcGIS as a means to verify the calculated information.

Significance of Study

It is anticipated that this study will alert Air Force leadership to installations that are increasingly vulnerable to power outages. Included within this finding will be statistics based on the overall type and duration of typical power outages within areas surrounding Air Force installations. This study builds upon previous studies pertaining to energy management by creating a tool to adequately understand the service provided by electric companies. The results from this study can be generalized to other defense branches and also large-scale industrial/commercial business such that they can take action to minimize affects from future power outages. This study helps the Air Force assess available assets and provides a solid foundation for transforming current energy management practices to ensure the Air Force mission is maintained during outages.

Organization of Remaining Chapters

Following this introductory chapter, there are four additional chapters to this thesis. The second chapter consists of a literature review that covers various topics relevant to power sustainment and reliability. The third chapter is a detailed overview of the methodology for the study, to include data collection, GIS overview, and risk assessment model construction. Results and discussions are presented in the fourth chapter, which explains all the findings from the GIS data analysis and provides a detailed description of each focus area from the model. The final chapter serves as a conclusion to the study and reviews all important details from the entire thesis process.

Chapter 2. Literature Review

The purpose of the literature review was to identify and analyze documents containing information relevant to the nation's bulk power system and the impact of associated vulnerabilities on Air Force operations. The bulk power system, or national grid, is continually evolving with some of the larger changes occurring in regulation over the past few decades (Apt, Lave, & Morgan, 2006). This includes the stressing of existing power lines to meet demand increases which have resulted in numerous power outages. However, these fluctuations have initiated a transformation to modernize the power grid to meet current and future needs. Efforts such as deregulation and the Energy Policy Act of 2005 (EPAct 2005) were efforts to revolutionize the electric grid. Mitigation efforts at the consumer level have been a step in the right direction, yet concerns still exist regarding the advancement of technology and future demands of the electric grid. To this point, many researchers have focused on the statistical analysis of power outages for trends relating to the duration and cause of the outage. The utilization of geographic information systems (GIS) to perform the analysis allows proximity to outages to be considered.

Evolution of the Bulk Power System

The nation's bulk power system, also known as the United States (U.S.) electric grid, is a massively interconnected web of power lines supplying electricity across the U.S. and Canada. Initially designed as vertical delivery systems with single companies being responsible for generation, transmission, and distribution as shown in Figure 1, the system has been transformed such that power now flows from the generator to the end-user through nearly unlimited paths.

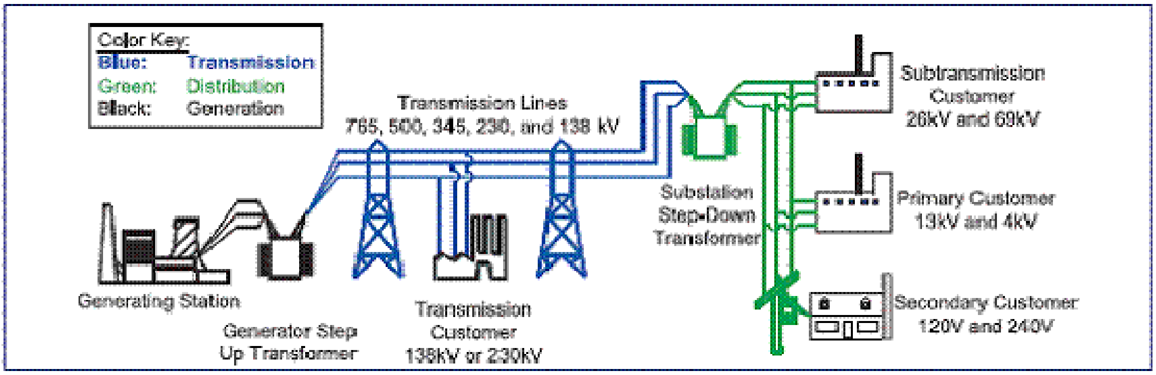


Figure 1. Nation’s Power Grid Physical Structure (About NERC, 2010)

Defining the Nation’s Power Grid

The national electric grid achieves power delivery by more than 3,100 electric utilities through three grids with limited interconnections (U.S. Department of Homeland Security, 2007). The combination of existing transmission lines and other equipment being more than 25 years old, there is reduced reliability in multiple regions of the national electric grid. Lower reliability often results in power interruptions in the form of a brownout or a blackout. A blackout represents an instance of complete power loss, while a brownout typically describes momentary fluctuations in voltage. Within these two types of power fluctuations are both short-term and long-term events, which encompass the reliability of supply, quality of power offered, and provision of information (Arrillaga et al., 2000).

Power reliability addresses all voltage changes and power losses due to complications within the electric grid. Since 1984, an average of 700,000 customers have been affected annually by power outages (Amin, 2005). In an effort to curb the rising concerns regarding power reliability, an increased focus on stability and security has been aimed at improving the nation's electric grid (Anjia, Jiaxi, & Zhizhong, 2006). However, one of the immediate obstacles to overcome with the existing electric grid is that most of the equipment is more than 25 years old. As electricity usage continues to grow, the reserve margin decreases on the existing power lines and increases the chance for future power failures (Mili et al., 2004; U.S. Department of Homeland Security, 2007; Brown, 2005). Over time, the electrical equipment loses the ability to transport its original design load due to deterioration, thus making it less able to handle increasing consumer demands. Operating power lines close to their reserve margin increases the stress on the lines, thereby reducing their safety factor and making the lines more susceptible to failing.

One of the most prominent power problems, as identified by experts, are momentary voltage sags (Arrillaga et al., 2000). These momentary sags are extremely problematic for larger industrial and commercial consumers who have a low tolerance for power fluctuations in which any change can shut down business operations for an extended period of time. This idea follows the 'first-law' efficiency created by Ayres et al. (2005) which refers to the ratio of useful outputs to inputs. In particular, the consumer's requirement for consistent power (output) is much more valuable to them than the money they pay for it (input), as it multiplies their ability to make additional money. In addition to momentary power sags, large-scale blackouts are extremely problematic for consumers and unfortunately have become more frequent in recent years (Mili et al., 2004). Some researchers (e.g., Mili et al., 2004; Eto & LaCommare, 2008) feel the increasing number of large-scale blackouts is a direct result of the transmission of power over long distances on a grid that was not designed for it. Complicating matters further, the capacity for improvements and expansions to the electric grid is severely limited by costs.

Power Fluctuation Implications

Prior research has aimed at investigating the different components of power fluctuations as well as identifying rising concerns within the U.S. electric grid. In particular, momentary power fluctuations (less than five minutes in duration) have a greater impact on organizations than larger, less frequent events. Unfortunately, utility companies are not required to report minor events to federal agencies (LaCommare & Eto, 2004). However, under certain circumstances, these small outages can domino into a much larger event that affects a wider range of consumers (Dobson, 2007).

LaCommare and Eto (2004) determined that the costs associated with power fluctuations tend to be driven by frequency rather than duration, with momentary outages accounting for nearly two-thirds of the overall cost to the U.S. Annually, these costs have been determined to range between $22 and $135 billion (LaCommare & Eto, 2004). However, the incurred losses to businesses is not directly proportional to the duration of the power fluctuation (LaCommare & Eto, 2004; Hines, Apt, & Talukdar, 2008); in other words, longer duration outages may not necessarily result in the highest monetary losses. The main reason for this difference is the result of businesses’ ability to adapt to the lack of power as the outage continues. Therefore, losses incurred later in an event do not have the same impact as those at the beginning of the event. Concerning this large cost of power outages, Brown (2005) estimated that for every dollar of lost electricity sales, costs incurred by businesses exceeded more than $100. Building on this idea, electricity can be thought of as a multiplier where more revenue is made than spent on electricity when power is on; however, when electricity is off, additional money must be spent to pay for workers while productivity is low. This does not take into consideration special organizations, such as the DoD, where mission degradation is more critical than monetary losses and can have far greater consequences.

Recent Power Fluctuation Examples

Power outages throughout the last 50 years have identified major concerns within the power grid regarding reliability and power quality. Investigations of both the 1965 cascading blackout of the Northeastern U.S. and the 2003 cascading blackout that also darkened the Northeastern U.S. have revealed key problem areas with the nation's electric grid. In particular, the results from the two events revealed both human error and a need for better communication between power areas. Both areas need to be addressed to improve system reliability. With each major power fluctuation, additional research is undertaken to better understand and prevent future outages (Brown, 2005; Abshier, 2007). Although interest regarding power fluctuations has increased, some researchers feel as though power failures are "nearly an unavoidable product of a collision between the physics of the system and the economic rules that now regulate them" (Lerner, 2003). The inability to successfully prevent power outages is a direct result of unexpected events, lack of system understanding, inadequate feedback controls, poor maintenance, and operator error (Hauer & Dagle, 1999).

The past 50 years is full of large-scale power outages, to include cascading power outages which are among the most problematic. Some of the more memorable power outages in recent years have been the blackouts in the western part of the U.S. in 1996, the rolling blackouts experienced in California in the summer of 2001, and the cascading blackout that plagued the northeastern U.S. and Canada in August 2003 (Hauer & Dagle, 1999; Mili et al., 2004; Apt et al., 2006; Lerner, 2003; Amin, 2005). From the available research (Ayres et al., 2005; EIA, 2009; Hauer & Dagle, 1999), Figure 2 was created to provide a visual representation of major power outages and the resulting regulatory efforts. Each of these events affected more than a local community, and they also represented many of the reasons for power fluctuations identified by Hauer & Dagle (1999).

The western U.S., especially California, has experienced its fair share of power reliability issues within the past 20 years. In July of 1996, one instance of power failure left 2.2 million California residents without power (Mili et al., 2004). In 2001, California experienced outages similar to those in 1996; however, with the increasing population growth, the effects were much larger and farther reaching. The resulting shortage of power forced utility companies to initiate rolling blackouts such that blackouts were intermittently shared across the whole area until sufficient power could be generated and transmitted to the consumers (Amin, 2005; Apt et al., 2006). The last major power fluctuation to discuss affected more than 50 million people, both within the U.S. and Canada. The northeast blackout in 2003 was the most widespread and largest blackout in

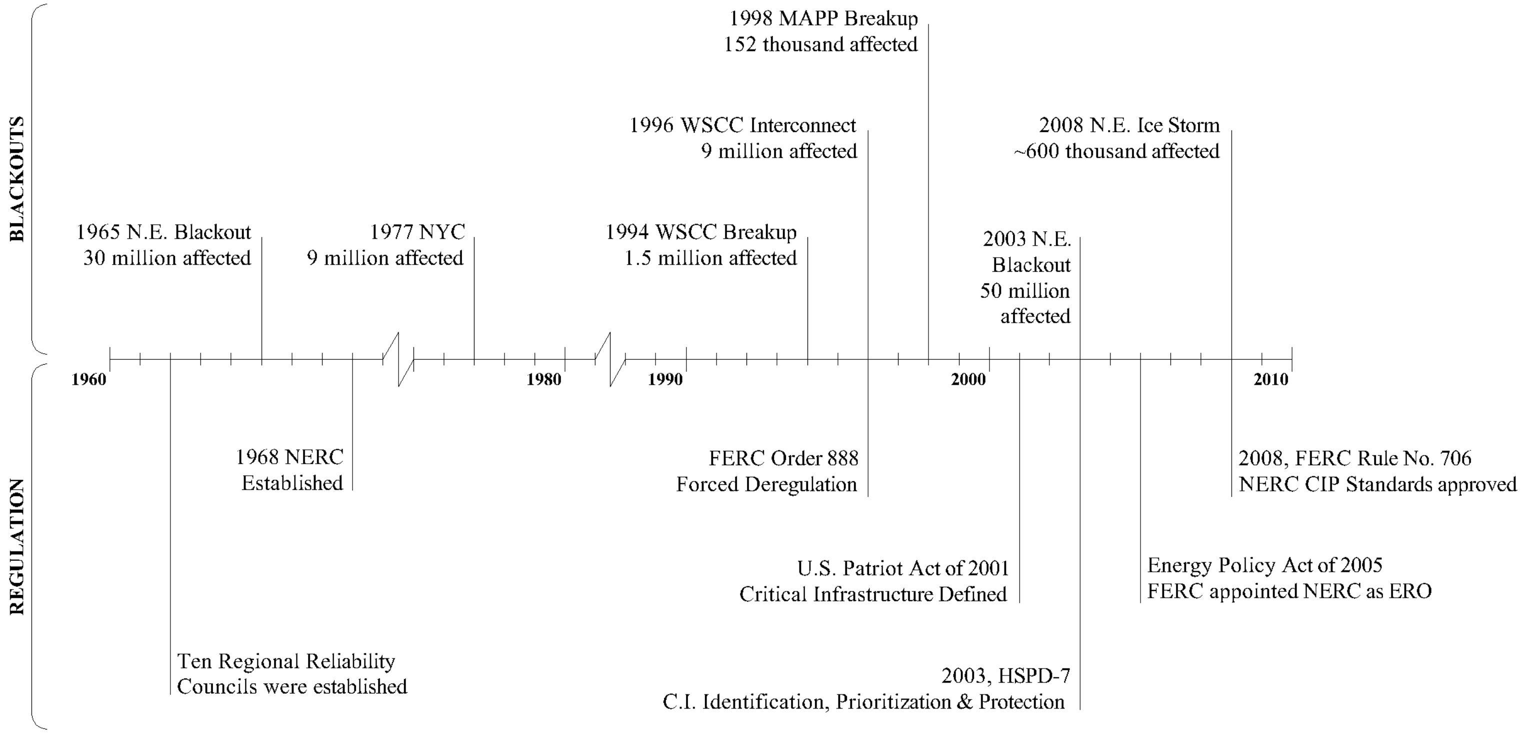


Figure 2. Comparison between Major Power Events and Regulator Efforts

history and was caused by numerous problems with failure to adhere to suggested regulations (Lerner, 2003; Amin, 2005). The initial cause of the blackout was determined to be human error and failure to properly trim trees around high-voltage power lines. Power ultimately failed when a sagging high voltage transmission line grounded on an overgrown tree, resulting in a domino effect of system failures throughout the northeast. Completed investigations of outage causes often identify areas needing improvement and ways to mitigate similar problems in the future.

Findings from the Identified Power Fluctuations

Investigations following large power fluctuations are among the best ways to identify causes, examine total effects, and recommend solutions to prevent the problems from occurring in the future. As with most technology today, 99.9 percent reliability is increasingly unacceptable and can prove disastrous in the digital world (Amin, 2005; Blankinship, 2001). Monetary losses are not the only effects felt by individuals from the loss of power; in fact, public health and safety, institutions, and national security are all affected by power loss and people's lives and well-being can become severely jeopardized (U.S. Department of Homeland Security, 2007). Bearing that in mind, finding ways to avoid and minimize the spread of power outages is important for the smooth operation of today's society.

Among the different types of power outages, cascading are the most devastating type as a single event can trigger a series of failures resulting in widespread blackouts. Studies have found that there are two main types of cascading outages: an outage started by a node removal or one that is started by an edge removal (Chassin & Posse, 2005; De la Ree, Liu, Mili, Phadke, & DaSilva, 2005). An example of a node removal would be the malfunction of a transformer or substation which receives electricity from one direction and sends it out along multiple paths. The second type, edge removal, can be as simple as the loss of a single power line that carries current from one point to another.

Additionally, hidden failures can be the most troublesome since they are permanent defects that only become evident during a failure and often times create larger, more immediate problems (De la Ree et al., 2005). There is a general belief that paying for reliable electricity should eliminate any type of power interruption (Brayley, Redfern, & Bo, 2005). However, previous research has found that reliability has not improved as electricity prices have increased, which is contrary to the desires of the consumer (Apt et al., 2006; Hines et al., 2008). The 2003 blackout was initially started by the loss of a single transmission line (edge removal) which caused other sections of the grid to overload and shut down (node removal). These two types of power failures are not mutually exclusive but can be initiated as a result of the other. What sometimes may be thought of as a minor outage, can sometimes escalate into a much larger effect, over a much larger area.

While blackouts have not shown a significant increase or decrease within the past two decades, there appear to be trends that show a higher number of power outages during the summer and winter months and also during mid-afternoon hours (Hines et al., 2008). Currently, there is dissent with who is responsible for mitigating blackout concerns and the best way to remedy the situation since no single entity manages electricity from generation to the consumer. Specifically, with a decentralized system, everyone is interested in their own assets, making it difficult for one organization to be blamed and held responsible for fixing the problems with the electric grid (Fox-Penner, 2005).

If no immediate actions are made to voluntarily increase the electric grid reliability, the next major power failure could force power companies to make significant improvements under a shortened timeline and at extremely high prices. As described by Dobson (2007), “blackouts cause reliability.” Sometimes, it takes a larger power outage to initiate needed reform once the consequences are observed, as opposed to being preventative in nature.

Mitigation Efforts

Electricity has become a necessity in today’s society. This is becoming more and more evident as each power outage brings some portion of society to a halt. As a result, efforts at both the federal and local levels are being undertaken to reduce the overall number of power fluctuations and increase overall power reliability.

Regulatory Evolution

In Amin’s (2005) study, the North American electric grid was referred to as the “most complex machine ever built.” Within this structure are three components responsible for connecting generation facilities to the actual consumer: (1) transmission level, (2) sub-transmission level, and (3) distribution level (Baker, 2008). The transmission level includes extra high voltage lines to transport electricity from the power plants to electrical substations. Sub-transmission lines connect to the substations and transport power to high voltage end-users such as manufacturing facilities or plants.

Lastly, distribution lines disseminate power to end-users through low-voltage power lines. Contrary to common belief, power does not move automatically through the bulk power system; it takes a concerted effort by the utility companies. According to McDonald (2008), utility companies have four main responsibilities to consumers: 1) provide reliable electricity, 2) create a secure operating environment, 3) ensure continuity for businesses, and 4) design plans for disaster preparedness and emergency management response. Each of these components ensures power is present to consumers over 99% of the time (Blankinship, 2001).

Involved Regulatory Organizations

Under the electric grid's regulated structure, power is regulated by the FERC to ensure the nation's interstate transmission system operates efficiently while sub-agencies, controlled by the state regulatory commissions, regulate the distribution system (U.S. Department of Homeland Security, 2007). The addition of long-range transmission lines connecting different geographic areas began creating problems with reliability and power quality as they eventually became bottlenecks for power running long distances while operating near maximum capacity.

In 1962, ten regional reliability councils, as shown in Figure 3, were established to plan and coordinate generation and transmission in their regional areas (Apt et al., 2006). Following the 1965 blackout in the Northeastern U.S., there was an apparent need for additional oversight beyond what the regional reliability councils and FERC were capable. As a result, the NERC was created to help reduce the risk of widespread electric system failures by creating standards to improve compliance by electric utilities (Chassin

& Posse, 2005; Lerner, 2003). Almost immediately, it became apparent that the standards created by the NERC would face significant resistance because NERC was a non-profit organization with no direct way to enforce the established standards, thereby making compliance with their standards voluntary (U.S. Department of Homeland Security, 2007; Brown, 2005).

Figure 3. NERC Regional Reliability Councils **(About NERC, 2010)**

In an effort to increase power reliability, FERC intended to break apart the monopolies that utility companies managed within the deregulated power structure. Consistent with FERC's mission of "reliable, efficient and sustainable energy for customers," they planned to create a market economy where power was traded as a commodity. It was anticipated that by FERC enforcing deregulation, power being traded as a commodity would result in lower costs and more reliable power to the end-user. With the passing of the Public Utility Regulatory Policies Act (PURPA) in 1978, wholesale competition was on the upturn, which was the first step towards a market economy (Brown, 2005). PURPA essentially regulated the rates such that it was more beneficial for electric utilities to buy power as opposed to making it.

The passing of the Energy Policy Act of 1992 (EPAct 92) authorized the FERC to break apart the vertical monopolies observed within the regulated electric grid. Following EPAct 92, it took until 1996 to write the directives in FERC Order 888 which allowed transmission line access to any generation facility (Baker, 2008; Lerner, 2003). This broke apart vertical monopolies and allowed generation facilities to transmit their power over any number of transmission lines. Figure 4 shows a visual representation of how power can be moved from the power plants to the consumer. This is contrary to what was shown earlier in Figure 1 where a single power company was responsible for generating, transmitting, and distributing power to the consumer.

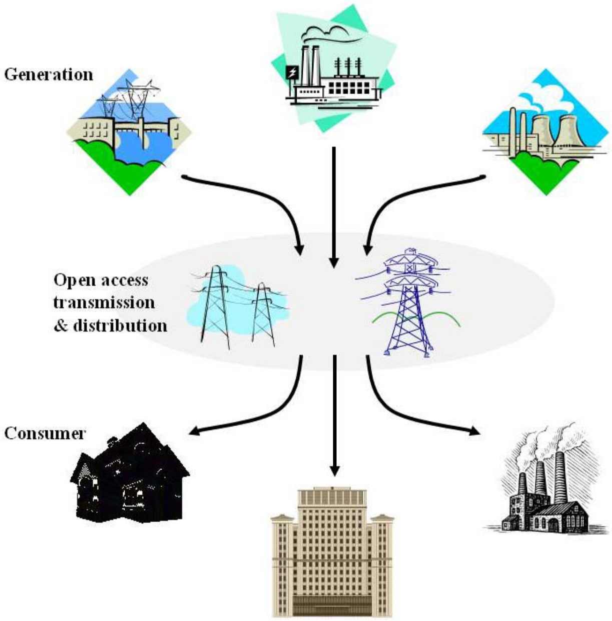


Figure 4. Post Deregulation Power System

Attempted Deregulation and Results

Deregulation within the power grid exacerbated existing problems and brought additional ones to the forefront. Restructuring has resulted in a rapid rate of wholesale market expansion and a large variability in electricity prices among states (Mili et al., 2004; Brown, 2005), sometimes without any apparent justification. Deregulation has also resulted in decreased line reserve margins (extra capacity on power lines during normal usage), redundancy, and quantity of spare parts while further increasing dependence on transmission lines (U.S. Department of Homeland Security, 2007). In addition, underinvestment in the electric supply infrastructure causes vulnerability within the overcomplicated system to continue to rise as power is transported over longer distances and results in more voltage sags (Anjia et al., 2006; Arrillaga et al., 2000; Baker, 2008). These concerns undermine the motivation for today's deregulated environment which was "to create a stable state able to withstand exogenous events and profitably deliver power to consumers" (Baker, 2008, p. 4).

Currently, only a limited number of states are currently operating the electric grid with a deregulated system. The guidance provided by the FERC passed the responsibility for the electric grid to the states such that they could make a decision regarding their power structure. This allowed the states to determine whether or not it would be within their best interests to deregulate their power structure or maintain control. Figure 5 displays the 50 states and structuring within each state. States identified as "Active" currently have a deregulated electricity system. Areas identified as "Suspended" have attempted deregulation but stopped after a multitude of complications occurred while the remainder of the states are operating in a state regulated system.

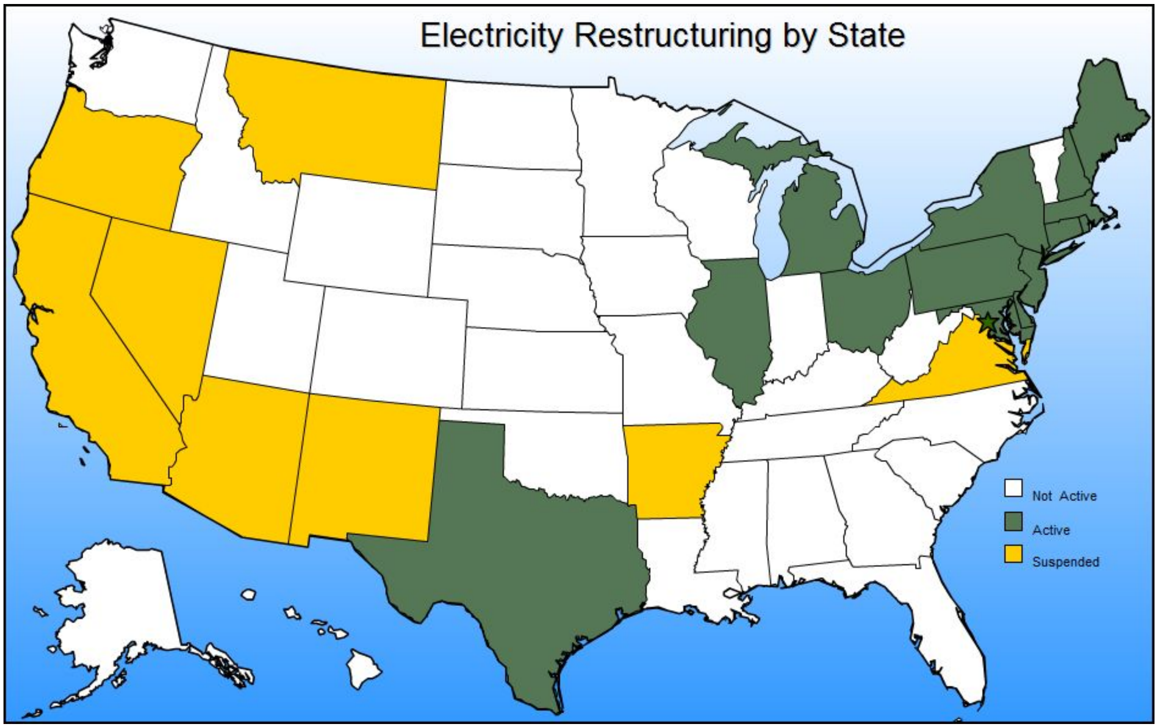


Figure 5. Current Status of Electricity Restructuring **(EIA, 2009)**

Factors Affecting Reliability

Whether investigating a regulated or deregulated grid, certain factors exist that complicate concerns regarding the reliability and quality of power being delivered. For instance, increased demand is stressing the grid and creating additional strain for which the system was not designed. About one-half of all domestic generation is sold and delivered over the stressed transmission lines (Baker, 2008; Albert, Albert, & Nakarado, 2004); therefore, unless changes are made, reliability and quality will continue to suffer. Compounding the effects of the additional stress on the grid, dependability is often favored at the expense of security (Mili et al., 2004). As shown in Figure 6, money spent on the electric grid since 1996 has been insufficient to cover the depreciation of the existing equipment. As a result, electric companies have invested to improve reliability by upgrading existing lines but have done little to protect against physical and cyber problems. In addition, electric companies have opted to use otherwise vacant transmission lines intended to provide necessary redundancy as opposed to expanding current capacity.

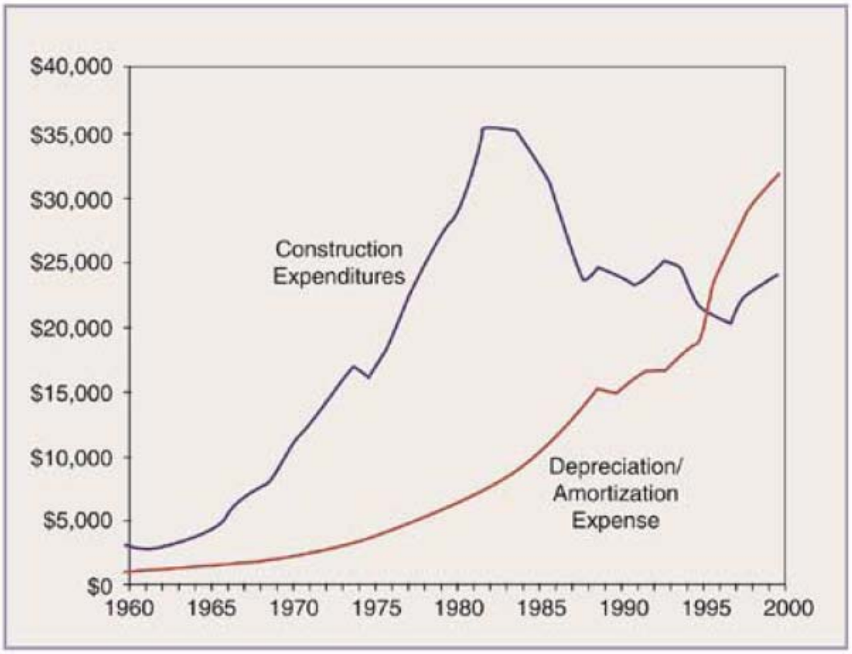


Figure 6. Electric Grid Investment vs. Depreciation **(Amin, 2005)**

From a consumer perspective, all the changes occurring within the national power grid have a direct effect on not only the power supplied but also the cost for the new and improved power. Improvements will more than likely require either increases in utility rates or government subsidies, which come from taxpayers. In conjunction with the rapid deregulation, there has been a large decrease in new incentives to improve system capacity, thereby making it difficult to market and implement technological advances

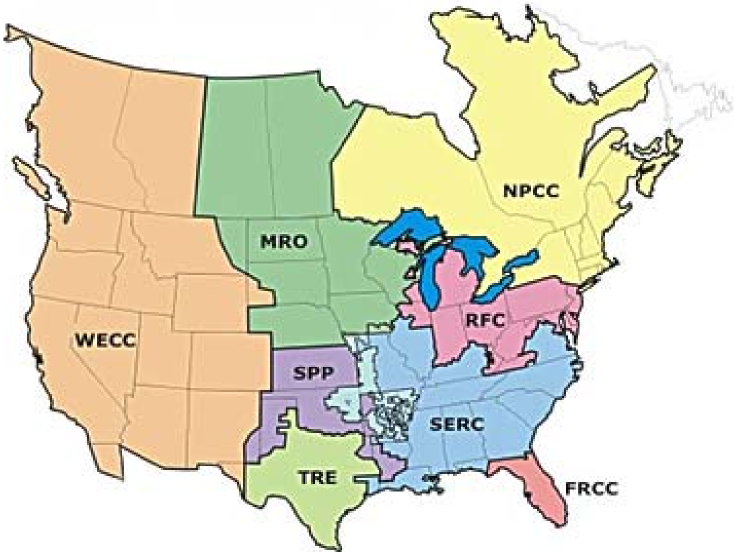
(Hauer & Dagle, 1999; Baker, 2008). As a result, utility companies rely on the existing infrastructure until an outage occurs and use the outage to identify both the underinvestment and problems with the aging power grid (Fox-Penner, 2005).

Anjia et al. (2006) identified five threats affecting power grid reliability and quality: (1) investment in power grid is insufficient, (2) impact of power industry restructuring and the lack of sole responsibility for grid reliability, (3) tendency for owners and operators to focus on a short-term, least-expensive operation approaches, (4) cyber threats and physical threats of the grid, and (5) natural disasters and terrorism threats. As mentioned earlier, deregulation favored utility companies using the existing infrastructure as opposed to investing in new equipment. This essentially created a decentralized web of blame as to who is responsible during outage events: are generation companies responsible for power issues or the transmission companies that transport the power? Similarly, companies are reluctant to spend money on long-term investments because they are focused on handling immediate issues. However, as few improvements are made to the existing system, the susceptibility to physical and cyber threats continually increases (Mili et al., 2004; Bruce, 2002).

One of the major concerns regarding mitigation efforts of power fluctuations is the idea that not enough is being done to secure the nation’s future energy needs. Looking back at the regulatory changes within the electric grid, they have mainly focused on widespread changes lacking specific guidelines as to what needs to be addressed. Unfortunately, these changes must be made on such a large scale that complete understanding and acceptance of what needs to be completed might be difficult. As a result, focused mitigation efforts need to be made to reduce the system deterioration and force electric companies to abide by national guidelines.

National Level Mitigation Efforts

The literature tends to point to the Energy Policy Act of 2005 (EPAct 2005) as a turning point when national attention was brought to bear on the electric grid's problems and a path was officially developed to help mitigate future problems (McDonald, 2008; Abshier, 2007). According to the EPAct 2005, Congress delegated the authority to approve and enforce rules affecting the reliability of the nation's bulk power system to the FERC in an effort to increase the reliability within the nation's electric grid (McDonald, 2008). As a result, the FERC certified the NERC as the Electric Reliability Organization (ERO) providing full control for creating and enforcing reliability standards for the nation's bulk power system (Abshier, 2007). This newly appointed power provided the NERC the ability to create standards and enforce policy affecting power reliability of the different regional entities. As shown in Figure 7, the different NERC regions cover a wide range of varying sizes with each having a completely different population set. Prior to 2005, little effort was being expended within the nation's bulk power system to improve reliability since no single organization wielded the power to enforce the developed standards.



NERC REGION	Total Size (Square miles)	Peak Demand	Number of Customers (U.S. & Canada)
Florida Reliability Coordination Council (FRCC)	~ 50,000	45,734 MW	~ 16,000,000
Midwest Reliability Organization (MRO)	~ 1,000,000	50,575 MW	~ 20,000,000
Northeast Power Coordinating Council (NPCC)	~ 1,200,000	109,798 MW	~ 55,000,000
Reliability*First* Corporation (RFC)	~ 238,000	178,100 MW	~ 72,000,000
SERC Reliability Corporation (SERC)	~ 560,000	202,738 MW	~ 68,000,000
Southwest Power Pool (SPP)	~ 370,000	44,463 MW	~ 5,000,000
Texas Regional Entity (TRE)	~ 200,000	63,491 MW	~ 22,000,000
Western Electricity Coordinating Council (WECC)	~ 1,760,000	160,688 MW	~ 71,000,000

Figure 7. Power Outages by NERC Region **(EIA, 2009)**

Prior to 2005, oversight of the nation's bulk power system was comprised of voluntary organizations lacking authority to enforce any "suggested" reliability standards (Abshier, 2007). Adherence to the developed standards were up to individual power companies and violations went unpunished. Among the most problematic areas with the electric grid is identifying who is responsible for bearing the costs to increase system reliability. One main area of concern is deciding how to estimate expenses needed for improving the system. Brown (2005) estimated that improvements could cost as much as $150 billion with little understanding as to who would be responsible for this tremendous burden since companies were only responsible for a small section of the electric grid.

One major downfall of deregulation resulted in utility companies having little desire to expand the system while operating existing lines closer to their capacity to maximize their economic benefit (Arrillaga et al., 2000). Additionally, the existing regional regulatory councils were more effective at responding to power issues as opposed to managing the risks that preceded it (Hauer & Dagle, 1999). One final area of concern that developed prior to 2005 was the need to strengthen the nation’s bulk power system and the development of an improved response plan (Bruce, 2002).

EPAct 2005 created many ripples within the bulk electric system as the grid’s mandatory reliability standards were developed within the NERC’s Critical Infrastructure Protection (CIP) standards (Abshier, 2007; McDonald, 2008). These standards required utility companies to take responsibility for their areas of the bulk electric systems in North America or risk heavy fines until compliance was achieved. One of the CIP standards required utility companies to identify and protect critical cyber assets responsible for controlling the reliability of the whole system (McDonald, 2008). In development for about three years, the CIP standards went beyond any existing guidance and focused on both security and cyber issues in preparation for possible future problems with the electric grid (McDonald, 2008; McClelland, 2009).

Initially, the NERC struggled to define what is actually considered critical infrastructure but eventually came up with the following definition: “CIP includes facilities, systems and equipment which, if destroyed, degraded or otherwise rendered unavailable, would affect the reliability or operability of the bulk electric system" (McClelland, 2009). As defined by the NERC, this definition leaves room for interpretation by utility companies regarding the actual definition of critical infrastructure. Since the bulk power system is constantly changing, the application of the new standards will limit flexibility and the ability to act decisively in case of an emergency (McClelland, 2009). Finally, the standards that are being created do not always tie directly into issues that are seen across the whole system and this can create issues with enforcing standards if they are not necessarily applicable to each area (Shaw, 2009).

Looking beyond the problems with the CIP standards and the surrounding grid, there appears to be some problems with the standards themselves. In particular, many of the standards contained vague guidance which left a lot of room for utility companies to interpret what they were actually required to do. If an asset is deemed critical in the middle of assessments, no additional time is allotted to rectify the situation and bring the asset into compliance (Mertz, 2008; McClelland, 2009). One area that the NERC left extremely vague is describing "how" companies are to ensure compliance with the standards. This vagueness creates much uncertainty when companies are trying to adhere to the defined standards as they will be audited for compliance by NERC according to their internal definition. These issues have raised additional concerns within the electric grid and have resulted in less-than-acceptable actions.

Once the NERC released the CIP standards and dictated their timeline for compliance, it was apparent little time was built into the schedule to reassess a company's assets to determine their criticality. This in turn put a strain on the utility companies to strive merely for compliance at the cost of possibly failing to adequately secure their systems (Mertz, 2008). As a result, many utility companies are under-reporting the number of critical assets that they own either through a failure to acknowledge a component's importance or intentionally calling it "non-critical" to avoid future actions (Bradbury, 2009; Shaw, 2009). However, even though problems with reliability of the nation's bulk power system are being addressed at the national level, there is an opportunity for consumers to protect their own investments and actually decrease their likelihood of being effected by new and recurring power fluctuations.

Local Level Mitigation Efforts

Whereas mitigation efforts at the national level can be expensive and difficult to coordinate, local efforts can be much less expensive and easier to implement. As with most mitigation attempts, efforts are made to improve the system such that a fast response can occur to prevent the cascading effects of power fluctuations and better isolate problems (Amin, 2005). Consumers often feel they must protect their own assets and invest in a wide range of technologies to help reduce their vulnerability to power fluctuations. Items such as surge protectors, stand-by generators, or even battery backup systems are all tools that help minimize the effects due to unforeseen power events. As noted by LaCommare and Eto (2004), upwards of 3 cents of every manufacturing dollar was spent annually on industrial equipment to address power fluctuation issues. However, simply trying to mask the problem with a small-scale solution might not work in the near-to-mid future (Masse et al., 2007).

If a company relies solely on backup generators to power their facilities during blackouts, unforeseen problems may arise regarding maintenance and continued operations. For instance, a shortage of fuel or trained maintenance personnel might result in a business being unable to supply their own power as they had only planned for short-duration outages. As a result, unknown external factors often alter an organization's plans, making it nearly impossible to be completely prepared for an unknown event with an undetermined duration.

Although it is extremely difficult to plan for a completely new problem, organizations can perform vulnerability assessments to determine where potential weaknesses may exist within their current operations. Specifically, if a power fluctuation were to occur from an outside source, how would it affect operations inside the company and their customers? Once the results from the event are thoroughly understood, steps must be taken to reduce associated risk, identify possible failing areas, develop the response to the incident, and standardize the operating procedures (Anjia et al., 2006).

Instead of passively waiting for the utility companies to restore the grid, the DoD has been developing detailed plans regarding procedures to be used during power outages. The DoD, the nation's largest single consumer of power, has a critical mission that cannot wait for utility companies to restore power. As a result, backup plans exist regarding power restoration to their critical infrastructure. Plans creating additional power production capability have been initiated at multiple locations across the U.S., thereby allowing installations to isolate themselves from the grid through self-sustainment during instances of prolonged power outages. For instance, renewable energy sources (i.e., geothermal, photovoltaic, and wind) and dedicated fossil fuel combustion plants are under construction, or have been completed, to provide sufficient backup for installations during commercial blackouts (Aimone, 2009). Unfortunately though, massive power generation support is not always economically feasible at all locations. Therefore, installations must look at a smaller scale and their internal capabilities to determine the best course of action that is both feasible and economically beneficial.

Future Concerns

One of the most difficult areas to plan for regarding the power grid is the uncertainty behind the demand for future power and any associated requirements. Within the near future, external threats, fuel supply-line issues, and the possibility of cascading failures will continue to be prominent and must have their needs adequately addressed. External threats to the bulk power system, such as terrorists or natural disasters, are often regarded as being able to bring down multiple areas of the system at one time (Amin, 2005). Although there is not a known successful attack by a terrorist on the power system, the potential exists for multiple node failures resulting in widespread outages of an unknown duration (Anjia et al., 2006). Natural disasters are another area that will remain a large concern as the power system will be continuously tested by hurricanes, tornadoes, earthquakes, and various weather events; additionally, scientists are also becoming increasingly worried about the possible negative effects due to solar flares from the sun. A severe solar flare has the possibility to not only bring down large areas of the power system, but it can physically destroy transformers and other conductors due to the large amount of induced current (McClelland, 2009). The effects from such a large storm could last for weeks or longer since equipment would almost surely need replacement due to permanent damage from the storm.

The possibility exists for prolonged power outages and only recently have these concerns been brought to the forefront. Another future concern for the power grid is the availability of a constant stream of fossil fuels required to run the generators powering the U.S. Although most generators are operating from coal mined in the U.S., the possibility exists for a break in the supply line. Such an event would have far reaching effects, possibly requiring other plants to produce additional power until the offline plants could be restored (Umstattd, 2009). The final area that is still a concern for the future is the possibility for more cascading power failures. It is unclear whether the NERC's CIP standards will decrease the possibility of cascading failures because major improvements are needed to the power system as the effects from these fluctuations have such a dramatic impact on our way of life (Watts, 2003).

Geographic Information Systems Analysis

Little research is available regarding GIS analysis and the electric grid. However, within the past few years, the implementation of GIS as a method to analyze geospatially referenced data has become increasingly popular; specifically, the importance of analyzing spatial relationships between events and the corresponding system has become apparent. This gives researchers tools to analyze more than point masses on a map while allowing flexibility to determine intermediate values.

Uses for GIS typically include mapping some sort of geospatial and nongeospatial data such that a visual representation of the data can be created (Shih et al., 2009). This provides a good visual representation of the information's specific locations in order to assess spatial relationships. Tools often used within ArcGIS for analyzing point data typically rely on interpolation through one or more of the following common methods: inverse distance weighted (IDW), splining, or kriging. Three studies in recent years have investigated the implementation of ArcGIS and the different tools to analyze the available information (Shih et al., 2009; Earls and Dixon, 2007; Karydas, Gitas, Koutsogiannaki, Lydakis-Simantiris, & Silleos, 2009). The work by Earls and Dixon (2007) used interpolation of rainfall to determine a more accurate representation through the use of IDW, splining, and kriging. Karydas et al. (2009) utilized interpolation to map the topsoil characteristics within Crete. Lastly, Shih et al. (2009) investigated coal mine disruptions to U.S. power generation facilities through the interpolation of available data.

The Earls and Dixon (2007) study intended to evaluate the different spatial interpolation techniques (splining, inverse distance weighting, kriging) to determine if one type was better for analyzing the available rain data for Charlie Creek, Florida. Varying different parameters within the respective tools resulted in interpolated values of varying accuracy when compared to the actual recorded data. However, for this particular study, it was determined that kriging was the best alternative since the contours followed the actual data more closely and did not lose small data points like the other tools. Similarly, Karydas et al. (2009) investigated different interpolation tools, but focused specifically on five common topsoil properties. In contrast to Earls and Dixon, no specific interpolation tool was determined to be better over another since the provided soil data did not demonstrate continuous trends. It was determined that fragmentation of the land and availability of data points resulted in no tool being better than another. As a result, each study will have a specific tool that matches the dataset closely and it must be analyzed to determine which tool is best in different situations.

The final study, Shih et al. (2009) went a step further than the two previous studies by actually mapping the different components necessary to supply coal to power plants and analyzed how an earthquake can have far-reaching effects. In fact, this study merged geospatial and nongeospatial data such that a model could be created showing the potential impacts of a disruption to one or more areas. This visual representation may not identify specific causes and effects, but it helps estimate the potential impacts of a supply shortage, due to an earthquake in this case, on power plants. In each of these studies, it is important to realize that interpolation is a technique being used by more and more researchers to analyze nongeospatial and geospatial data. However, depending on the intent of the analysis, the interpolation tool will vary.

Management of Vulnerability

No matter the mitigation efforts at the national level, some level of vulnerability for power fluctuations will always exist and it is up to the end-user to create adequate management programs. As discussed in the previous section, EPAct 2005 is a step in the right direction for improving the national power system. Unfortunately, it is anticipated that changes will take an extended amount of time to implement and may need revisions due to ever changing technology. In the meantime, vulnerability can be assessed and managed at the user level such that some responsibility can be removed from the electric companies and placed on the consumers. This in turn will make consumers better prepared for future power fluctuations that might affect their operations.

Vulnerability Defined

Whereas Merriam-Webster (2009) defines vulnerability as “open to attack or damage,” there is much more involved when trying to understand the different intricacies during power outages. When there is a loss within the nation’s power grid, there can either be a partial loss in voltage (sag) or a complete loss of power resulting in a blackout (or brownout). Most of the areas discussed thus far have been about complete blackouts, yet the potential for power sags still exists and must also be addressed. The vulnerability of the electric grid can be interpreted as the overall exposure that exists regarding an attack on the electric grid (LaCommare & Eto, 2004). In recent years, the electric grid has become increasingly vulnerable to physical attacks or even overloading of existing power lines as reinvestment in the electric grid has been low (Mili et al., 2004). However, adequate management of these vulnerabilities can help sustain mission operations even during times of power fluctuations.

Vulnerability Assessment and Management

After determining the associated vulnerabilities throughout the power grid, it is important to determine the specific level associated to the end-user. According to Anjia et al., (2006), the purpose of a vulnerability assessment is to determine when a disruption of service is likely to occur, take steps to reduce the associated risk, identify weak parts, develop the response to the incident, enhance operator’s awareness, and standardize the operation procedures. A vulnerability assessment can be performed in a number of different ways to include the analysis of historical trends regarding outages and their overall affects. The remainder of the steps identified by Anjia et al. (2006) are dependent upon the situation and the available resources that locations have to help mitigate the overall vulnerability. In fact, the USAF Infrastructure Energy Strategy (2008) mentions specifics regarding the DoD's vulnerability of power fluctuations at Air Force installations.

> Risk to critical missions at installations is a site-specific problem that is being studied within the Air Force in concert with DoD, the DHS, and the DOE, but the different parts of the problem are not yet integrated into a comprehensive "get well" plan. We can reduce some of this mission risk through conservation and expanded site-generated renewable energy. A number of steps are required to ensure more resilient electrical and logistics fuel systems support at Air Force installations: Energy must be included in Air Force Critical Infrastructure Program plans, studied during Vulnerability Assessments, exercised during base response activities, and, ultimately, incorporated into full-spectrum operational planning to fully observe and consider the potential deleterious effects.

The Air Force is working to determine an associated level of vulnerability at their installations but needs complete integration of information from other Department of Energy, Department of Homeland Security, and DoD entities. Whatever tool the end-user decides to implement, vulnerability will only be adequately managed if there is a system in place that keeps reiterating the importance of what is being done. Whether it is incentive based or otherwise, individuals need to be reminded that they can make a difference in managing a much larger vulnerability.

Chapter 3. Methodology

This chapter explains the unique methodology used to analyze historical power outage data and the potential impacts on Air Force installations. Through the data collection and analysis, an awareness tool was created to help properly identify an installation's vulnerability to future power outages. Information collected from the Energy Information Administration (EIA) was imported and analyzed with a geographic information system (GIS) software, ArcGIS, to determine the geographic locations of historical power outages and their proximity to Air Force installations. The main tool utilized within the ArcGIS was the inverse distance weighted (IDW) methodology, which interpolates the value between data points to create contour maps. The information developed from the GIS analysis provided historical trends for power outages based on duration, number of customers affected, and total power loss. The combination of these three maps using the raster calculator in ArcGIS, creates an overall vulnerability map for the different regions of the United States (U.S.) as shown in Figure 8.

Data Source

Utilizing GIS to analyze power outages is an innovative approach compared to traditional statistical analysis often used to determine historical trends (Hines et al., 2008; Mili et al., 2004). In fact, this approach needs three important types of data (duration, number of people affected, and power loss) to successfully perform the spatial analysis. Collecting and scrubbing the information about power outages was the first step that needed to be completed before being able to analyze the data. Although the EIA's database contained a large volume of information, some data were found to be either missing or incorrect. In particular, since the formation of the database in January 2000, many utility companies have changed names since they originally reported information. Additionally, although the EIA forms require utility companies to report details regarding the location of power outages, this information typically only identifies the equipment affected and not the geographic location. As a result, it was important to be able to interpolate the origins of the power outages and the areas affected. The addition of spatial reference through latitude and longitude global positioning coordinates facilitates interpolation within the GIS software.

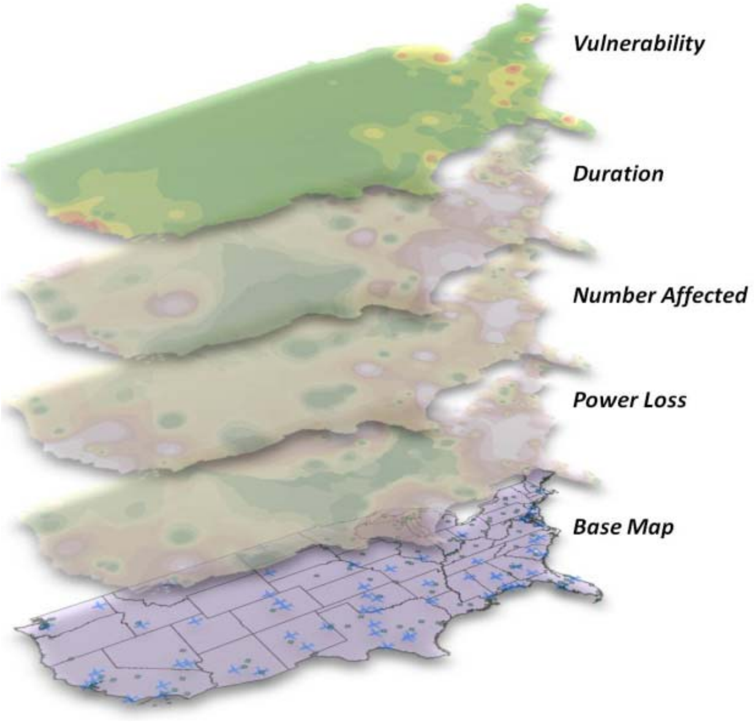


Figure 8. Data Collection and Analysis Process

Major Disturbances and Unusual Occurrences Data

Published research efforts analyzing the electric grid often rely on the Disturbance Analysis Working Group (DAWG) database maintained by the North American Electric Reliability Corporation (NERC). Although the DAWG database is fairly complete, its major shortcomings include a lack of outage duration and no requirement for all outages to be reported. Therefore, the analysis presented in this research used data obtained from monthly Electric Disturbance Events summaries maintained by the EIA. The time period for the data ranged from 1 January 2000 to 31 August 2009. The specific data fields included in the analysis were the power loss (in Megawatts (MW)), number of people affected, and duration of the power disturbance. Previous research had utilized these same fields to perform their analysis, in addition to considering the time of day (Mili et al., 2004; Hines et al., 2008; Savageau, 2004).

Over the past 10 years, the EIA has changed the forms utility companies use to report outages. Therefore, the summaries are based on information obtained from emergency incident and disturbance reports (EIA-417) prior to December 2008 and electric emergency incidence and disturbance reports (OE-417) from December 2008 to August 2009. Both forms, shown as Appendix A and B, respectively, require the same information to be filed with the EIA's Office of Electricity Delivery and Energy Reliability (Defense Science Board Task Force, 2008). The EIA requires companies to file an EIA-417 when one or more of the following conditions are met.

(1) Initiates 3 percent or more system voltage reduction
(2) Disconnects circuits supplying over 100 megawatts of firm customer load
(3) Issues a public appeal to the public for a voluntary reduction in electricity use
(4) Has existing or anticipated fuel supply emergency situations
(5) Suspects an act of sabotage or terrorism

The OE-417 form is actually an alert notification to the Department of Energy (DOE) regarding actual problems within the electric system; it can be also used to identify potential concerns. However, the EIA does not record all power disturbances because the reporting thresholds specified for the OE-417 are typically not applicable to smaller utilities. In other words, the data does not include all power outages – only reported power disturbances meeting the above criteria. As a result, the data represents events with far larger customer impacts over a much wider service territory.

After it was determined that electric companies were required to report a power outage, the timeliness of informing the EIA was determined by whether the event constituted a 'normal alert' or an 'emergency alert.' The requirements for both alert levels are described in Table 1. For 'emergency alerts,' utility companies are required to complete the OE-417 within an hour of the event and must follow-up as circumstances change. In addition, for events classified as 'normal alerts,' utility companies must complete the OE-417 within 6 hours of the incident and follow-up with any change in the outage. Both alerts require the reporting company to submit a final form to the EIA within 48 hours detailing as much information as possible regarding the power outage.

As was briefly discussed, both the EIA and DAWG databases lacked specific detailed information about the location of the people affected and the origin of the original power incident. EIA's OE-417 (Appendix A) requires utility companies to report the origin of the power outage within their service area, but this information is "protected" and not readily available for analysis as it details significant failure points within the nation's power grid. The specifics regarding what is actually required can be found in Schedule 2 of the OE-417 (Appendix B).

Table 1. EIA Alert Reporting Guidance (Form OE-417)

Emergency Alert	[ ] Actual physical attack that causes major interruptions or impacts to critical infrastructure facilities or to operations [ ] Actual cyber or communications attack that causes major interruptions of electrical system operations [ ] Complete operational failure or shut-down of the transmission and/or distribution electrical system [ ] Electrical System Separation (Islanding) where part or parts of a power grid remain(s) operational in an otherwise blacked out area or within the partial failure of an integrated electrical system [ ] Uncontrolled loss of 300 Megawatts or more of firm system loads for more than 15 minutes from a single incident [ ] Load shedding of 100 Megawatts or more implemented under emergency operational policy [ ] System-wide voltage reductions of 3 percent or more [ ] Public appeal to reduce the use of electricity for purposes of maintaining the continuity of the electric power system
Normal Alert	[ ] Suspected physical attacks that could impact electric power system adequacy or reliability; or vandalism which target components of any security systems [ ] Suspected cyber or communications attacks that could impact electric power system adequacy or vulnerability [ ] Loss of electric service to more than 50,000 customers for 1 hour or more [ ] Fuel supply emergencies that could impact electric power system adequacy or reliability

Geospatially Referenced Layers

The second data collection involved the integration of pre-made layer files into a consolidated map showing U.S. boundaries and the location of military installations. Within ArcGIS, layers are defined as a collection of components that are projected over other components and can be manipulated separately from other layers. For the purposes of this analysis, the coordinate system that was used was an industry standard, the geographic coordinate system world geodetic system 1984 (GCS WGS 1984). The data layers for Air Force installations and states were collected from the online National Atlas (U.S. Department of the Interior, 2009), which replaced the original paper-bound version of this service for maps of the U.S. Two layer files were subsequently used, one layer showing all military installations and another showing state boundaries. Since the focus of this analysis strictly pertained to Air Force installations, all other military installations were removed from the layer. The incorporation of these two layers with data collected from the EIA's database aggregated all the information necessary to analyze and assess an Air Force installation's vulnerability to power outages.

Data Adjustment

The main objective of the data collection effort was to assess historical power outage data and determine if individual Air Force installations appear to be susceptible (or vulnerable) to certain types of power outages, to include overall duration and number of customers affected. As is the case with receiving third party information, it does not always contain all the necessary components to easily perform the desired analysis. In this instance, much of the data received from the EIA, through the EO-417 and EIA-417 forms, needed to be adjusted such that it could be analyzed within ArcGIS. In addition, it was necessary to attach spatial references to each power outage, which was performed in conjunction with the validation of current electric companies and renaming ones that have since merged. The final database is found in Appendix C.

Power Outage Company Identification Adjustment

Utility companies are required to report a great deal of information on the EIA-417 and OE-417 forms, including the name of the power company responsible for the outage and the NERC region to which they belong. However, many of the companies were found to no longer exist; they were either sold, merged with other companies, or simply went bankrupt. As a result, it was important to create a consolidated list of existing companies and their respective areas of responsibility. For instance, if company X reported an outage in March 2005 and merged with corporation Y in 2008, corporation Y would assume responsibility for all reported outages by company X. Once a consolidated list of existing power companies was created, it was necessary to determine the service areas for each power company and the centroid of their area of responsibility. An example of this is shown in Figure 9 for a gas and electric service provider in South Carolina. Following one of the study's original assumptions, the information for each power outage is applied at the center of each power company's service area. The resulting center (or centroid) is based on the geographic location of the electric service provider's service area.

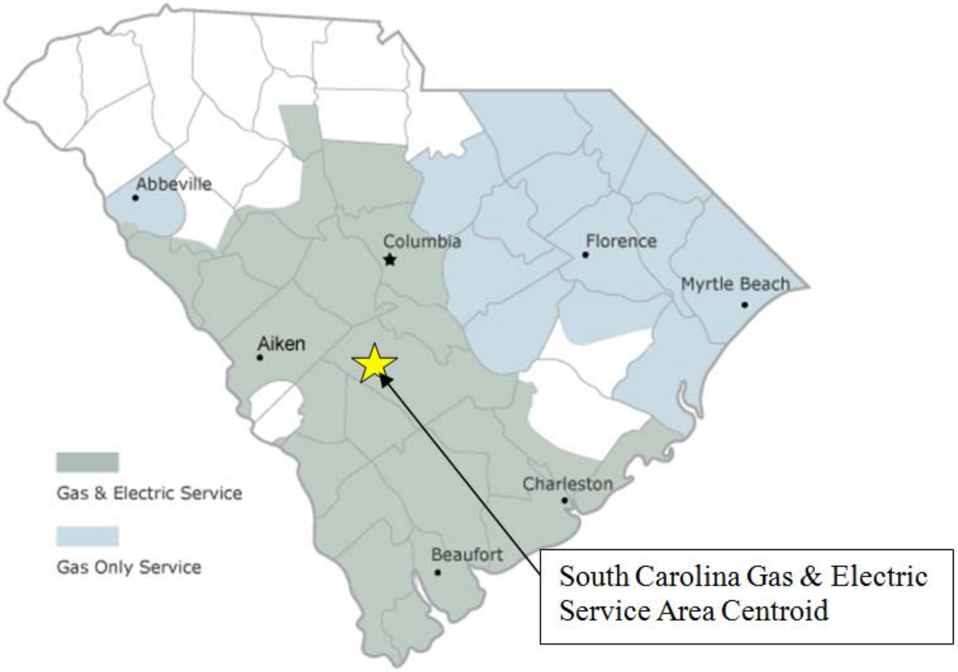


Figure 9. Example Centroid of Electric Service Area (SCE&G, 2010)

By searching each utility company's website, it was possible to determine their service area and then use a global coordinate system to determine the centroid of the area of responsibility. This information was then incorporated into the spreadsheet containing the EIA's power outages. The inclusion of this information allows for spatial analysis within GIS to be performed. However, it was necessary to polish the data from the EIA to remove data points that were missing information and ensure that all the reported data was in a consistent format.

EIA Database Adjustment

At this point in the process, the spreadsheet contains the names of the updated power companies and their spatial coordinates; however, the remainder of the information needed to be standardized. Of the initial 720 records in the database, 234 were missing at least one of the identified attributes and 43 were outside the continental U.S. Eliminating these records resulted in a total of 443 data records to be analyzed. Within the remaining data, it was important to ensure that the fields for power loss, number of people affected, and duration each used a standardized format. Otherwise, an extraneous value that was either too large or small could bias the analysis. Upon importing the information from the spreadsheets into ArcGIS, it was important to remove any special formatting in the database. This was required since the spreadsheet software and GIS do not always interpret formulas and formatting the same. The remaining modifications included simple formatting within the spreadsheet program. Once the adjustments of the EIA's database were complete, the data analysis could proceed.

Data Analysis

Before conducting spatial analysis, the data was examined for any trends in either the number or magnitude of power outages from January 2000 to August 2009. Caution must be used with these trend plots since the charts represent the number of reported outages and not the actual number of outages. However, the incorporation of geospatial analysis through GIS can provide a much more detailed picture displaying the impacts of power outages on surrounding communities. To analyze the data with ArcGIS, the IDW method was used with each of the three separate components (power loss, number of people affected, and duration). Using the raster calculator in ArcGIS, the three layers were compiled into an overall vulnerability contour map showing different levels across the continental U.S.

To investigate the vulnerability of Air Force installations to different types of power outages, the Spatial Analyst Tools in the ArcGIS software from the Environmental Systems Research Institute, Inc. (ESRI), were used to perform spatial interpolation of the data. As part of the initial setup, it was necessary to ensure that the coordinate system of all layers and the imported EIA data records were consistent with the GCS WGS 1984 format. The next step was to create a personal geodatabase (GDB) file, which is an object-oriented graphic database that allows all information contained within the map file to be consolidated in one central location. Typically, if information is added from random places, the map simply uses these references to refer to the information. As a result, if the information was moved or deleted, the different map components would need to be re-referenced before being displayed correctly. Where this comes in handy is if the map were to move from one computer to another computer; each referenced layer would only have to be referenced back to one location as opposed to searching for all the scattered components. The creation of the personal GDB file, in conjunction with setting up the layers with uniform coordinate systems, puts the information into a format where it can now be analyzed.

The ability to analyze data with GIS software ultimately depends on the anticipated results and the type of outcome expected. As defined by Childs (2004), procedures involving interpolation determine values on a surface between sampled points. As displayed in Table 2, there are multiple interpolation tools available within ArcGIS. However, the IDW tool provided the best option, when comparing the different options in Table 2, since it allows flexibility to weight closer data points more heavily than those far away. The Spatial Analyst Tools, and specifically IDW, focus on the use of deterministic approaches to estimate "cell values by averaging the values of sample data points in the neighborhood of each processing cell" (ESRI, 2007).

Table 2. Interpolation Tools within ESRI ArcGIS (ESRI, 2006)

TYPE	**DESCRIPTION**
IDW	Interpolates a surface from points using an inverse distance weighted technique
Spline	Interpolates a surface from points using a minimum curvature spline technique
Trend	Interpolates a surface from points using a trend technique
Kriging	Interpolates a grid from a set of points using kriging
Natural Neighbor	Interpolates a surface from points using a natural neighbor technique
Topo to Raster	Interpolates a hydrologically correct surface from point, line, and polygon data.

Since power outages are scattered across the U.S., it is important to be able to interpolate between observed points to determine an Air Force installation's vulnerability to power outages. According to Tobler's Law (Tobler, 1970), "everything is related to everything else, but near things are more related than distant things." This concept is the premise behind IDW analysis, which states that points closer to a central node (i.e., an Air Force installation) will affect the node more than points farther away, even though the points may be larger. In other words, power outages closer to a base are more likely to affect the base than those far away. The IDW method was performed by calculating values based on a variable radius determined by the closest 12 points. Interpolating through IDW was performed on the individual power outage points in relation to Air Force installations as shown in Figure 10.

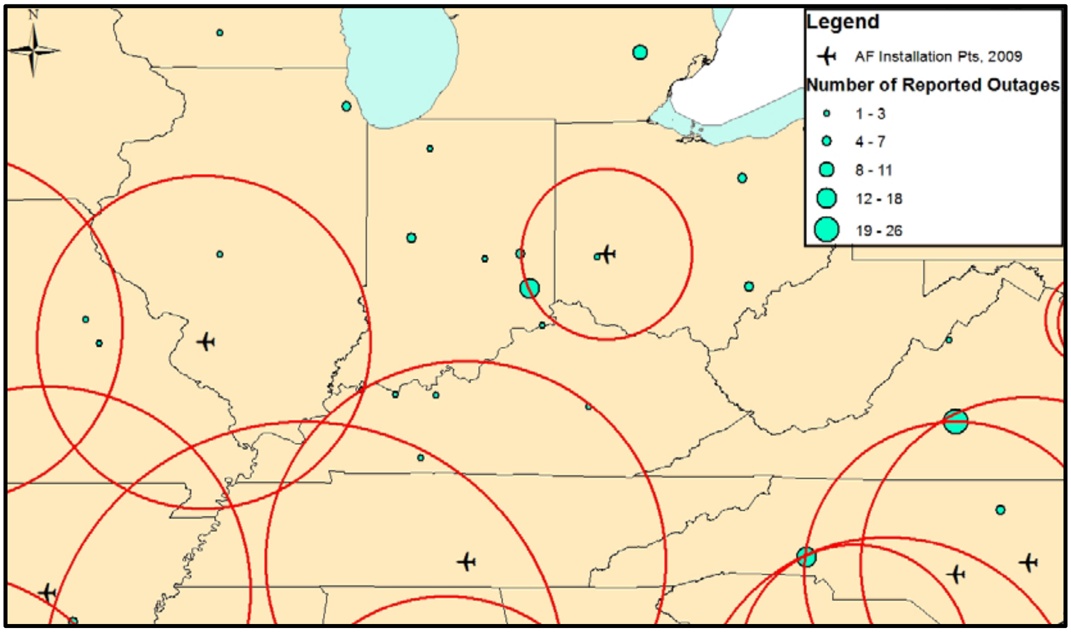


Figure 10. IDW for a Sample set of Air Force Installations

The search radii, in conjunction with power, were two components that had the largest impact on the overall IDW results. In Figure 10, the different radius diameters are dependent on the number of power outages in the surrounding area such that each circle includes 12 power outages. For instance, the base in Ohio has the smallest circle since 12 power outages were in closer proximity than the base found in Tennessee, which has a much larger circle. It can be interpreted that the smaller a circle, the higher the apparent concentration of power outages surrounding the base. A higher power value created a larger emphasis on the nearest points which in turn would create more detail on the final map.

Elaborating further with Figure 11, IDW utilizes a technique called Shepard's Method to interpolate values of data points based on existing data. Equation 1 states that the magnitude at (x,y) is equal to the summation of all surrounding points at some particular weight (w_i). The weight is further defined in Equation 2 as the distance between the known data point and the value to be determined at (x,y) raised to a negative power. Throughout this model, the power (p) was determined to be 2, which is the default value in both Shepard's Method and ArcGIS IDW interpolation. Equation 3 defines the actual distance between the known data points and areas being interpolated. Finally, Equation 4 is the combination of Equations 1 through 3 which calculates the magnitude of the interpolated data points. The combination of these three equations fully defines Shepard's Method for interpolating unknown values. In ArcGIS, these equations are hidden from the user and the only values that must be entered are n, the number of data points to be considered, and the power, p. For both n and p, the default values (12 and 2, respectively) were chosen as a starting point for the analysis. The rest of the analysis is automatically performed and the results are produced as a raster file which can be further analyzed.

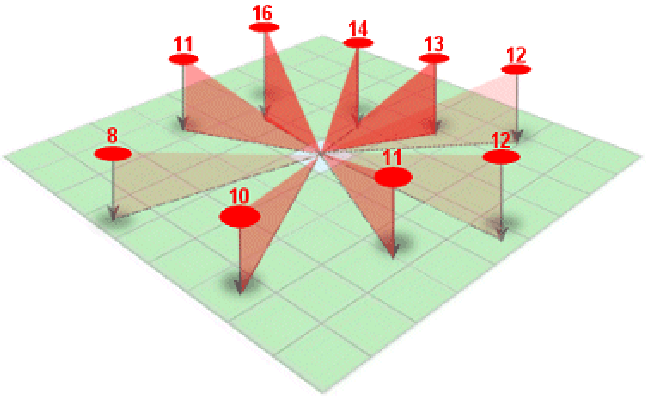


Figure 11. Inverse Distance Weighted Model **(ESRI, 2007)**

$$F(x,y) = \sum_{i=1}^{n} w_i\, f_i \tag{1}$$

$$w_i = \frac{h_i^{-p}}{\sum_{j=1}^{n} h_j^{-p}} \tag{2}$$

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{3}$$

$$\therefore F(x,y) = \frac{\sum_{i=1}^{n} \frac{f_i}{h_i^{\,p}}}{\sum_{i=1}^{n} \frac{1}{h_i^{\,p}}} \tag{4}$$

$F(x,y)$ = Unknown magnitude at unknown point (x,y)
(x_i, y_i) = Point with known magnitude
f_i = known magnitude at point (x_i, y_i)
w_i = weighted value of point (x_i, y_i) on (x, y)
h_i = distance from point (x_i, y_i) to (x, y)
p = power (or effect) that point (x_i, y_i) has on (x, y) (2 is the default)
n = number of points (12 is the default)

GIS Data Analysis and Model Development

IDW can now be performed in ArcGIS using the guidelines described in the Procedural Log developed for this research and shown in Appendix D. The first step is to perform an IDW for each of the three previously identified components: duration, power loss (in MW), and number of people affected. The output was a contour map for each component across the U.S. Individually, these created layers do not tell the complete story; when combined into a single contour map though, they reveal the vulnerability of areas based on varying levels of outage durations, power loss, and number of people affected.

To properly compile the three layers, it was important to first normalize, or somehow standardize, the information across the three layers. This is important because if the data from the three layers is simply added, the number of people affected will completely dominate the output results. The reason behind this assumption is the units: the number of people affected is in the millions, while both the power loss and duration are in the hundreds. In addition, all three components are necessary to be compiled since the three components are not directly related to one another. In some instances, a power outage that has a high power loss might affect a large group of people; however, this is not always true. For instance, industry can dominate power consumption even though it typically represents only a small population. This led to the development of the following equation to determine vulnerability.

$$Vulnerability\ Index = \left(\frac{N}{N_{MAX}}\right) + \left(\frac{M}{M_{MAX}}\right) + \left(\frac{D}{D_{MAX}}\right) \qquad (5)$$

N = *Total number of people affected*
N_{MAX} = *Maximum value for number of people affected*
M = *Megawatt loss*
M_{MAX} = *Maximum value for megawatt loss*
D = *Duration*
D_{MAX} = *Maximum value for duration*

Using Equation 5, the three layers are individually normalized such that the resulting values range from 0 to 1 (with 0 being no effect and 1 having the largest effect). The numerators of the terms in the equation represent all values calculated within the respective layers through IDW interpolation, whereas the denominators are the maximum value for each respective layer.

The incorporation of the above equations in ArcGIS is accomplished using the raster calculator. This tool allows different components to be aggregated into a single layer. Once Equation 1 is used in the raster calculator, the output is a contour map showing the vulnerability of regions in the U.S. to power outages. The output is a unit-less map with associated vulnerabilities based on the weights described in Equation 2. Within the map are contour levels showing areas with a low and high vulnerability index such that areas with lower levels are less likely to be impacted by large-scale power outages; whereas, in areas with a high vulnerability index, they are more likely to be impacted by a large-scale power outage. Each base falls within a region on the map and therefore a value, based on the calculated vulnerability layer, can be determined for each Air Force installation.

Summary

The objective of this study was to develop a model for assessing the level of vulnerability for Air Force installations based on power outages from 2000 to 2009 in the EIA database. Scrubbing the data and putting it in the same format, along with using the same coordinate system, was required prior to analyzing the point masses. IDW and the raster calculator were used in ArcGIS to determine the associated levels of vulnerability for Air Force installations. These results then provided what is called the level of vulnerability, ranging from low to high, which installations can use as a basis to investigate mitigation efforts.

Chapter 4. Results and Analysis

Existing literature has a void regarding research on power outages in the United States (U.S.) and the effects from their spatial relationship to surrounding communities. The focus of this thesis was to examine the effects of power outages on Air Force installations by analyzing the Energy Information Administration's (EIA) power outage database using both spreadsheet software and ArcGIS. Previous research has focused strictly on the statistical analysis of existing power outage databases to investigate trends and correlations. Analysis for this thesis began by utilizing spreadsheet software to determine trends in the EIA's database, to include different North American Electric Reliability Corporation (NERC) regions which might be a predictor of the anticipated results discovered from ArcGIS. The main approach used in this study was the inverse distance weighted (IDW) method to examine the EIA's power outage data points for megawatt (MW) loss, number of people affected, and duration for the individual points from January 2000 to August 2009. Although the nation's grid is connected to Canada, and NERC regions extend to Canada, the focus of this analysis is strictly limited to the continental U.S. and the effects felt therein.

Initial Results

A large number of data points from the EIA's power outage database were missing one or more of the following components: MW loss, number of affected customers, and total duration. Of the original 720 data points from the EIA's database, only 443 total points contained complete records and were subsequently used in the analysis. Additionally, some data points had incorrect information, to include utility company names that no longer existed. A significant search for older companies led to the finding that many companies had merged into larger, present-day corporations. Although this might create some discrepancies within the final analysis, it is important to group the companies together such that the analysis could be performed within both the spreadsheet software and ArcGIS.

Initial analysis of the EIA's power outage database involved the utilization of spreadsheet software to graph different outage characteristics (duration, number affected, power loss) from January 2000 to September 2009. Figures 12 through 14 represent categorized charts of the different outage characteristics. No trends are apparent in any of the charts, yet it is apparent that between 2002 and 2003, there is a sizable jump in reported data. The next analysis strove to investigate the number of reported outages per year since January 2000. As shown in Figure 15, it is readily apparent that there are two distinct time periods within the specified timeframe, one from 2000 to 2002 and the other from 2003 to 2009. Within each time period, the number of outages is relatively consistent (except for the anomaly in 2008). It is unclear what caused the increase in outages between the two time periods; similarly, there is insufficient information to explain why reported power outages remained higher in the 2003 to 2009 time period.

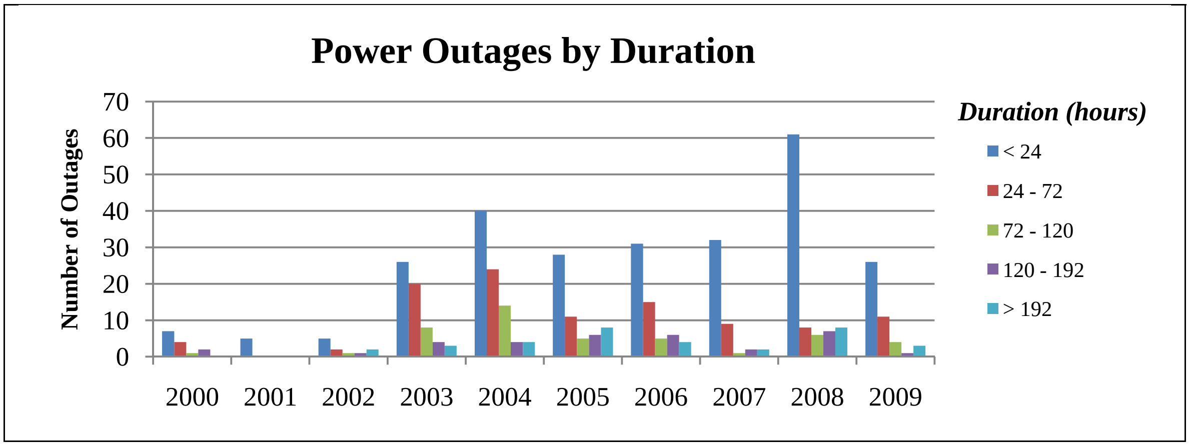


Figure 12. Categorized Power Outages by Duration

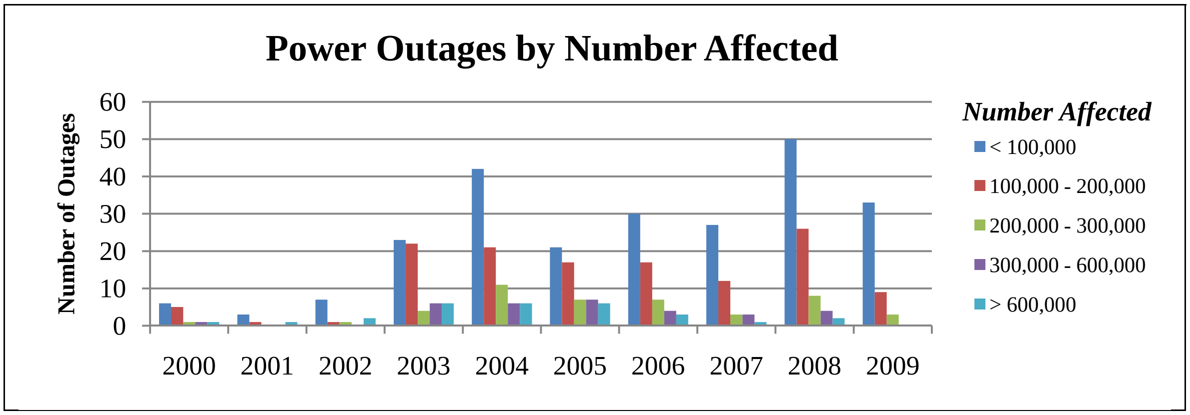


Figure 13. Categorized Power Outages by Number Affected

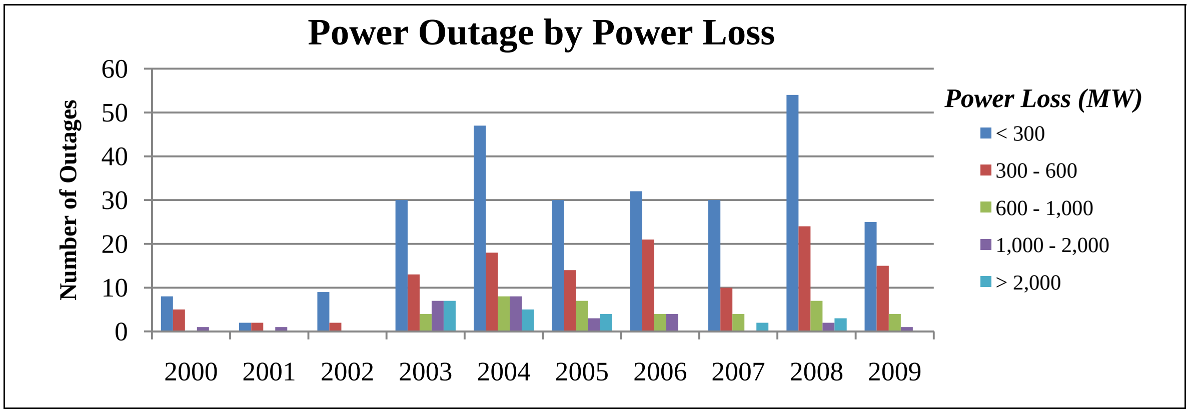


Figure 14. Categorized Power Outages by Power Loss

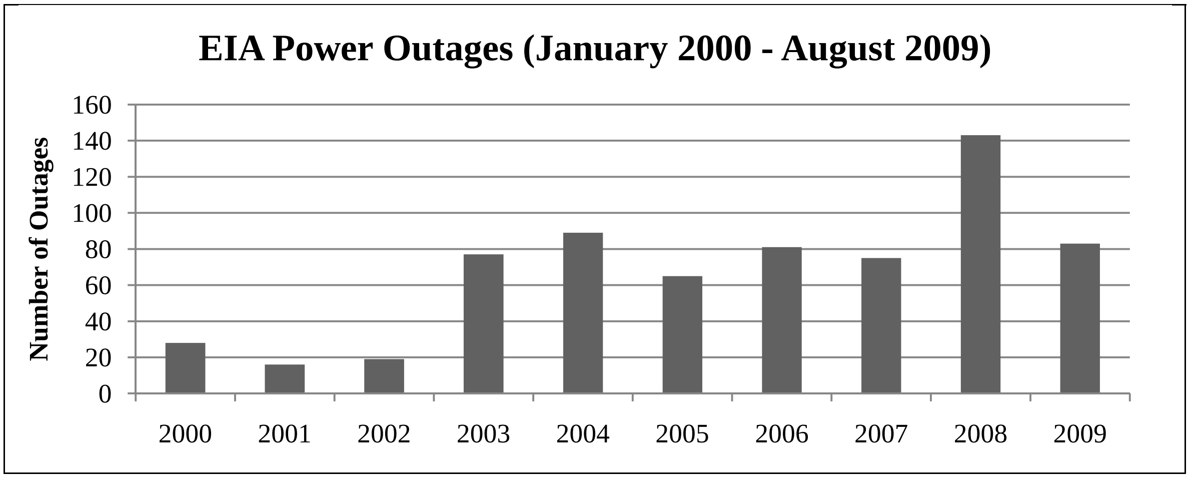


Figure 15. Total Power Outages by Year

The number of reported outages can be further broken down into the different NERC regions, power companies, and causes of disturbances. It is important to investigate the origin of the outages to be able to determine if there are any patterns involving regional power reliability or even a significant impact due to natural disasters. First, it is important to understand that although the different NERC regional entities can be compared on paper, the fact of the matter is that their size and population they serve vary greatly. However, further investigation of any possible regional trends might provide good insight regarding possible problems within a specific area. As shown in Figure 16, the NERC regions experienced an unequal amount of power outages. It is interesting to note that while some NERC regions (e.g., SPP, MRO, FRCC) experienced a fairly consistent number of outages, other regions (e.g., WECC, RFC, NPCC) had a sizeable increase in reported outages from January 2000 to August 2009.

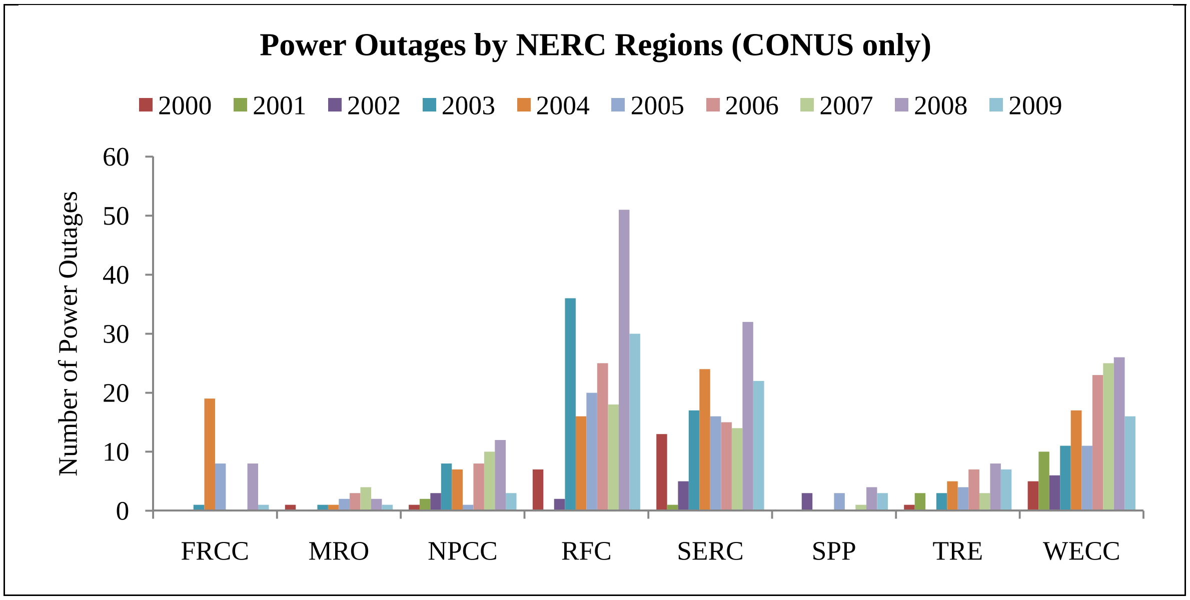


Figure 16. Power Outages by NERC Regions (EIA, 2009)

Without additional research, it is difficult to fully address why some regions experienced a sudden jump in power outages. Referencing Figure 16, it is possible to make the determination that over the past 10 years, some NERC regions had little to no gain in the number of power outages while other areas displayed a constant, annual increase in the number of outages. For instance, California and the Western U.S. (WECC) have experienced many disturbances in recent years that have had a widespread impact and have occurred more frequently than in past years.

In addition to examining trends in the number of power outages, it is also possible to investigate if there are any trends in the reported causes of the power outages. As shown in Figure 17, there were 13 different categories of causes for reported power outages. No immediate observations can be made regarding the different types of power outages except the fact that nature tends to be the source of most power outages.

Information supporting the justification for why the outages caused by natural events are the highest cannot be specifically determined since it could be for a multitude of reasons. However, the nation's electric grid might be increasingly susceptible to repeated abuse by nature and the lack of adequate preventive maintenance is causing additional numbers of power outages. Another interpretation of Figure 17 could be that no matter how much preventative maintenance is performed, natural events are still going to occur at random and have a significant impact on the ability to supply power. From the literature review in Chapter 2 though, this is unlikely since power companies have spent little money on the existing grid while operating it as close to maximum capacity as possible. This in turn makes it easier for an otherwise small event to have a much larger impact. Although insights can be gained from trend analysis, more detailed analysis is necessary.

Intermediate Results

The initial part of this research involved simply charting the EIA's electrical disturbance database to determine any types of trends that might exist. This section takes the next step by performing interpolation of the three separate data categories (duration, number of people affected and MW loss). As was discussed in the literature review, the nation's electric grid has evolved such that it is heavily interconnected and there exists a large potential for more widespread power outages. This is the premise behind the use of IDW for the electric grid since what might happen in one area could permeate to other areas through the web of wires connecting the electric grid.

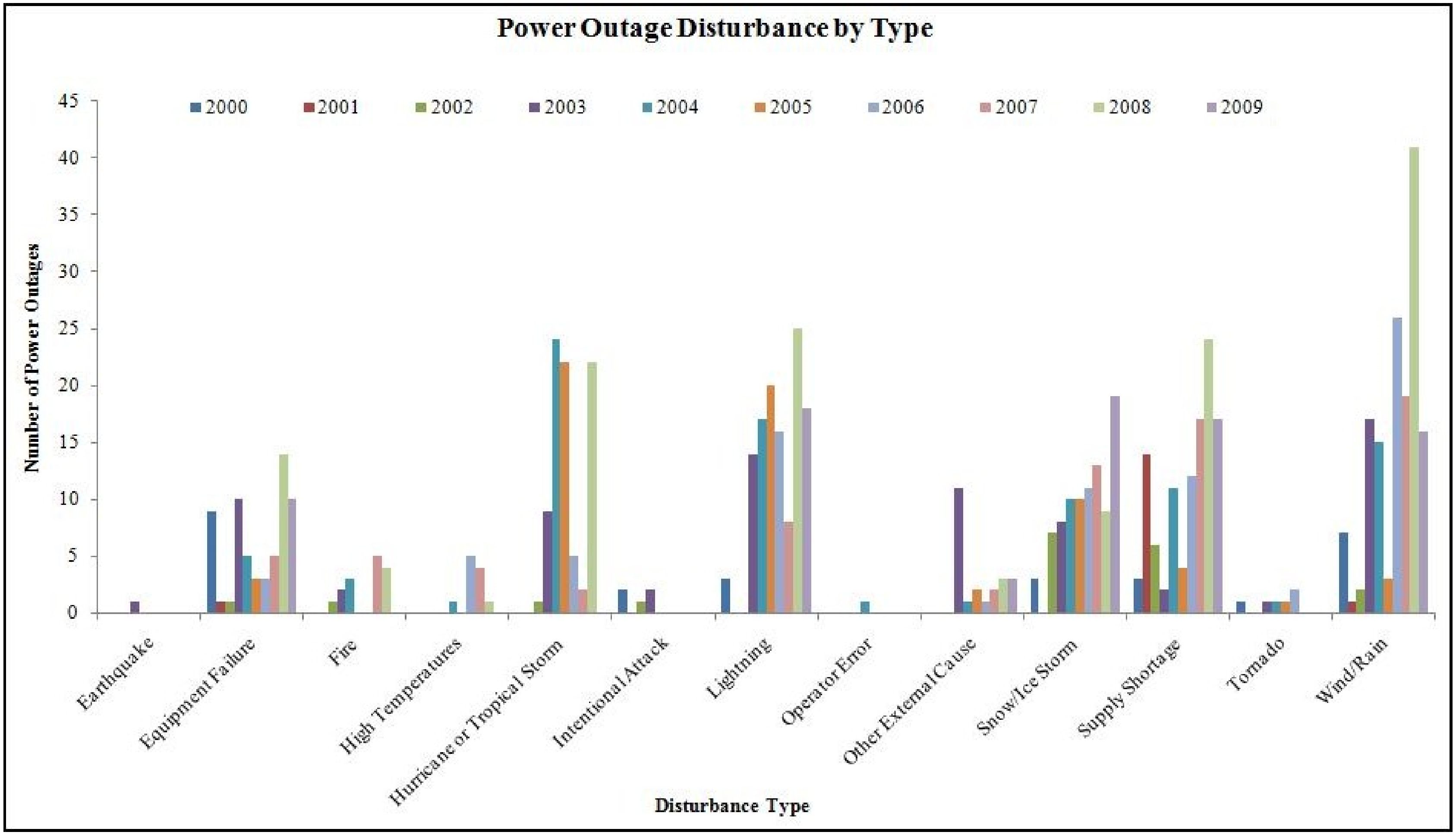


Figure 17. Power Outage Disturbances by Type (EIA, 2009)

The results described herein take the next step in analysis by performing interpolation on the available data points to create a contour map reflecting vulnerability. Through the analysis of the three data categories, it was possible to create an overall vulnerability map compiling these different components. Categories were created for the specific components, ranging from green to red scales as shown in Table 3, to allow the interpolated layers to be interpreted based on related data.

Table 3. Categorized Outage Components

	MW Loss	**Number Affected**	**Duration (Hours)**	**Vulnerability Index**
Green (A)	< 300	< 100,000	< 24	< 0.25
Teal (B)	300 – 600	100,000 – 200,000	24 – 72	0.25 – 0.5
Yellow (C)	600 – 1,000	200,000 – 300,000	72 – 120	0.5 – 0.75
Orange (D)	1,000 – 2,000	300,000 – 600,000	120 – 192	0.75 – 1
Red (E)	> 2,000	> 600,000	> 192	> 1

The categories for the megawatt loss were grouped based on actual power plant sizes found within the U.S. For instance, of the 5,336 generators supplying power within the U.S., 81% produced power less than 300 MW, 7% produced power ranging from 300 to 600 MW, 5% produced power ranging from 600 to 1,000 MW, 5% produced power ranging from 1,000 to 2,000 MW, and 2% produced power greater than 2,000 MW. Similarly, population categories were determined from the 2000 U.S. census. For this category, 81% of U.S. counties have a population less than 100,000; 9% have a population between 100,000 and 200,000; 3% have a population between 200,000 and 300,000; 4% have a population between 300,000 and 600,000; and 3% have a population in excess of 600,000. For the power outage duration, the EIA database was used to group outage durations in similar categories. Accordingly, 55% of the outages had a duration less than 24 hours, 22% had a duration between 24 and 72 hours, 9% had a duration between 72 and 120 hours, 7% had a duration between 120 and 192 hours, and 7% had a duration greater than 192 hours. These categories allow for bases to be categorized according to the ranges specified in Table 3.

The last column in Table 3 shows the vulnerability index classifications as it was calculated for this particular study. Based on Equation 5, it is important to keep in mind that the highest vulnerability index that could be calculated would theoretically be 3. This would be considered the worst case scenario where the maximum number of people are effected with the largest power loss and for the longest duration. However, the ranges in this study were found to range from 0 to 1.83. This implies that the largest value in one category did not always translate into the largest value in another category. In order to determine the specific categorical breaks, a natural break option within ArcGIS was utilized to create the best group of similar values which maximizes the difference between the groups. As shown by the different break points in Table 3, the vulnerability index levels are categorized for bases using the following descriptions.

- Green (A) Level – Installations have a chance to experience a widespread power outage lasting a short duration
- Teal (B) Level – Installations have a chance to experience a small scale power outage lasting less than two days.
- Yellow (C) Level – Installations have a chance to experience a mid-size power outage lasting upwards of four days.
- Orange (D) Level – Installations have a chance to experience a large power outage lasting upwards of a week.
- Red (E) Level – Installations have an chance to experience a catastrophic power outage lasting more than one week.

Inverse Distance Weighted for Number of People Affected

The number of people that a power disturbance actually affects depends on the utility company's best guess as to the total number of homes affected. Upon initial reporting, companies are required to submit an estimate for the total number of people affected; however, if the outage is widespread, or conversely, isolated, the exact number of individuals affected can vary significantly. As a result, the total number of people affected by the power outage tends to align with both the duration and magnitude (in MW) of the power disturbance. However, the higher the number of people affected, typically the wider the area impacted by the actual outage. This was evident in the northeast blackout of 2003, when approximately 50 million people were affected across multiple states for an extended amount of time.

The first analysis performed IDW on the number of people affected by power outages as shown in Figure 18. Additional figures are provided in Appendix E showing a more detailed view of the IDW analysis for the number of people affected. The proper way to interpret Figure 18 is that based on historical power outages, areas in red would have experienced outages that affected more than 600,000 people. As it pertains to the Air Force, there are some installations that find themselves within the "hot zone," where more people have technically been affected. As shown in Table 4, Little Rock AFB, Los Angeles AFB, Tinker AFB, and Vance AFB have all experienced outages affecting more than 600,000 people. This is a weighted collection over the past decade such that there might have been a large amount of small outages around the bases or simply a few large outages that had a very large impact. Either way, bases that are shown as being in either the orange or red categories have experienced outages totaling the highest in the nation.

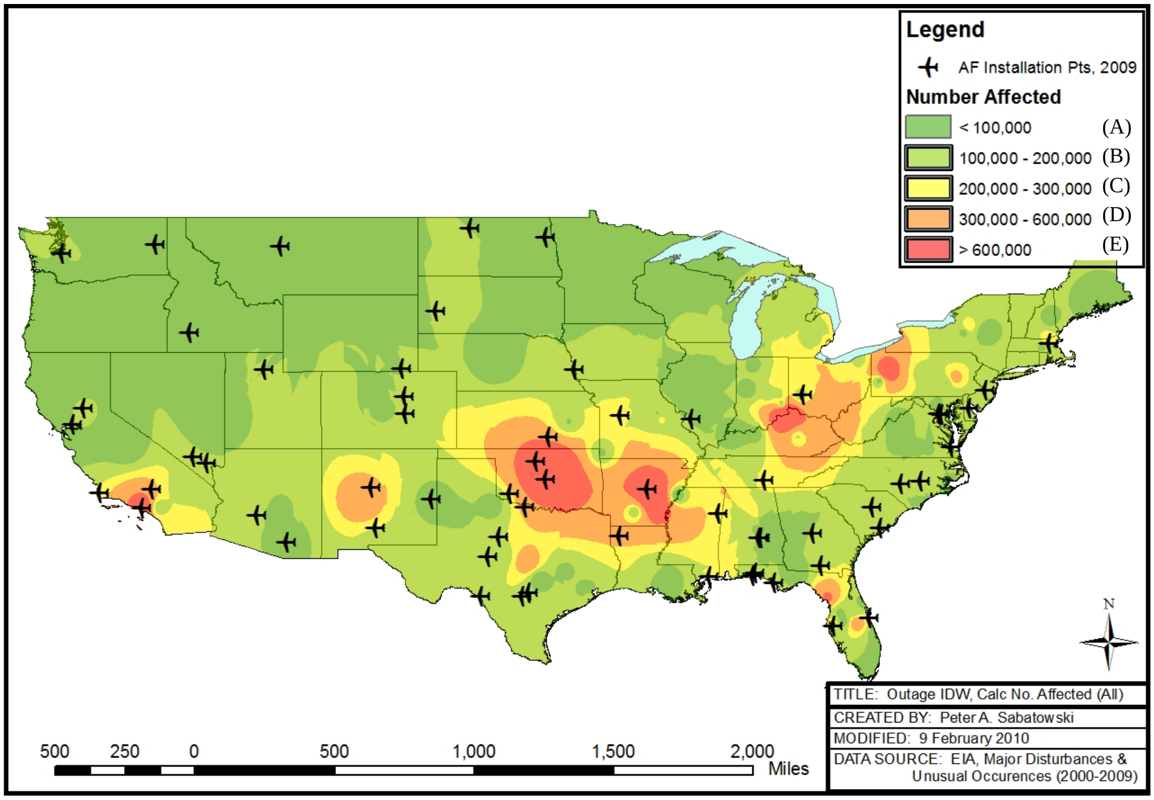


Figure 18. Calculated IDW for Number Affected

Table 4. Calculated IDW of Number of People Affected for Air Force Installations

FULLNAME	Number Affected	
Altus AFB	C	264,371
Andrews AFB	B	124,079
Arnold AFB	C	217,659
Barksdale AFB	D	350,195
Beale AFB	B	115,465
Bolling AFB	B	148,516
Buckley AFB	B	125,064
Cannon AFB	A	23,774
Charleston AFB	B	142,870
Columbus AFB	C	255,011
Creech AFB	B	139,430
Davis-Monthan AFB	A	40,950
Dover AFB	B	113,662
Dyess AFB	B	168,562
Edwards AFB	D	400,411
Eglin AFB	B	113,105
Ellsworth AFB	B	126,094
F E Warren AFB	A	96,672
Fairchild AFB	A	80,391
Goodfellow AFB	B	142,972
Grand Forks AFB	A	28,169
Hanscom AFB	C	220,442
Hill AFB	A	82,519
Holloman AFB	B	199,341
Hurlburt Fld	B	116,088
Keesler AFB	C	200,000
Kirtland AFB	D	402,893
Lackland AFB	B	163,511
Langley AFB	B	108,650
Laughlin AFB	B	190,901
Little Rock AFB	E	1,418,436
Los Angeles AFB	E	850,400
Luke AFB	B	106,151
Macdill AFB	C	255,096
Malmstrom AFB	A	61,763
Maxwell AFB	A	85,197
Maxwell (Gunter) AFB	A	84,448
McChord AFB	A	81,442
McConnell AFB	D	481,009
McGuire AFB	A	76,587
Minot AFB	A	47,157
Moody AFB	B	153,806
Mountain Home AFB	A	37,141
Nellis AFB	B	136,155
Offutt AFB	B	122,956
Patrick AFB	B	196,924
Peterson AFB	B	124,628
Pope AFB	B	105,149
Randolph AFB	B	138,498
Robins AFB	B	133,704
Scott AFB	A	71,228
Seymour Johnson AFB	B	101,857
Shaw AFB	B	137,264
Sheppard AFB	D	386,399
Tinker AFB	E	1,660,047
Travis AFB	A	72,402
Tyndall AFB	B	124,403
Vance AFB	E	1,201,370
Vandenberg AFB	C	240,031
Whiteman AFB	C	251,038
Wright-Patterson AFB	B	122,554

*NOTE: Letter designations correspond to color codes in Figure 18.

Inverse Distance Weighted for Total Hours Lost

The total duration of the reported power outages has a large impact on the consumer’s ability to successfully operate. In terms of power outage duration, there are two main factors to consider: 1) repeated power outages of short duration and 2) long-term, sustained power outages. As was previously discussed with the EIA database, power outages are not required to be reported unless 50,000 or more people are affected for greater than one hour. As such, momentary outages, or outages lasting only minutes, often go unreported by utility companies unless they must be reported based on meeting other criteria. As a result, the categorical values in Table 5 were based on the premise that long-term outages are much worse than shorter outages. In some instances, if a power outage is very widespread, there are instances where some consumers have power restored almost immediately, whereas others are left without power for days or even weeks.

As shown in Figure 19, a great deal of the U.S. has experienced power outages totaling more than 72 hours over the past decade. A more detailed view of Figure 19 is displayed in Appendix F. When utility companies file OE-417 (or EIA-417 prior to 2008), they are required to report the final time that power was restored to all users. Whether or not the utility companies actually reported the data correctly, outages for over a week, or even five to seven days, represent a significant amount of time to be without power. As shown in Table 5, only Macdill AFB was classified in the category for outages in excess of 192 hours; however, there were an additional 18 bases scattered through the U.S. that have experienced power failure lasting between 72 to 192 hours.

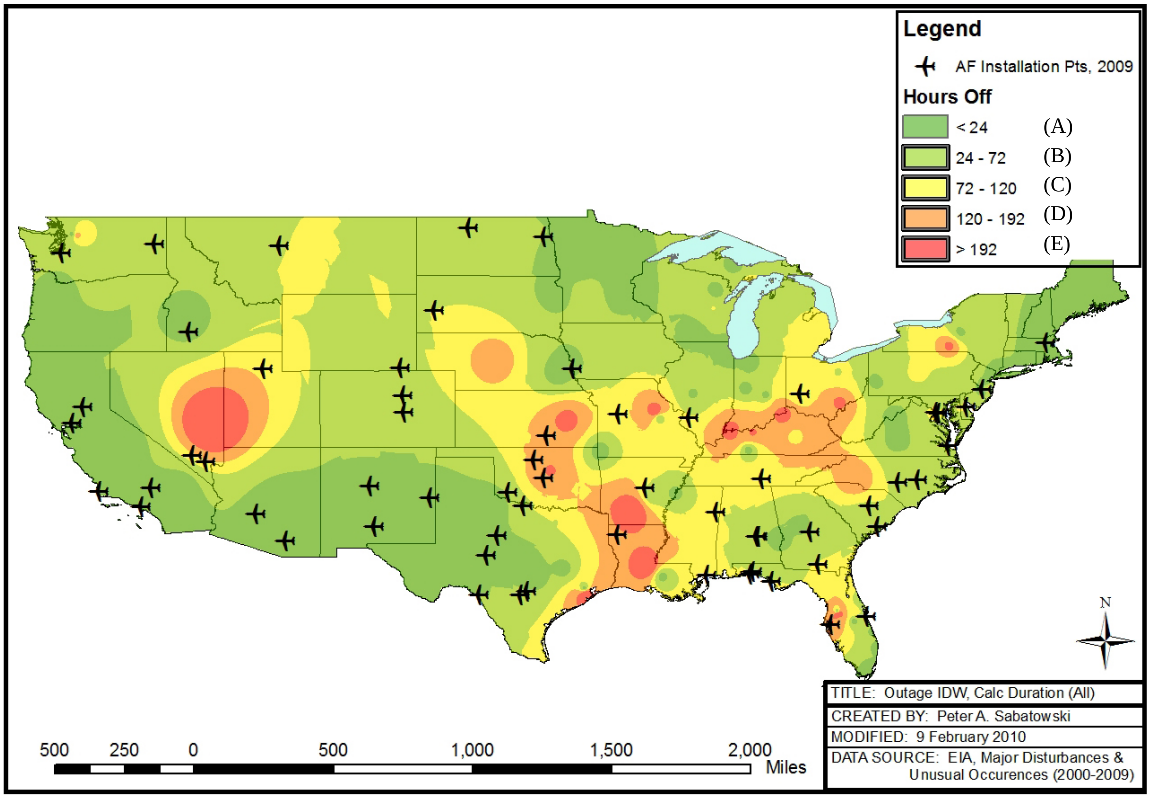


Figure 19. Calculated IDW for Total Duration

Table 5. Calculated IDW of Total Duration for Air Force Installations

FULLNAME	Duration		FULLNAME	Duration		FULLNAME	Duration	
Altus AFB	B	34	Hanscom AFB	A	4	Moody AFB	C	74
Andrews AFB	C	95	Hill AFB	C	103	Mountain Home AFB	A	8
Arnold AFB	C	100	Holloman AFB	A	3	Nellis AFB	C	108
Barksdale AFB	D	173	Hurlburt Fld	C	78	Offutt AFB	A	7
Beale AFB	A	8	Keesler AFB	A	2	Patrick AFB	B	61
Bolling AFB	C	118	Kirtland AFB	A	5	Peterson AFB	B	45
Buckley AFB	B	47	Lackland AFB	B	31	Pope AFB	B	54
Cannon AFB	A	5	Langley AFB	B	48	Randolph AFB	B	26
Charleston AFB	B	59	Laughlin AFB	B	24	Robins AFB	B	26
Columbus AFB	C	88	Little Rock AFB	C	77	Scott AFB	C	79
Creech AFB	C	107	Los Angeles AFB	A	2	Seymour Johnson AFB	B	40
Davis- Monthan AFB	A	1	Luke AFB	A	6	Shaw AFB	B	62
Dover AFB	B	67	Macdill AFB	E	197	Sheppard AFB	B	51
Dyess AFB	A	14	Malmstrom AFB	B	70	Tinker AFB	D	180
Edwards AFB	A	9	Maxwell AFB	B	37	Travis AFB	A	3
Eglin AFB	C	73	Maxwell (Gunter) AFB	B	35	Tyndall AFB	B	72
Ellsworth AFB	B	72	McChord AFB	B	46	Vance AFB	D	152
F E Warren AFB	B	48	McConnell AFB	D	156	Vandenberg AFB	A	12
Fairchild AFB	B	49	McGuire AFB	A	6	Whiteman AFB	C	105
Goodfellow AFB	A	10	Minot AFB	B	42	Wright-Patterson AFB	C	74
Grand Forks AFB	A	24						

*NOTE: Letter designations correspond to color codes in Figure 19.

Inverse Distance Weighted for Total Megawatts Lost

The total megawatt loss pertains to the amount of power not being supplied to meet the customer's demand. In other words, the megawatt loss can be directly tied to either productivity service or inconvenience. The overall effect depends on the requirements set out by the consumer. In fact, when individuals experience power loss, it is not always a complete blackout; it can also be a brownout where insufficient power is supplied. Sometimes this can be even more devastating for industry since lower voltages can possibly damage equipment requiring a minimum standard to operate. Unfortunately, similar to the other two components, there are stipulations that require a utility company to report only on total megawatt loss resulting from an uncontrollable loss of at least 300 megawatts for more than 15 minutes. As a result, outages not meeting this threshold go unreported, even though they could have potentially had a large impact.

As mentioned previously, the amount of power loss was categorized according to the EIA's database on available power generators across the U.S. Large outages mean that more generators were affected by the drop in power; additionally, an increased strain was placed on remaining generators as they tried to compensate for the power shortage. After performing IDW for the power loss during the reported outages, the contour map shown in Figure 20 was created. A more detailed view of Figure 20 can be found in Appendix G. Only one base, Los Angeles AFB, fell within the high categorical range whereas an additional 14 bases had experienced power loss greater than 600 MW. Table 6 shows the interpolated values as determined by the available power outage data and IDW within ArcGIS. The remainder of the installations fell within the lower ranges where power loss could be considered marginal.

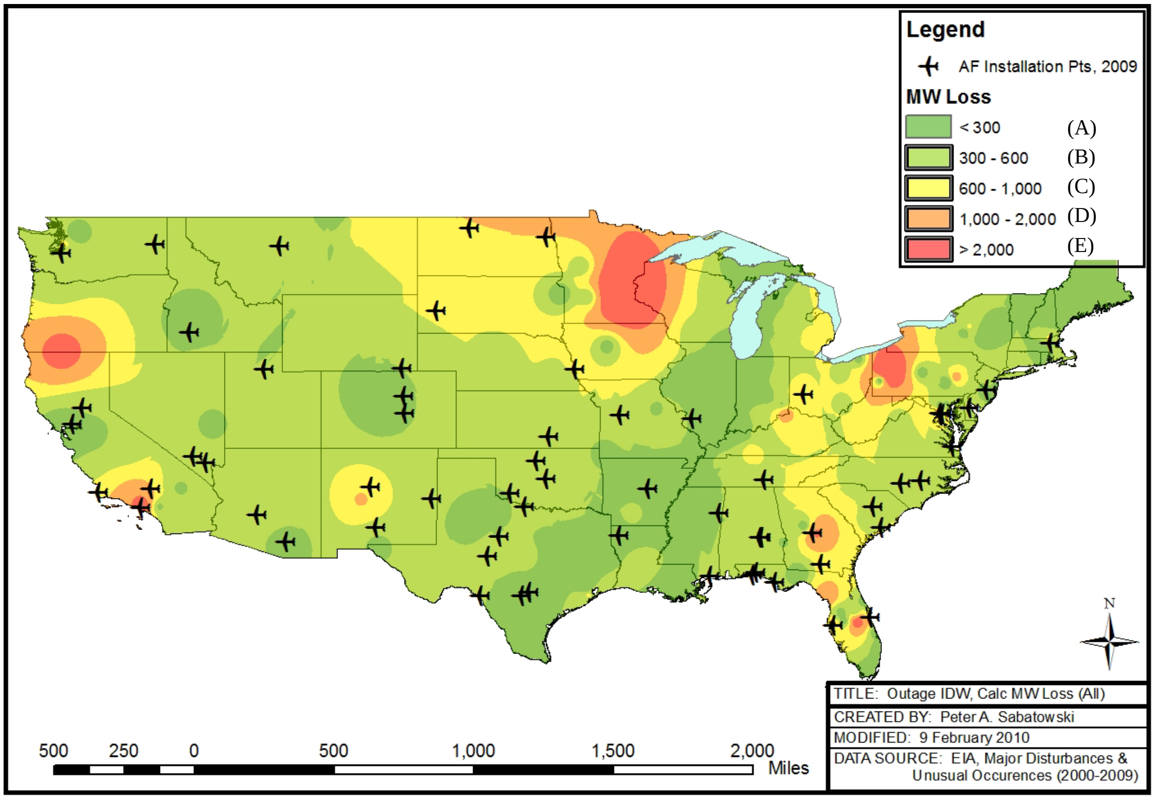


Figure 20. Calculated IDW for Power Loss

Table 6. Calculated IDW of Power Loss for Air Force Installations

FULLNAME	MW Loss	
Altus AFB	B	305
Andrews AFB	D	1,093
Arnold AFB	B	571
Barksdale AFB	A	276
Beale AFB	B	323
Bolling AFB	D	1,444
Buckley AFB	A	242
Cannon AFB	B	551
Charleston AFB	B	573
Columbus AFB	A	296
Creech AFB	B	437
Davis- Monthan AFB	A	138
Dover AFB	B	391
Dyess AFB	B	306
Edwards AFB	D	1,111
Eglin AFB	B	475
Ellsworth AFB	C	737
F E Warren AFB	B	303
Fairchild AFB	B	435
Goodfellow AFB	B	325
Grand Forks AFB	C	991
Hanscom AFB	B	456
Hill AFB	B	300
Holloman AFB	B	436
Hurlburt Fld	B	482
Keesler AFB	B	300
Kirtland AFB	C	869
Lackland AFB	A	223
Langley AFB	B	488
Laughlin AFB	B	306
Little Rock AFB	A	78
Los Angeles AFB	E	2,430
Luke AFB	B	403
Macdill AFB	D	1,040
Malmstrom AFB	B	437
Maxwell AFB	B	455
Maxwell (Gunter) AFB	B	449
McChord AFB	B	310
McConnell AFB	B	449
McGuire AFB	A	215
Minot AFB	C	982
Moody AFB	C	683
Mountain Home AFB	A	186
Nellis AFB	B	422
Offutt AFB	C	629
Patrick AFB	C	940
Peterson AFB	A	239
Pope AFB	B	462
Randolph AFB	A	189
Robins AFB	D	1,896
Scott AFB	A	277
Seymour Johnson AFB	B	405
Shaw AFB	B	567
Sheppard AFB	B	324
Tinker AFB	B	473
Travis AFB	A	161
Tyndall AFB	B	491
Vance AFB	B	456
Vandenberg AFB	C	772
Whiteman AFB	B	360
Wright-Patterson AFB	C	970

*NOTE: Letter designations correspond to color codes in Figure 20.

Final Results

The final step in performing the analysis for this thesis was compiling the different layers into a consolidated vulnerability map, showing the weighted vulnerability index. Defined in Chapter 3, Equation 4 utilized the maximum value found within each component layer in an effort to transform the compiled elements into unit-less values ranging between 0 and 1. As a result, the theoretical maximum value which could be assessed within the consolidated analysis is 3; since the data categories for the vulnerability index were shifted to the left though, the calculated vulnerabilities never reached above 1.8 units. As a result, the vulnerability index categories were shifted to the left, thereby providing a more realistic view of the interpolated data. The use of raster calculation created the map in Figure 21 and Table 7, which displays the vulnerability levels at Air Force installations. More detailed maps of Figure 21 are displayed in Appendix H. It is important to understand these results do not mean that an area is more susceptible to the extremes for each category: in other words, high vulnerability indices do not mean that the area will experience power outages that affect a large number of people, last for an extended duration, and have a high power loss.

There are only a few bases in categories at or above the average level (level C), with most bases being in the lower range for more significant power outages. Tinker AFB, located near Oklahoma City, Oklahoma, was the only base with a vulnerability score greater than 1. This implies that the base, compared to the remainder of the U.S. based on historical data, experiences power outages that have the largest impact. Seven other bases are within the yellow and orange (0.5 to 1) groupings. Each of these bases might consider evaluating their power generation capability to determine its adequacy.

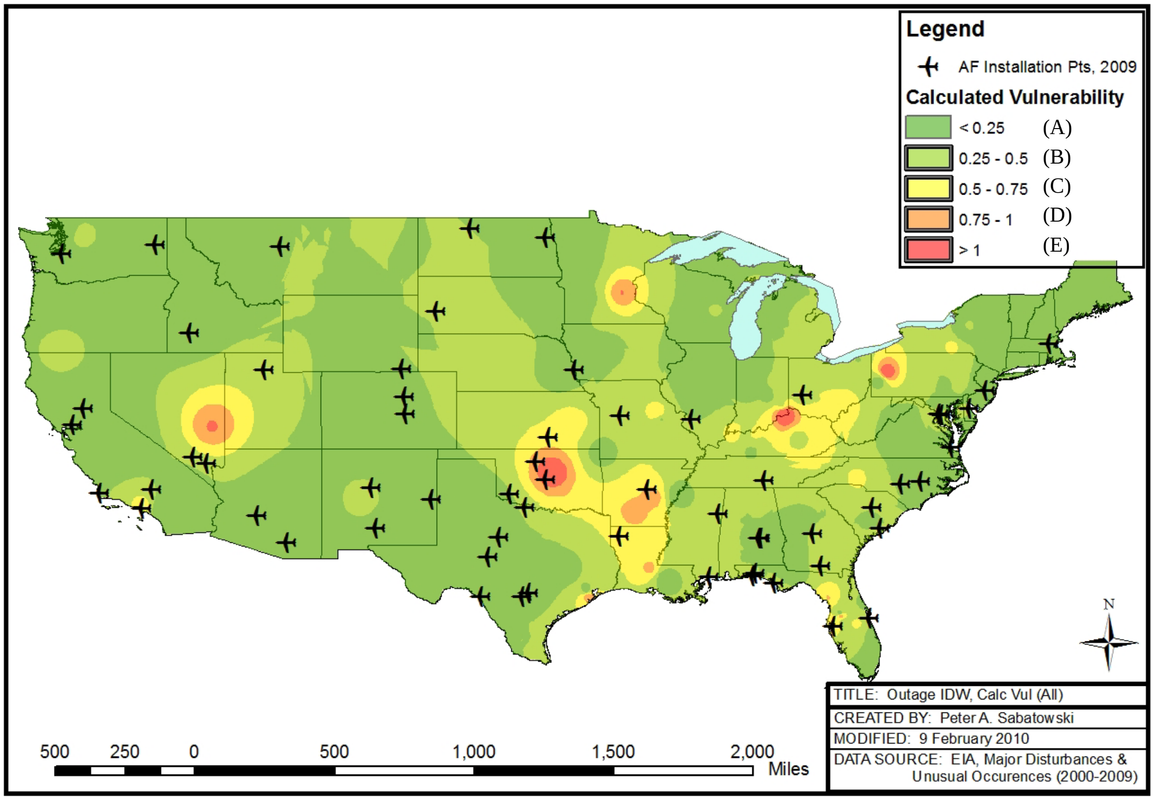


Figure 21. Calculated Weighted Vulnerability (Individual Outages)

Table 7. Calculated Vulnerability of Power Outages for Air Force Installations

FULLNAME	Vulnerability Index	
Altus AFB	A	0.22
Andrews AFB	B	0.40
Arnold AFB	B	0.39
Barksdale AFB	C	0.59
Beale AFB	A	0.10
Bolling AFB	C	0.51
Buckley AFB	A	0.19
Cannon AFB	A	0.08
Charleston AFB	B	0.26
Columbus AFB	B	0.35
Creech AFB	B	0.36
Davis- Monthan AFB	A	0.03
Dover AFB	B	0.25
Dyess AFB	A	0.14
Edwards AFB	B	0.30
Eglin AFB	B	0.28
Ellsworth AFB	B	0.31
F E Warren AFB	A	0.19
Fairchild AFB	A	0.20
Goodfellow AFB	A	0.12
Grand Forks AFB	A	0.18
Hanscom AFB	A	0.15
Hill AFB	B	0.32
Holloman AFB	A	0.14
Hurlburt Fld	B	0.29
Keesler AFB	B	0.35
Kirtland AFB	B	0.27
Lackland AFB	A	0.17
Langley AFB	A	0.21
Laughlin AFB	A	0.17
Little Rock AFB	D	0.76
Los Angeles AFB	C	0.62
Luke AFB	A	0.10
Macdill AFB	C	0.69
Malmstrom AFB	A	0.24
Maxwell AFB	A	0.18
Maxwell (Gunter) AFB	A	0.17
McChord AFB	A	0.18
McConnell AFB	C	0.62
McGuire AFB	A	0.07
Minot AFB	A	0.23
Moody AFB	B	0.32
Mountain Home AFB	A	0.06
Nellis AFB	B	0.36
Offutt AFB	A	0.14
Patrick AFB	B	0.33
Peterson AFB	A	0.19
Pope AFB	A	0.22
Randolph AFB	A	0.14
Robins AFB	B	0.33
Scott AFB	A	0.25
Seymour Johnson AFB	A	0.18
Shaw AFB	B	0.27
Sheppard AFB	B	0.31
Tinker AFB	E	1.15
Travis AFB	A	0.05
Tyndall AFB	B	0.28
Vance AFB	D	0.90
Vandenberg AFB	A	0.21
Whiteman AFB	B	0.40
Wright-Patterson AFB	B	0.34

*NOTE: Letter designations correspond to color codes in Figure 21.

Summary

The consolidated vulnerability map created with ArcGIS is a good tool for Air Force installations to use to interpret their vulnerability to power outages based on historical data. Although interpolation is only a best guess for determining values between existing data points, it provides a good baseline for bases to determine their potential for future power outages. However, that is only part of the problem. Mitigation plans must be developed to anticipate and prepare for future outages.

Power outages throughout the U.S. are going to continue into the future and, according to Figure 16, are beginning to rise in certain geographic regions. As such, it is important for Air Force installations to adequately address their own capabilities and act upon these findings to secure their power for the future. Power failure is no excuse for critical missions to be affected since national security could also be affected.

Chapter 5. Conclusion

This research effort sought to analyze historical power outages reported to the Energy Information Administration (EIA) to determine areas of variable vulnerability to future power outages. These findings are the result of applying a new method to investigate historical power outage data by analyzing them using spatial relationships. One of the major assumptions supporting this approach has been the idea that the electric grid is highly interconnected and events in one area could have a direct impact on surrounding areas. The analysis of power outage data using ArcGIS allowed for the creation of contour maps representing varying vulnerability levels. The previous chapter discussed the findings and provided insight as to the vulnerability levels at Air Force installations relating to varying levels of power outage duration, power loss, and number of people affected. This chapter summarizes the findings from this research effort and provides suggestions for future research.

Thesis Purpose

As previously identified in Chapter 1, the purpose of this thesis contained two important components: the analysis of data to determine vulnerabilities and the identification of mitigation efforts to reduce those vulnerabilities at Air Force installations. This research aimed to investigate historical power outages by utilizing the EIA's unusual occurrence and disturbance database and focusing on information regarding power outage loss, duration, and number of people affected. Utilizing a handful of tools within ArcGIS, in conjunction with the location of the power companies responsible for the individual outages, it was possible to perform spatial analysis of the areas affected by the outages. The results from this analysis provide critical information necessary to determine overall levels of vulnerability for areas between the power outages.

The second portion of this research concerns recommendations to mitigate associated vulnerabilities. In contrast, one of the worst decisions to be made would be to simply do nothing and hope the problem corrects itself. However, as it relates to the Air Force, the consequence for inaction could result in an immediate threat to national security. Therefore, three suggested actions must be considered: changing user behaviors, investigating internal capacity, and negotiating special actions with the electric company. Changing individual behaviors would result in immediate benefits as load levels would decrease and on reserve margin would increase, thereby resulting in a decreased chance for power outages in the near future.

Besides addressing individual behavior, the Air Force could initiate an investigation to determine the availability of both personnel and equipment to manage critical facilities during instances of prolonged power outages. The result could be that some bases may have sufficient capacity for their critical facilities, as opposed to other bases which might simply be lacking in adequate generation capability. As a result, Air Force senior leadership could allocate additional resources to bases in higher vulnerability categories if it is deemed a priority. This would help ensure that all Air Force installations are prepared for future power outages.

The last suggestion for mitigation involves negotiating with electric companies through one of two methods. The first approach involves changing existing contracts such that bases receive priority after power outages such that restoration efforts would be focused on restoring power to military installations first. Since individual bases are not experts regarding contract negotiations, the Air Force Civil Engineer Support Agency (AFCESA) Utility Rates Management Team (URMT) might need to lead negotiation efforts. However, this would come at a tremendous cost to bases as utility companies would more than likely increase electricity rates. If this is not possible, a second alternative would be to construct privately operated generation facilities on Air Force installations. Some bases have already begun working with local power companies to allow generation facilities on military installations that would provide immediate power to bases during power outages. This last alternative secures the demands for future Air Force installations, yet it is a long-term approach and not the best option for all bases. Regardless, bases need to investigate not only their internal power generation capability, but also ensure plans exist for securing future power.

Recommendations for Future Research

This research is a pioneering study using historical power outage information and transforming it into an awareness tool for future power disturbances. However, as with any new effort, there are areas outside the scope of the research which serve as recommendations for future researchers. This thesis effort subsequently identified multiple areas that should be pursued to further investigate U.S. power outages and their implications on Air Force installations. The first recommendation is to refine the components used in the raster calculator; in particular, the weights associated with the categories of power loss, people affected, and duration should be further investigated, especially their impact as it relates to vulnerability calculations. A second recommendation would be to pursue the concept of risk and how vulnerability levels translate into individual risk levels. A third recommendation would be to refine the collected data and the way in which power outage origins were defined; specifically, is there a better way to identify outage origins besides service area centroids? A fourth recommendation involves narrowing the project scope and investigating regional impacts of power outages in limited areas of the country. This would involve focusing additional data collection and analyses to a smaller geographic region of the U.S. than the lower 48 states. Lastly, the integration of causes and the created maps would allow a determination to be made regarding correlations between the causes and the outcomes experienced from outages.

Conclusion

It has not been until recently that the condition of the nation’s electric grid has been understood and actions been initiated to fix identified problems. Although, efforts are currently underway to modernize the electric grid to reduce power disturbances, they will take significant time to successfully implement. This is further compounded by the fact that even though more restrictive guidance would be in place, it is no guarantee that everyone will follow the standards or that the standards will be adequately enforced. Herein lies the focus behind this research in being able to determine varying vulnerabilities levels based on historical data. With this thesis, it is possible to address the following question: what vulnerabilities exist at installations for future power outages? This is crucial since the power to assess each Air Force installation's vulnerability can only help in being a planning tool for focusing mitigation efforts.

Whether Air Force installations use power to simply operate maintenance shops or power the flight line, the demand for power is a necessity. Especially as it relates to military installations, the lack of power can sometimes prove detrimental to not only daily activities but also national security. Therefore, further efforts by the consumer to control vulnerabilities to power outages must be taken in order to ensure power is available to critical facilities.

APPENDIX A. Form EIA-417 (Emergency Incident and Disturbance Report)

U.S. Department of Energy **Energy Information Administration** **Form EIA-417 (2004)**	*EMERGENCY INCIDENT AND DISTURBANCE REPORT*	**Form Approved** **OMB No. 1901-0288** **Approval Expires 08/31/05**

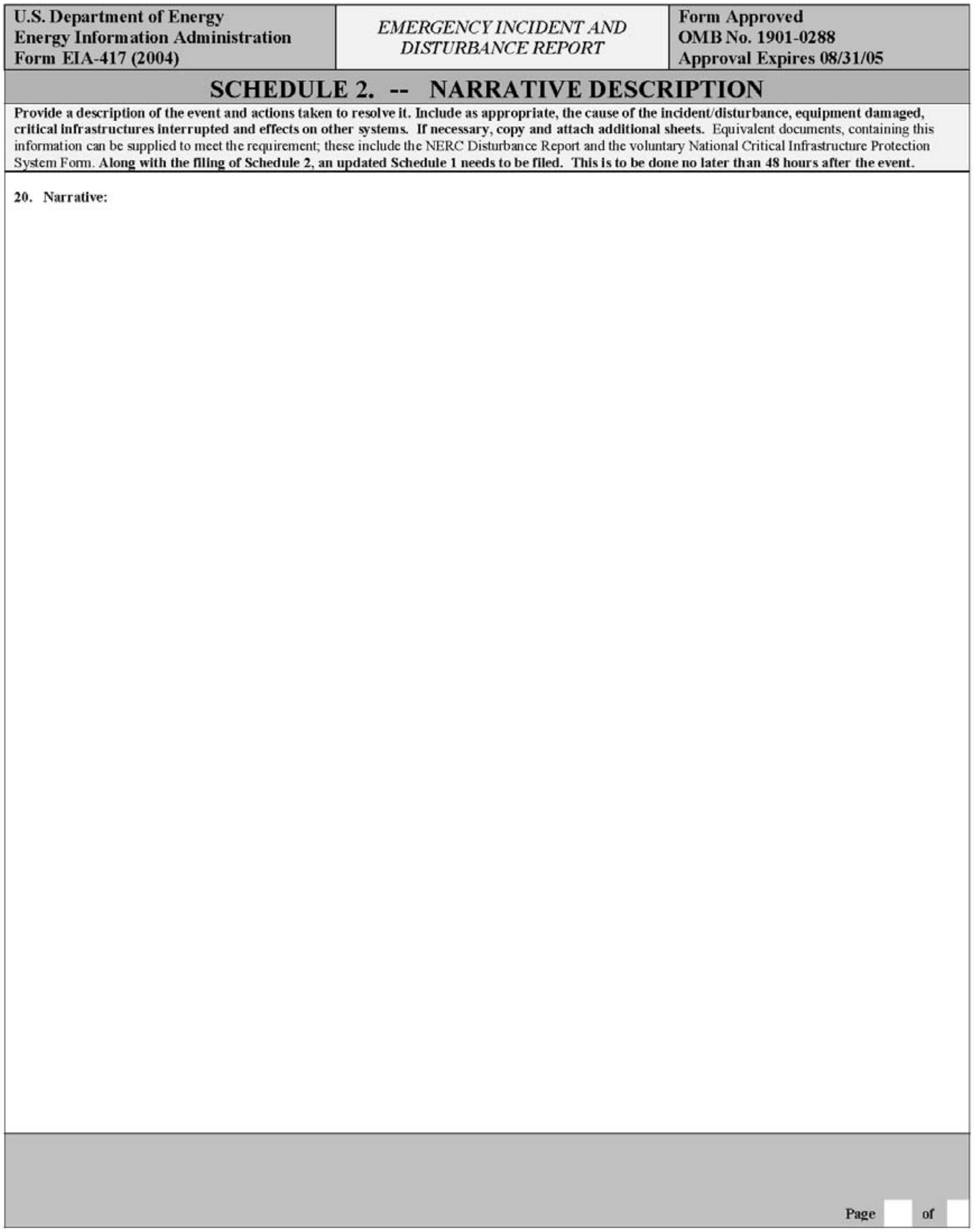
NOTICE: The timely submission of Form EIA-417 by those required to report is mandatory under Section 13(b) of the Federal Energy Administration Act of 1974 (FEAA) (Public Law 93-275), as amended. Failure to respond may result in a penalty of not more than $2,750 per day for each civil violation, or a fine of not more than $5,000 per day for each criminal violation. The government may bring a civil action to prohibit reporting violations, which may result in a temporary restraining order or a preliminary or permanent injunction without bond. In such civil action, the court may also issue mandatory injunctions commanding any person to comply with these reporting requirements. **Title 18 U.S.C. 1001 makes it a criminal offense for any person knowingly and willingly to make to any Agency or Department of the United States any false, fictitious, or fraudulent statements as to any matter within its jurisdiction.** A person is not required to respond to collection of information unless the form displays a valid OMB number. Data reported on Form EIA-417 in Schedule 1, lines 4, 5, 6, 7, and 8 are considered to be confidential. Schedule 2 is considered confidential. **All other data are not confidential.** (See form instructions for a full list of legal citations covering data collection authorization.)

RESPONSE DUE: Submit a completed Schedule 1 as an initial report within 60 minutes of the incident. A final report (completed copy of the Form EIA-417, Schedule 1 and 2) is due within 48 hours of the event. Electronic submission by facsimile or e-mail is the preferred method of notification.

SCHEDULE 1. -- EMERGENCY ALERT NOTICE

LINE NO.				
	ORGANIZATION FILLING			
1.	Alert Status (check one)	Preliminary Alert [ ]	Update Notice [ ]	Final Report [ ]
2.	Organization Name			
3.	Address of Principal Business Office			
	NAME OF OFFICIAL THAT NEEDS TO BE CONTACTED FOR FOLLOW-UP AND ANY ADDITIONAL INFORMATION			
4.	Name			
5.	Title			
6.	Telephone Number			
7.	FAX Number			
8.	E-mail Address			
	INCIDENT AND DISTURBANCE DATA			
9.	Geographic Area(s) Affected			Unknown at this time [ ]
10.	Date/Time Incident Began (mm-dd-yy/hh:mm) using 24-hour clock			
11.	Estimated Date/Time of Restoration (mm-dd-yy/ hh:mm) using 24-hour clock			Unknown at this time [ ]
12.	Date/Time Incident Ended (mm-dd-yy/ hh:mm) using 24-hour clock			
13.	Did the incident/disturbance originate in your system/area? (check one response)	Yes [ ]	No [ ]	Unknown [ ]
14.	Estimate of Amount of Demand Involved (megawatts)			Unknown at this time [ ]
15.	Estimate of Number of Customers Affected			Unknown at this time [ ]
16.	Internal Organizational Tracking Number			

17. Type of Emergency Check all that apply (a)		18. Cause of Incident Check if known or suspected (b)		19. Actions Taken Check all that apply (c)	
Major Transmission System Interruption	[ ]	Weather or Natural Disaster	[ ]	Implemented a Warning, Alert, or Contingency Plan	[ ]
Major Generation Inadequacy	[ ]	Transmission Equipment	[ ]	Made Public Appeals	[ ]
Major Distribution System Interruption	[ ]	Operator Action(s)	[ ]	Reduced Voltage	[ ]
Other	[ ]	Suspected Malicious/Intentional		Shed Interruptible Load	[ ]
		Physical	[ ]	Shed Firm Load	[ ]
		Cyber/Computer/Telecom	[ ]	Repaired/Restored	[ ]
		Inadequate Electric Resources to Serve Load	[ ]	Other	[ ]
		Fuel Supply Deficiency (e.g., gas, oil, water)	[ ]		
		Unknown Cause	[ ]		
		Other	[ ]		



U.S. Department of Energy **Energy Information Administration** **Form EIA-417 (2004)**	*EMERGENCY INCIDENT AND DISTURBANCE REPORT*	**Form Approved** **OMB No. 1901-0288** **Approval Expires 08/31/05**

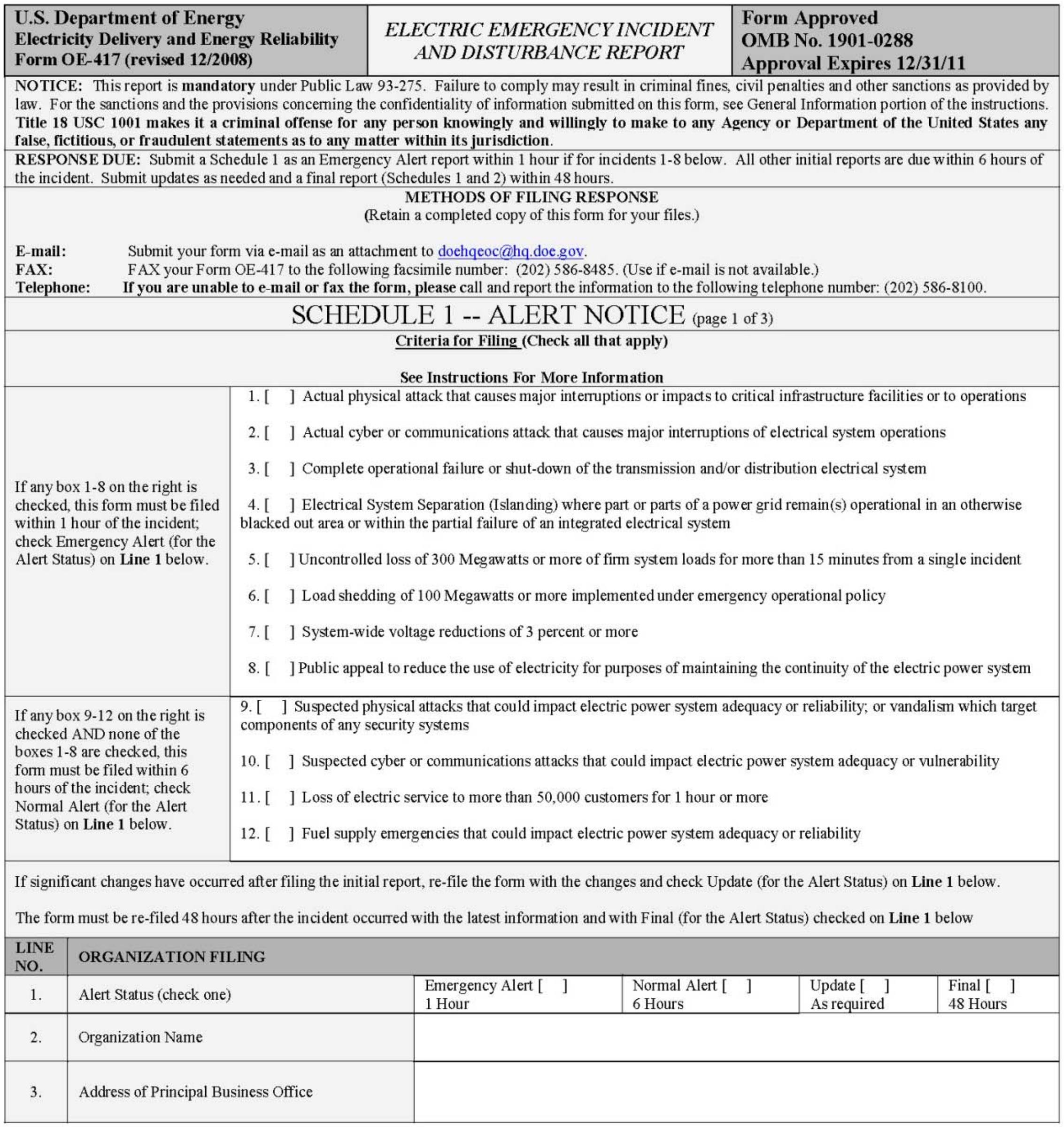
SCHEDULE 2. -- NARRATIVE DESCRIPTION

Provide a description of the event and actions taken to resolve it. Include as appropriate, the cause of the incident/disturbance, equipment damaged, critical infrastructures interrupted and effects on other systems. If necessary, copy and attach additional sheets. Equivalent documents, containing this information can be supplied to meet the requirement; these include the NERC Disturbance Report and the voluntary National Critical Infrastructure Protection System Form. **Along with the filing of Schedule 2, an updated Schedule 1 needs to be filed. This is to be done no later than 48 hours after the event.**

20. Narrative:

Page ☐ **of** ☐

APPENDIX B. Form OE-417 (Electric Emergency Incident Report)



U.S. Department of Energy **Electricity Delivery and Energy Reliability** **Form OE-417 (revised 12/2008)**	*ELECTRIC EMERGENCY INCIDENT AND DISTURBANCE REPORT*	**Form Approved** **OMB No. 1901-0288** **Approval Expires 12/31/11**

NOTICE: This report is **mandatory** under Public Law 93-275. Failure to comply may result in criminal fines, civil penalties and other sanctions as provided by law. For the sanctions and the provisions concerning the confidentiality of information submitted on this form, see General Information portion of the instructions. **Title 18 USC 1001 makes it a criminal offense for any person knowingly and willingly to make to any Agency or Department of the United States any false, fictitious, or fraudulent statements as to any matter within its jurisdiction.**

RESPONSE DUE: Submit a Schedule 1 as an Emergency Alert report within 1 hour if for incidents 1-8 below. All other initial reports are due within 6 hours of the incident. Submit updates as needed and a final report (Schedules 1 and 2) within 48 hours.

METHODS OF FILING RESPONSE

(Retain a completed copy of this form for your files.)

E-mail: Submit your form via e-mail as an attachment to doehqeoc@hq.doe.gov.
FAX: FAX your Form OE-417 to the following facsimile number: (202) 586-8485. (Use if e-mail is not available.)
Telephone: **If you are unable to e-mail or fax the form, please** call and report the information to the following telephone number: (202) 586-8100.

SCHEDULE 1 -- ALERT NOTICE (page 1 of 3)

Criteria for Filing (Check all that apply)

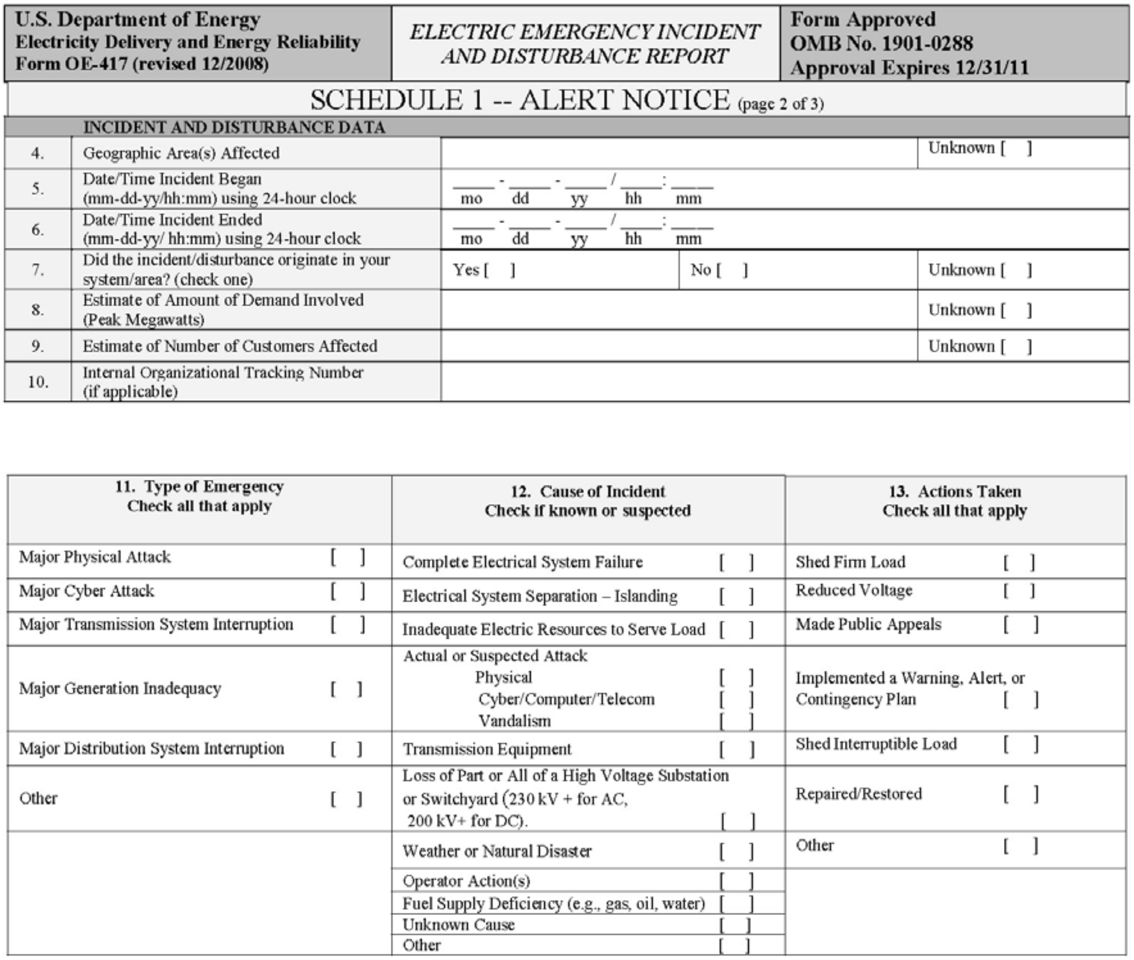
See Instructions For More Information

If any box 1-8 on the right is checked, this form must be filed within 1 hour of the incident; check Emergency Alert (for the Alert Status) on **Line 1** below.	1. [ ] Actual physical attack that causes major interruptions or impacts to critical infrastructure facilities or to operations 2. [ ] Actual cyber or communications attack that causes major interruptions of electrical system operations 3. [ ] Complete operational failure or shut-down of the transmission and/or distribution electrical system 4. [ ] Electrical System Separation (Islanding) where part or parts of a power grid remain(s) operational in an otherwise blacked out area or within the partial failure of an integrated electrical system 5. [ ] Uncontrolled loss of 300 Megawatts or more of firm system loads for more than 15 minutes from a single incident 6. [ ] Load shedding of 100 Megawatts or more implemented under emergency operational policy 7. [ ] System-wide voltage reductions of 3 percent or more 8. [ ] Public appeal to reduce the use of electricity for purposes of maintaining the continuity of the electric power system
If any box 9-12 on the right is checked AND none of the boxes 1-8 are checked, this form must be filed within 6 hours of the incident; check Normal Alert (for the Alert Status) on **Line 1** below.	9. [ ] Suspected physical attacks that could impact electric power system adequacy or reliability; or vandalism which target components of any security systems 10. [ ] Suspected cyber or communications attacks that could impact electric power system adequacy or vulnerability 11. [ ] Loss of electric service to more than 50,000 customers for 1 hour or more 12. [ ] Fuel supply emergencies that could impact electric power system adequacy or reliability

If significant changes have occurred after filing the initial report, re-file the form with the changes and check Update (for the Alert Status) on **Line 1** below.

The form must be re-filed 48 hours after the incident occurred with the latest information and with Final (for the Alert Status) checked on **Line 1** below

LINE NO.	**ORGANIZATION FILING**				
1.	Alert Status (check one)	Emergency Alert [ ] 1 Hour	Normal Alert [ ] 6 Hours	Update [ ] As required	Final [ ] 48 Hours
2.	Organization Name				
3.	Address of Principal Business Office				

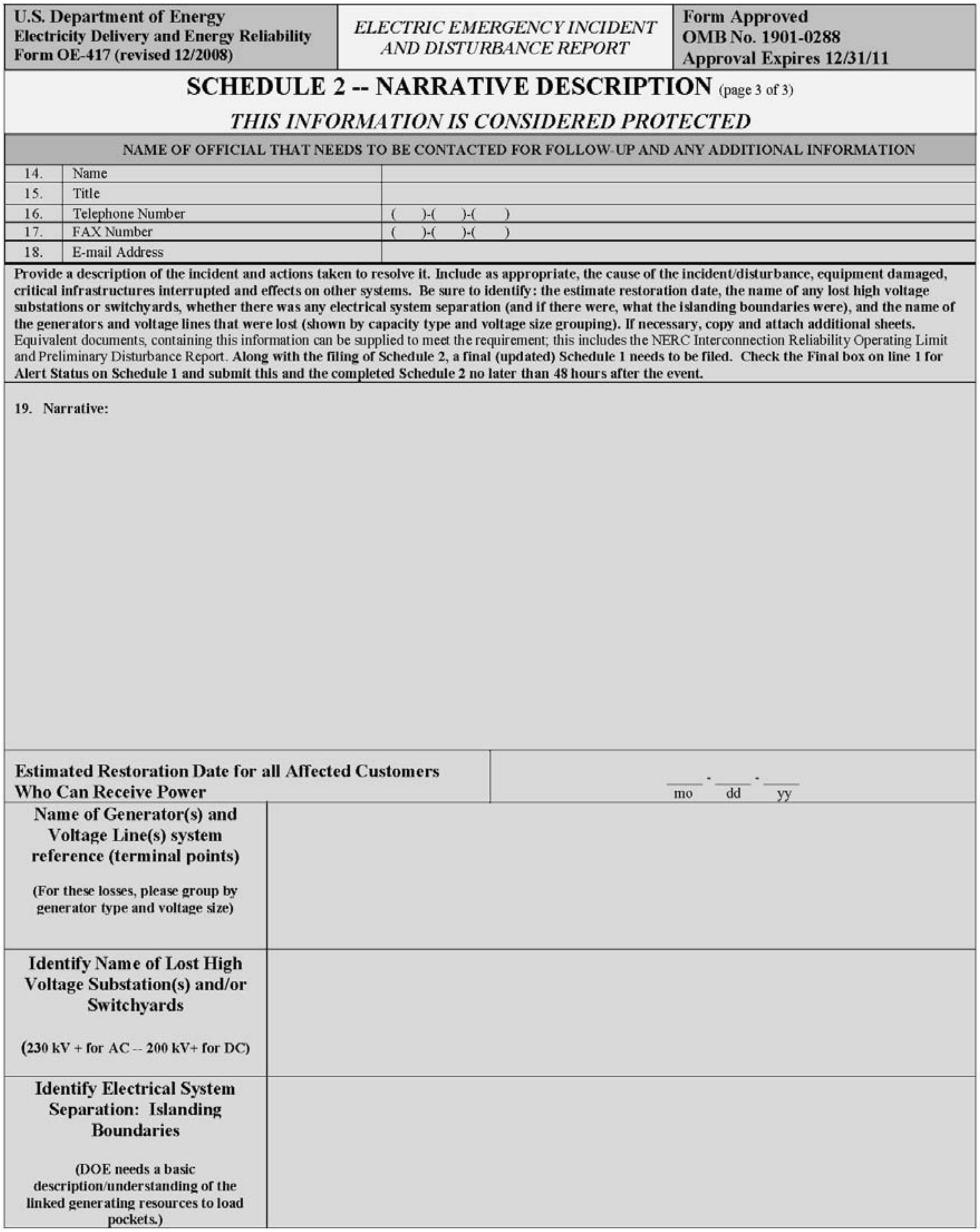


U.S. Department of Energy **Electricity Delivery and Energy Reliability** **Form OE-417 (revised 12/2008)**	*ELECTRIC EMERGENCY INCIDENT AND DISTURBANCE REPORT*	**Form Approved** **OMB No. 1901-0288** **Approval Expires 12/31/11**

SCHEDULE 1 -- ALERT NOTICE (page 2 of 3)

	INCIDENT AND DISTURBANCE DATA			
4.	Geographic Area(s) Affected			Unknown [ ]
5.	Date/Time Incident Began (mm-dd-yy/hh:mm) using 24-hour clock	____ - ____ - ____ / ____ : ____ mo dd yy hh mm		
6.	Date/Time Incident Ended (mm-dd-yy/ hh:mm) using 24-hour clock	____ - ____ - ____ / ____ : ____ mo dd yy hh mm		
7.	Did the incident/disturbance originate in your system/area? (check one)	Yes [ ]	No [ ]	Unknown [ ]
8.	Estimate of Amount of Demand Involved (Peak Megawatts)			Unknown [ ]
9.	Estimate of Number of Customers Affected			Unknown [ ]
10.	Internal Organizational Tracking Number (if applicable)			

11. Type of Emergency **Check all that apply**		**12. Cause of Incident** **Check if known or suspected**		**13. Actions Taken** **Check all that apply**	
Major Physical Attack	[ ]	Complete Electrical System Failure	[ ]	Shed Firm Load	[ ]
Major Cyber Attack	[ ]	Electrical System Separation – Islanding	[ ]	Reduced Voltage	[ ]
Major Transmission System Interruption	[ ]	Inadequate Electric Resources to Serve Load	[ ]	Made Public Appeals	[ ]
Major Generation Inadequacy	[ ]	Actual or Suspected Attack Physical Cyber/Computer/Telecom Vandalism	 [ ] [ ] [ ]	Implemented a Warning, Alert, or Contingency Plan	[ ]
Major Distribution System Interruption	[ ]	Transmission Equipment	[ ]	Shed Interruptible Load	[ ]
Other	[ ]	Loss of Part or All of a High Voltage Substation or Switchyard (230 kV + for AC, 200 kV+ for DC).	[ ]	Repaired/Restored	[ ]
		Weather or Natural Disaster	[ ]	Other	[ ]
		Operator Action(s)	[ ]		
		Fuel Supply Deficiency (e.g., gas, oil, water)	[ ]		
		Unknown Cause	[ ]		
		Other	[ ]		



U.S. Department of Energy **Electricity Delivery and Energy Reliability** **Form OE-417 (revised 12/2008)**	*ELECTRIC EMERGENCY INCIDENT AND DISTURBANCE REPORT*	**Form Approved** **OMB No. 1901-0288** **Approval Expires 12/31/11**

SCHEDULE 2 -- NARRATIVE DESCRIPTION (page 3 of 3)

THIS INFORMATION IS CONSIDERED PROTECTED

NAME OF OFFICIAL THAT NEEDS TO BE CONTACTED FOR FOLLOW-UP AND ANY ADDITIONAL INFORMATION

14.	Name	
15.	Title	
16.	Telephone Number	( )-( )-( )
17.	FAX Number	( )-( )-( )
18.	E-mail Address	

Provide a description of the incident and actions taken to resolve it. Include as appropriate, the cause of the incident/disturbance, equipment damaged, critical infrastructures interrupted and effects on other systems. Be sure to identify: the estimate restoration date, the name of any lost high voltage substations or switchyards, whether there was any electrical system separation (and if there were, what the islanding boundaries were), and the name of the generators and voltage lines that were lost (shown by capacity type and voltage size grouping). If necessary, copy and attach additional sheets. Equivalent documents, containing this information can be supplied to meet the requirement; this includes the NERC Interconnection Reliability Operating Limit and Preliminary Disturbance Report. **Along with the filing of Schedule 2, a final (updated) Schedule 1 needs to be filed. Check the Final box on line 1 for Alert Status on Schedule 1 and submit this and the completed Schedule 2 no later than 48 hours after the event.**

19. Narrative:

Estimated Restoration Date for all Affected Customers Who Can Receive Power	____ - ____ - ____ mo dd yy
Name of Generator(s) and Voltage Line(s) system reference (terminal points) **(For these losses, please group by generator type and voltage size)**	
Identify Name of Lost High Voltage Substation(s) and/or Switchyards **(230 kV + for AC -- 200 kV+ for DC)**	
Identify Electrical System Separation: Islanding Boundaries **(DOE needs a basic description/understanding of the linked generating resources to load pockets.)**	

APPENDIX C. EIA Power Outages (January 2000 – September 2009)

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2003	AEP	Region is RFC	RFC	-85.1674	39.3146	Texas	Hurricane or Tropical Storm	265.00	108000	146
2005	AEP	Region is RFC	RFC	-85.1674	39.3146	Shreveport, Louisiana	Hurricane or Tropical Storm	700.00	190000	104
2003	AEP	Region is RFC	RFC	-85.1674	39.3146	Ohio	Lightning	11000.00	134500	84
2004	AEP	Region is RFC	RFC	-85.1674	39.3146	Northern and Southern Michigan, AEP Fort Wayne/Michigan Region, Buchanan, Elkhart, New Buffalo, South Bend, St. Joseph, Three Rivers areas	Lightning	303.00	122600	130
2004	AEP	Region is RFC	RFC	-85.1674	39.3146	Shreveport, Louisiana	Lightning	350.00	59057	134
2004	AEP	Region is RFC	RFC	-85.1674	39.3146	Tulsa, Oklahoma	Lightning	280.00	56874	111
2005	AEP	Region is RFC	RFC	-85.1674	39.3146	Northwest Arkansas	Lightning	650.00	50797	2
2006	AEP	Region is RFC	RFC	-85.1674	39.3146	Ohio and Indiana	Lightning	750.00	195000	129
2004	AEP	Region is RFC	RFC	-85.1674	39.3146	Columbus District	Snow/Ice Storm	800.00	359171	211
2005	AEP	Region is RFC	RFC	-85.1674	39.3146	Indiana Michigan Region - Muncie Distric	Snow/Ice Storm	545.00	114791	254
2007	AEP	Region is RFC	RFC	-85.1674	39.3146	Tulsa, Oklahoma	Snow/Ice Storm	800.00	256663	221
2006	AEP	Region is RFC	RFC	-85.1674	39.3146	AEP Texas Central/Texas North	Supply Shortage	108.00	51404	2
2009	AEP	Region is RFC	RFC	-85.1674	39.3146	Roanoke, Virginia	Supply Shortage	350.00	0	22
2008	AEP	Region is RFC	RFC	-85.1674	39.3146	Port Isabel, Harlingen, Weslaco, Pharr, San Benito, Mission, McAllen, Edinburg, Texas	Hurricane or Tropical Storm	703.00	211266	190
2003	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Maryland, West Virginia, Virginia and Pennsylvania	Hurricane or Tropical Storm	3085.00	237366	130
2005	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Maryland, North Central West Virginia, Southwestern Pennsylvania, and Northern Pennsylvania	Hurricane or Tropical Storm	400.00	303795	212
2004	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Maryland, Southeastern West Virginia, Northern Virginia, Northern Pennsylvania and South Central Pennsylvani:	Snow/Ice Storm	60.00	87456	96
2004	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Western Pennsylvania, Northern West Virginia, Western Maryland, Northern Virginia	Wind/Rain	162.00	225353	91
2008	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Southwestern Pennsylvania, West Virginia, Virginia, Maryland	Wind/Rain	412.00	100969	65
2008	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Maryland, West Virginia, Virginia	Wind/Rain	634.00	157168	102
2008	Allegheny Power	Region is RFC	RFC	-82.0016	39.3301	Western Pennsylvania	Hurricane or Tropical Storm	546.00	160875	112
2007	Alliant Energy		MRO	-89.6377	43.0039	Central Iowa and Cedar Rapids areas	Snow/Ice Storm	400.00	140000	6
2009	Ameren Corporate		SERC	-84.9931	38.7667	Southern Illinois	Lightning	300.00	68800	154
2002	Ameren Corporate		SERC	-84.9931	38.7667	Illinois	Supply Shortage	232.00	53565	6
2006	Ameren Corporate		SERC	-84.9931	38.7667	Greater St. Louis Metropolitan area (Missouri and Illinois)	Wind/Rain	1500.00	2500000	278
2003	American Transmission Company, LLC		SERC	-88.4355	45.0819	Upper Michigan Peninsula	Equipment Failure	310.00	4	13
2003	American Transmission Company, LLC		SERC	-88.4355	45.0819	Northeast Wisconsin and Central/Western Upper Peninsula of Michigan	Equipment Failure	650.00	6	58
2003	American Transmission Company, LLC		SERC	-88.4355	45.0819	County of Waukesha, Wisconsin, & Town of Lisbon, Wisconsin	Intentional Attack	0.00	0	20
2003	Arizona Public Service	Region is WECC	WECC	-111.0890	34.0298	Phoenix, Arizona	Equipment Failure	1000.00	47000	1
2003	Arizona Public Service	Region is WECC	WECC	-111.0890	34.0298	Arizona	Equipment Failure	440.00	90000	2
2004	Arizona Public Service	Region is WECC	WECC	-111.0890	34.0298	Phoenix, Arizona	Equipment Failure	200.00	30000	7
2009	Associated Electric Cooperative, Inc.		SERC	-91.3826	38.5174	South Central and Southeast Missouri	Snow/Ice Storm	200.00	62500	79
2009	Associated Electric Cooperative, Inc.		SERC	-91.3826	38.5174	Northern Arkansas	Snow/Ice Storm	600.00	215700	33
2006	Atlantic City Electric		RFC	-74.3980	40.1521	Southern New Jersey Counties	Hurricane or Tropical Storm	400.00	100000	69
2006	Atlantic City Electric		RFC	-74.3980	40.1521	Entire Atlantic City Electric territory Southern New Jersey	Snow/Ice Storm	80.00	130000	62

Major Disturbances Unusual Occurences Energy Information Administration (EIA) 1 / 14

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2008	Atlantic City Electric		RFC	-74.3980	40.1521	Cape May, Cumberland, Gloucester, Salem, Camden, Atlantic, Burliington Counties, New Jersey	Wind/Rain	55.00	135000	48
2006	Austin Energy	Region is TRE	TRE	-97.7429	30.2666	State of Texas (all of Austin Energy)	Supply Shortage	39.00	10000	2
2009	Baltimore Gas & Electric Company		SERC	-76.6245	39.3090	Ruston, Louisiana	Equipment Failure	32.00	11000	0
2003	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland (Baltimore City, Baltimore County, Anne Arundel County, Hartford County, Montgomery County, Calvert County, Prince George's County, Carroll County and Howard County)	Hurricane or Tropical Storm	2000.00	650000	203
2003	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Maryland: Anne Arundel County, Baltimore County, Calvert County Carroll County, Howard County, Montgomery County, Prince George's and Baltimore City.	Lightning	625.00	133000	68
2006	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland	Lightning	335.00	70000	44
2007	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland - Baltimore City and surrounding Counties	Lightning	160.00	138000	51
2009	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland	Lightning	60.00	85091	36
2004	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Harford County, Maryland	Snow/Ice Storm	300.00	70000	16
2006	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Baltimore Metropolitan and Central Maryland	Snow/Ice Storm	500.00	180000	74
2007	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland	Snow/Ice Storm	400.00	155183	84
2003	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland (Baltimore City, Baltimore County, Anne Arundel County, Harford County, Montgomery County, Calvert County, Prince George's County, Carroll County and Howard County)	Wind/Rain	375.00	110000	82
2004	Baltimore Gas & Electric Company		RFC	-76.6245	39.3090	Central Maryland (Baltimore City, Baltimore County, Anne Arundel County, Hartford County, Montgomery County, Calvert County, Prince George's County, Carroll County and Howard County)	Wind/Rain	270.00	122000	38
2009	Big Rivers Electric Corporation		SERC	-86.5271	37.7571	Henderson County, Kentucky	Equipment Failure	342.00	1	11
2009	Big Rivers Electric Corporation		SERC	-86.5271	37.7571	Western Kentucky and Southern Indiana	Snow/Ice Storm	350.00	3	204
2006	Bonneville Power Administration		WECC	-114.6958	38.1577	Oregon, Washington, Idaho, Montana	Wind/Rain	258.00	24	413
2003	Bryan Texas Utilities	Region is TRE No service area map	TRE	-96.3639	30.6752	Cities of Bryan, College Station & Surrounding Areas	Equipment Failure	212.00	68530	3
2009	CA Department of Water Resources	No Service area map	WECC	-89.6437	39.8017	A.D. Edmonston Pumping Plant	Other External Cause	300.00	0	3
2008	CA Department of Water Resources	No Service area map	WECC	-89.6437	39.8017	A.D. Edmonston Pumping Plant	Other External Cause	300.00	0	2
2007	California ISO		WECC	-119.0852	37.0083	Southern California	Fire	700.00	300000	0
2008	California ISO		WECC	-119.0852	37.0083	California	Supply Shortage	483.00	0	2
2008	California ISO		WECC	-119.0852	37.0083	Southern California	Supply Shortage	430.00	400000	1
2008	California ISO		WECC	-119.0852	37.0083	ISO Balancing Area	High Temperatures	0.00	0	77
2008	California ISO		WECC	-119.0852	37.0083	Santa Barbara County, California, near Goleta	Fire	208.00	200000	4
2004	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and surrounding suburban areas	Lightning	100.00	85000	20
2004	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and surrounding suburban areas	Lightning	85.00	62500	2
2004	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and surrounding suburban areas	Lightning	150.00	119000	3

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2007	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas	Lightning	179.00	67000	11
2009	Center Point Energy		TRE	-95.2738	29.6914	Houston/Galveston Area	Lightning	51.00	73000	26
2009	Center Point Energy		TRE	-95.2738	29.6914	South Houston Service Area	Lightning	491.00	73000	4
2009	Center Point Energy		TRE	-95.2738	29.6914	Houston Metropolitan Service Area	Lightning	544.00	80000	13
2003	Center Point Energy		TRE	-95.2738	29.6914	North Texas	Supply Shortage	476.00	192000	13
2006	Center Point Energy		TRE	-95.2738	29.6914	System-wide greater Houston metro area (and across ERCOT)	Supply Shortage	260.00	68000	2
2003	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas	Wind/Rain	350.00	64801	10
2006	Center Point Energy		TRE	-95.2738	29.6914	System-wide greater Houston metro area	Wind/Rain	219.00	82000	3
2006	Center Point Energy		TRE	-95.2738	29.6914	System-wide greater Houston area	Wind/Rain	221.00	83000	10
2009	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas	Wind/Rain	350.00	64801	10
2009	Center Point Energy		TRE	-95.2738	29.6914	Greater Houston/Galveston Area	Wind/Rain	176.00	158000	20
2008	Center Point Energy		TRE	-95.2738	29.6914	Greater Houston-Galveston Metro Area	Hurricane or Tropical Storm	8087.00	2142678	462
2005	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and the surrounding suburban areas	Hurricane or Tropical Storm	1950.00	715000	27
2005	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and surrounding suburban areas	Lightning	672.00	243000	7
2005	Center Point Energy		TRE	-95.2738	29.6914	Houston, Texas and surrounding suburban areas	Lightning	328.00	123000	6
2006	Central Maine Power Company		NPCC	-69.0701	44.2937	Southern and Central Maine	Wind/Rain	75.00	63000	3
2003	City of Homestead	No service area map	FRCC	-80.4776	25.4687	State of Florida - Dade County	Equipment Failure	27.00	16500	2
2002	City of Lakeworth Utilities	No service area map	SERC	-80.0570	26.6159	Florida	Supply Shortage	51.00	25000	4
2002	City of Lakeworth Utilities	No service area map	SERC	-80.0570	26.6159	Florida	Wind/Rain	67.60	25000	13
2006	City Water, Light & Power (Electric Division)	No service area map	RFC	-89.6437	39.8017	Springfield, Illinois and vicinity	Wind/Rain	200.00	65400	40
2002	ConEdison		NPCC	-73.8603	40.9296	New York	Fire	278.00	63500	8
2007	ConEdison		NPCC	-73.8603	40.9296	Northern Manhattan NY (Yorkville) and SW Bronx (Motthaven, Melrose, High Bridge Sections)	Lightning	460.00	137000	1
2003	ConEdison		NPCC	-73.8603	40.9296	Entire Con Edison System (five boroughs of NYC and Westchester County)	Other External Cause	11202.00	3125350	29
2003	Consumers Energy		RFC	-86.7282	45.4632	Lower Michigan Peninsula	Lightning	85.00	131000	55
2004	Consumers Energy		RFC	-86.7282	45.4632	Lower peninsula of Michigan following cities: Grand Rapids, Kalamazoo, Battle Creek, Jackson, Bronson, Jonesville, Flint	Lightning	200.00	248209	95
2005	Consumers Energy		RFC	-86.7282	45.4632	Portions of the southern 2/3 of Michigan's Lower Peninsula	Lightning	55.00	105000	52
2005	Consumers Energy		RFC	-86.7282	45.4632	Western and Central portions of Michigan's Lower Peninsula	Lightning	408.00	272355	49
2006	Consumers Energy		RFC	-86.7282	45.4632	Muskegon, Michigan easterly to Bay City, Michigan	Lightning	100.00	252089	107
2006	Consumers Energy		RFC	-86.7282	45.4632	Middle 1/3 of Michigan Lower Peninsula	Lightning	150.00	315000	106
2008	Consumers Energy		RFC	-86.7282	45.4632	Lower 2/3 of Michigan's Lower Peninsula	Lightning	100.00	358000	137
2003	Consumers Energy		RFC	-86.7282	45.4632	Southern Lower Michigan and small areas near Flint, Alma, Saginaw, and Lansing Michigan	Other External Cause	1007.00	101000	45
2003	Consumers Energy		RFC	-86.7282	45.4632	Lower Michigan Peninsula	Snow/Ice Storm	300.00	425000	70
2007	Consumers Energy		RFC	-86.7282	45.4632	Lower 2/3 of Michigan Lower Peninsula	Snow/Ice Storm	50.00	134288	61
2009	Consumers Energy		RFC	-86.7282	45.4632	Michigan, Lower Peninsula	Snow/Ice Storm	75.00	70793	59
2002	Consumers Energy		RFC	-86.7282	45.4632	Lower Peninsula of Michigan	Wind/Rain	190.00	190000	60
2003	Consumers Energy		RFC	-86.7282	45.4632	Lower Michigan Peninsula	Wind/Rain	85.00	245000	97
2004	Consumers Energy		RFC	-86.7282	45.4632	Lower peninsula of Michigan. following area: Grand Rapids, Kalamazoo, Battle Creek, Greenville, Jackson, Flint, Lansing, Allegan, Temperance	Wind/Rain	60.00	122000	56
2009	Consumers Energy		RFC	-86.7282	45.4632	Michigan Lower Peninsula	Wind/Rain	75.00	99000	71
2008	Consumers Energy		RFC	-86.7282	45.4632	Lower 2/3 of Michigan's Lower Peninsula	Wind/Rain	125.00	239663	93

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2007	Crawfordsville Electric Light and Power	No service area map	RFC	-86.8745	40.0412	City of Crawfordsville, Indiana	Supply Shortage	50.00	9600	1
2009	Crawfordsville Electric Light and Power	No service area map	RFC	-86.8745	40.0412	Crawfordsville, Indiana	Supply Shortage	50.00	9700	1
2008	Crawfordsville Electric Light and Power	No service area map	RFC	-86.8745	40.0412	City of Crawfordsville, Indiana	Supply Shortage	57.00	9700	2
2008	Crawfordsville Electric Light and Power	No service area map	RFC	-86.8745	40.0412	Crawfordsville, Indiana	Supply Shortage	41.00	9700	1
2008	Crawfordsville Electric Light and Power	No service area map	RFC	-86.8745	40.0412	City of Crawfordsville, Indiana	Equipment Failure	47.00	9700	4
2007	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Francisco Bay Area, Californi	Equipment Failure	130.00	158977	2
2007	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Francisco Bay Area, Californi	Equipment Failure	150.00	1	4
2007	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Francisco Bay Area, Californi	Equipment Failure	150.00	1	3
2007	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Franscisco Bay Area, Californi	Equipment Failure	140.00	1	3
2009	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Francisco Bay Area, Californi	Equipment Failure	136.00	1	3
2005	Crockett Cogeneration	No service area map	WECC	-122.2130	38.0524	San Francisco Bay area, California	Lightning	126.00	69979	0
2008	Dayton Power & Light	No service area map	RFC	-84.1916	39.7589	South Metropolitan Areas of Dayton, OHi	Wind/Rain	380.00	45000	1
2008	Dayton Power & Light	No service area map	RFC	-84.1916	39.7589	Dayton Ohio Area	Hurricane or Tropical Storm	1000.00	95000	70
2006	Delmarva Power		RFC	-75.7542	39.0336	Southern Delmarva Peninsula	Hurricane or Tropical Storm	380.00	105000	76
2006	Delmarva Power		RFC	-75.7542	39.0336	Entire Delmarva Power service territory	Snow/Ice Storm	50.00	58000	29
2004	Detroit Edison		RFC	-83.5695	42.7181	Southeast Michigan	Lightning	630.00	250000	76
2005	Detroit Edison		RFC	-83.5695	42.7181	Southeast Michigan	Lightning	1826.00	201580	113
2005	Detroit Edison		RFC	-83.5695	42.7181	Southeast Michigan	Lightning	1000.00	114711	127
2005	Detroit Edison		RFC	-83.5695	42.7181	Southeast Michigan	Lightning	366.00	53000	108
2005	Detroit Edison		RFC	-83.5695	42.7181	Southeast Michigan	Lightning	212.00	118000	136
2007	Detroit Edison		RFC	-83.5695	42.7181	Southeastern Michigan	Lightning	500.00	66000	40
2003	Detroit Edison		RFC	-83.5695	42.7181	Southeastern Michigan including all of Detroit	Other External Cause	11000.00	2100000	39
2007	Detroit Edison		RFC	-83.5695	42.7181	Eastern and Lower Michigan	Snow/Ice Storm	500.00	129607	152
2003	Detroit Edison		RFC	-83.5695	42.7181	Southeastern Michigan	Wind/Rain	75.00	160000	95
2004	Detroit Edison		RFC	-83.5695	42.7181	Southeastern Michigan	Wind/Rain	700.00	159870	97
2008	Detroit Edison		RFC	-83.5695	42.7181	Southwestern Michigan (DECO Service Territory	Wind/Rain	500.00	150000	197
2003	Dominion Virginia Power		SERC	-79.0116	37.3781	North Eastern North Carolina, Eastern Central , and Northern Virginia	Hurricane or Tropical Storm	6512.00	1800000	278
2004	Dominion Virginia Power		SERC	-79.0116	37.3781	Central Virginia, South to North Carolina and East to the Virginia Coast	Hurricane or Tropical Storm	150.00	99816	21
2006	Dominion Virginia Power		SERC	-79.0116	37.3781	Virginia and North Carolina	Hurricane or Tropical Storm	500.00	333000	57
2000	Dominion Virginia Powe		SERC	-79.0116	37.3781	Virginia & North Carolina	Lightning	175.00	30500	1
2003	Dominion Virginia Powe		SERC	-79.0116	37.3781	Northern Central and Eastern Virgini	Lightning	120.00	80000	2
2004	Dominion Virginia Powe		SERC	-79.0116	37.3781	Central Virginia	Lightning	120.00	88110	10
2006	Dominion Virginia Powe		SERC	-79.0116	37.3781	Northern Virginia	Lightning	300.00	75000	6
2006	Dominion Virginia Powe		SERC	-79.0116	37.3781	Northern Virginia	Lightning	335.00	67000	3
2006	Dominion Virginia Power		SERC	-79.0116	37.3781	North, Central and Eastern Virginia and Northern North Carolina	Lightning	84.00	56500	2
2007	Dominion Virginia Powe		RFC	-79.0116	37.3781	Central and Eastern Virginia	Lightning	100.00	58500	2
2008	Dominion Virginia Powe		RFC	-79.0116	37.3781	Northern Virginia	Lightning	850.00	253800	30
2008	Dominion Virginia Powe		RFC	-79.0116	37.3781	Northern Virginia	Lightning	900.00	115000	7
2003	Dominion Virginia Power		SERC	-79.0116	37.3781	Northern Virginia to Fredericksburg & Staunton to Harrisonburg	Snow/Ice Storm	63.00	130000	57
2006	Dominion Virginia Powe		RFC	-79.0116	37.3781	Northern and Northwestern Virginia	Snow/Ice Storm	250.00	126000	8
2009	Dominion Virginia Powe		SERC	-79.0116	37.3781	Central Virginia - Spotsylvania Count	Snow/Ice Storm	210.00	217000	44
2001	Dominion Virginia Powe		SERC	-79.0116	37.3781	Virginia	Supply Shortage	1050.00	600000	4

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2003	Dominion Virginia Powe		SERC	-79.0116	37.3781	Northern Virginia, Richmond area, Eastern Virgini	Wind/Rain	300.00	67000	2
2007	Dominion Virginia Power		SERC	-79.0116	37.3781	North, East and Central Virginia/Parts of Northeast North Carolina	Wind/Rain	90.00	242000	5
2007	Dominion Virginia Powe		SERC	-79.0116	37.3781	North, East and Central Virginia	Wind/Rain	72.00	107000	6
2007	Dominion Virginia Power		RFC	-79.0116	37.3781	Virginia and Eastern North Carolina - Primarily in Central Virginia	Wind/Rain	200.00	93300	25
2008	Dominion Virginia Powe		RFC	-79.0116	37.3781	Dominion Service Territor	Wind/Rain	170.00	114618	9
2008	Dominion Virginia Power		RFC	-79.0116	37.3781	North East North Carolina and Virginia	Hurricane or Tropical Storm	220.00	64463	2
2008	Dominion Virginia Powe		RFC	-79.0116	37.3781	Virginia and Eastern Part of North Carolin	Wind/Rain	210.00	141130	8
2008	Dow Chemical Company	No service area map	SERC	-91.2343	30.2891	Louisiana	Supply Shortage	200.00	0	7
2008	Dow Chemical Company	No service area map	SERC	-91.2343	30.2891	Plaquemine, Louisiana	Supply Shortage	200.00	0	458
2004	Duke Energy	Merged in 2005 to become Duke Power	RFC	-85.3073	39.8134	West, West Central and Southern Indiana	Lightning	600.00	135000	88
2006	Duke Energy	Merged in 2005 to become Duke Power	RFC	-85.3073	39.8134	Southern half of Indiana	Tornado	1000.00	186000	55
2000	Duke Energy	Merged in 2005 to become Duke Power	RFC	-85.3073	39.8134	Ohio	Wind/Rain	0.00	92000	29
2003	Duke Energy	Merged in 2005 to become Duke Power	RFC	-85.3073	39.8134	Southwest Ohio, portions of Indiana	Wind/Rain	200.00	55142	45
2003	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Triangle and Tridad (Greensboro – High Point) Areas North Carolina - Northern Region	Hurricane or Tropical Storm	550.00	50000	25
2004	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Western North and South Carolina	Hurricane or Tropical Storm	500.00	175000	91
2000	Duke Energy - Carolinas		SERC	-81.1777	35.4248	North Carolina	Lightning	200.00	50000	24
2003	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Piedmont, North and South Carolina	Lightning	1500.00	139000	43
2005	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Piedmont North and South Carolin	Lightning	300.00	52200	93
2006	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Charlotte, North Carolina Metropolitan area	Lightning	70.00	72000	3
2008	Duke Energy - Carolinas		SERC	-81.1777	35.4248	North and South Carolina	Lightning	300.00	55267	1
2000	Duke Energy - Carolinas		SERC	-81.1777	35.4248	South Carolina	Snow/Ice Storm	450.00	133000	124
2000	Duke Energy - Carolinas		SERC	-81.1777	35.4248	South Carolina	Snow/Ice Storm	300.00	81000	110
2003	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Piedmont, North Carolina	Snow/Ice Storm	1000.00	340000	44
2005	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Piedmont North Carolina and South Carolin	Snow/Ice Storm	3500.00	683000	157
2009	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Duke Energy Carolinas Balance Authorit	Snow/Ice Storm	1000.00	180000	43
2000	Duke Energy - Carolinas		SERC	-81.1777	35.4248	North Carolina	Wind/Rain	475.00	100000	188
2000	Duke Energy - Carolinas		SERC	-81.1777	35.4248	North Carolina	Wind/Rain	500.00	130000	41
2004	Duke Energy - Carolinas		SERC	-81.1777	35.4248	North and South Carolina	Wind/Rain	1000.00	206000	38
2009	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Piedmont of North and South Carolin	Wind/Rain	300.00	70000	3
2008	Duke Energy - Carolinas		SERC	-81.1777	35.4248	Greenboro, North Carolina and I-40 Corrido	Wind/Rain	300.00	50718	10
2009	Duke Energy - Midwest		RFC	-85.3073	39.8134	Southwest Ohio, Northern Kentudky, Central and Southern Indiana	Lightning	327.00	85000	32
2009	Duke Energy - Midwest		RFC	-85.3073	39.8134	Northern Kentucky, Southwest Ohio and Central and South Indiana	Lightning	50.00	63700	103
2007	Duke Energy - Midwest		RFC	-85.3073	39.8134	Indiana and Southwest Ohi	Snow/Ice Storm	250.00	367500	58
2006	Duke Energy - Midwest		RFC	-85.3073	39.8134	Southwest Ohio, Northern Kentucky, Central Indian	Wind/Rain	800.00	210000	37
2007	Duquesne Light Company		RFC	-80.0920	40.5095	Highland Area of Pittsburgh, Pennsylvani	Lightning	90.00	55000	1
2008	Duquesne Light Company		RFC	-80.0920	40.5095	Allegheny and Beaver Counties in Pennsylvania	Hurricane or Tropical Storm	600.00	105000	5
2009	East Kentucky Power Cooperative		SERC	-84.3203	37.6015	Central and Eastern Kentrucky	Snow/Ice Storm	600.00	190000	108
2000	El Paso Electric Company		WECC	-106.0781	31.9361	Texas	Equipment Failur	400.00	100000	1
2004	El Paso Electric Company		WECC	-106.0781	31.9361	El Paso, Texas	Equipment Failur	300.00	100000	1
2009	El Paso Electric Company		WECC	-106.0781	31.9361	City of El Paso, Texas, County of El Pas	Equipment Failur	250.00	132000	3
2002	Entergy		SERC	-90.5662	34.5944	Arkansas	Snow/Ice Storm	0.00	43000	148
2004	Entergy		SPP	-90.5662	34.5944	Southeast Texas	Supply Shortage	0.00	0	10

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2004	Entergy		SPP	-90.5662	34.5944	Southeastern Louisiana in the New Orleans area	Supply Shortage	0.00	0	23
2006	Entergy		SERC	-90.5662	34.5944	Greater Little Rock, Arkansas	Supply Shortage	40.00	8000	7
2008	Entergy		SERC	-90.5662	34.5944	Entergy System	Supply Shortage	300.00	19	4
2008	Entergy		SERC	-90.5662	34.5944	Entergy System	Supply Shortage	300.00	19	5
2000	Entergy		SPP	-91.7649	34.4813	Texas	Supply Shortage	0.00	2000000	36
2005	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Chicago, Illinois	Equipment Failure	350.00	51500	2
2004	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Chicago, Illinois	Lightning	200.00	200000	26
2000	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Illinois	Wind/Rain	0.00	239567	20
2003	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Northern Illinois	Wind/Rain	80.00	130000	4
2003	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Northern Illinois	Wind/Rain	371.10	51000	2
2004	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Northern Illinois	Wind/Rain	127.00	127000	10
2007	Exelon Corp - ComEd		RFC	-87.8172	41.9455	Northern Counties of Illinois	Wind/Rain	300.00	135000	8
2008	First Energy - Jersey Central Power & Light		RFC	-74.4319	40.3073	Central New Jersey	Equipment Failure	438.00	156729	11
2002	First Energy - Met-Ed		RFC	-76.5973	40.4345	Reading, York, Hanover, Hamburg Pennsylvania	Snow/Ice Storm	0.00	95630	47
2004	First Energy - Ohio Edison		RFC	-82.0945	40.9011	Akron and Youngstown areas	Lightning	392.00	281000	70
2005	First Energy - Ohio Edison		RFC	-82.0945	40.9011	Akron and Mansfield areas	Snow/Ice Storm	250.00	246990	194
2003	First Energy - Ohio Edison		RFC	-82.0945	40.9011	Central and Eastern Ohio	Wind/Rain	168.00	184000	49
2009	First Energy - Ohio Edison		RFC	-82.0945	40.9011	Central and Eastern Ohio	Wind/Rain	168.00	184000	49
2008	First Energy - Ohio Edison		RFC	-82.0945	40.9011	Southern, Eastern, and Central Ohio	Wind/Rain	469.00	564728	192
2003	First Energy - Penelec		RFC	-77.8981	40.9248	Western and North Eastern Pennsylvania	Wind/Rain	130.00	132000	86
2009	First Energy - Penelec		RFC	-77.8981	40.9248	Western and North Eastern Pennsylvania	Wind/Rain	130.00	132000	86
2008	First Energy - Penelec		RFC	-77.8981	40.9248	Western Pennsylvania	Wind/Rain	72.00	124596	116
2004	First Energy - The Illuminating Company		RFC	-81.1773	41.6135	Cleveland area	Lightning	177.00	127000	70
2008	First Energy - The Illuminating Company		RFC	-81.1773	41.6135	Northeast Ohio	Wind/Rain	430.00	245164	178
2003	First Energy Corp		RFC	-79.6916	40.9770	Northeast, Ohio	Other External Cause	7000.00	1203000	52
2009	Florida Keys Electric Cooperative Assoc. Inc.	No service area map	FRCC	-81.2904	24.6530	Florida Keys	Equipment Failure	55.00	31000	12
2004	Florida Municipal Power Agency	No service area map	FRCC	-80.3257	27.4470	City of Fort Pierce, Florida	Hurricane or Tropical Storm	125.00	26000	41
2004	Florida Municipal Power Agency	No service area map	FRCC	-80.3257	27.4470	City of Fort Pierce, Florida	Hurricane or Tropical Storm	125.00	26000	16
2005	Florida Municipal Power Agency	No service area map	FRCC	-82.0771	28.3534	South Florida - Cities of Key West, Clewiston, Lake Worth, and Ft. Pierce	Hurricane or Tropical Storm	148.00	84900	401
2008	Florida Municipal Power Agency	No service area map	FRCC	-82.0771	28.3534	Various Cities in Florida	Supply Shortage	140.00	47661	1
2008	Florida Power & Light		FRCC	-81.2567	27.9683	Primary Dade County Florida	Equipment Failure	3200.00	584384	3
2004	Florida Power & Light		FRCC	-81.2567	27.9683	West Coast of Florida from Naples to Charlotte and in an area centered around Daytona Beach	Hurricane or Tropical Storm	1400.00	1200000	8
2004	Florida Power & Light		FRCC	-81.2567	27.9683	West Palm Beach to Daytona Beach, Florida	Hurricane or Tropical Storm	6000.00	2775093	48
2005	Florida Power & Light		FRCC	-81.2567	27.9683	South Florida, Naples, Ft. Myers, Miami, Ft. Lauderdale, West Palm Beach and Martin county	Hurricane or Tropical Storm	10000.00	3241437	18
2004	Florida Power & Light		FRCC	-81.2567	27.9683	FPL's service territory mostly in Naples and Ft. Myers Florida	Wind/Rain	250.00	179000	5
2004	Georgia System Operations Corporation		SERC	-83.3765	32.5802	Georgia	Hurricane or Tropical Storm	2200.00	150000	26
2005	Georgia System Operations Corporation		SERC	-83.3765	32.5802	Georgia	Snow/Ice Storm	100.00	82000	23
2008	Golden Spread Electric Cooperative, Inc		TRE	-100.1926	34.0514	Texas Panhandle and Texas South Plains Regions, and Oklahoma Panhandle	Lightning	276.00	37330	2

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2007	Great River Energy	No service area map	MRO	-93.4364	45.0943	Minnesota, North Dakota, Manitoba	Supply Shortage	9000.00	11175	1
2009	Henderson Municipal Power and Light	No service area map	RFC	-87.5900	37.8362	City of Henderson, Kentucky and Portions of Henderson County, Kentucky	Snow/Ice Storm	21.00	3500	253
2006	Idaho Power Company		WECC	-116.0533	43.6117	Southwest Idaho and Eastern Oregon	Lightning	90.00	65000	40
2003	Idaho Power Company		WECC	-116.0533	43.6117	Idaho	Supply Shortage	0.00	0	26
2004	Idaho Power Company		WECC	-116.0533	43.6117	Southern Idaho	Supply Shortage	157.00	35000	2
2007	Idaho Power Company		WECC	-116.0533	43.6117	Southwest Idaho and Eastern Oregon	Supply Shortage	424.00	80000	1
2007	ISO New England		NPCC	-71.2320	43.6475	Eastern Massachusetts, Rhode Island, Cape Cod	Hurricane or Tropical Storm	100.00	62843	12
2008	ISO New England		NPCC	-71.2320	43.6475	South West Connecticut	Lightning	130.00	56400	2
2004	ISO New England		NPCC	-71.2320	43.6475	Nova Scotia	Snow/Ice Storm	165.00	165000	21
2008	ISO New England		NPCC	-71.2320	43.6475	State of Maine	Snow/Ice Storm	50.00	50462	17
2001	ISO New England		NPCC	-71.2320	43.6475	Boston & NE MA	Supply Shortage	340.00	130000	2
2007	ISO New England		NPCC	-71.2320	43.6475	State of Maine	Supply Shortage	0.00	0	28
2009	ISO New England		NPCC	-71.2320	43.6475	Northern Maine	Supply Shortage	0.00	0	3
2008	ISO New England		NPCC	-71.2320	43.6475	Bangor Hydro System, northern Maine	Lightning	180.00	110000	10
2008	ISO New England		NPCC	-71.2320	43.6475	All Six New England States	Wind/Rain	50.00	60000	10
2003	ISO New England - REMVEC		NPCC	-71.3582	42.7150	Cape Cod and part of SE Massachusetts	Fire	630.00	300000	2
2005	Lakeland Electric	No service area map	FRCC	-81.9498	28.0395	Lakeland, Florida	Hurricane or Tropical Storm	0.00	0	124
2004	Lincoln Electric System	No service area map	MRO	-96.6502	40.8466	Lincoln, Nebraska	Tornado	428.00	120212	0
2005	Los Angeles Department of Water & Power		WECC	-118.3036	34.0754	Los Angeles, California	Other External Cause	2578.00	900000	1
2007	Los Angeles Department of Water & Power		WECC	-118.3036	34.0754	City of Los Angeles, California	Wind/Rain	200.00	158977	20
2008	Los Angeles Department of Water & Power		WECC	-118.3036	34.0754	City of Los Angeles	Fire	211.00	115500	1
2008	Lubbock Power & Light	City of Lubbock, TX	TRE	-101.8552	33.5779	City of Lubbock	Lightning	153.00	71823	2
2007	MidAmerican Energy Company		MRO	-94.2299	42.2881	NE quarter of State of Iowa and Rock Island, Illinois	Snow/Ice Storm	210.00	75000	177
2008	MidAmerican Energy Company		MRO	-94.2299	42.2881	Sioux City, Carroll, Des Moines, Iowa City, and Davenport Iowa, Rock Island, Moline, and Surrounding Area of Illinois	Wind/Rain	170.00	185000	41
2008	Midwest ISO		RFC	-95.2440	44.8424	St. Louis, Missouri	Fire	135.00	53000	2
2003	Midwest ISO		RFC	-95.2440	44.8424	Northern Kentucky and Southwest Ohio	Lightning	350.00	63000	15
2009	Midwest ISO		RFC	-95.2440	44.8424	Northern Kentucky and Southwest Ohio	Lightning	350.00	63000	15
2009	Midwest ISO		RFC	-95.2440	44.8424	East Central Missouri	Snow/Ice Storm	300.00	1	57
2007	Midwest ISO		RFC	-95.2440	44.8424	Cedar Rapids, Iowa	Snow/Ice Storm	750.00	215000	5
2007	Midwest ISO		RFC	-95.2440	44.8424	Manitoba, Minnesota, North Dakota, Portions of South Dakota and Wisconsin. Midwest ISO's Market subregions: OTP, NSP, GRE, ALTW, MP	Supply Shortage	9000.00	11175	7
2009	Midwest ISO		RFC	-95.2440	44.8424	Western South Dakota	Supply Shortage	84.00	0	1
2003	Midwest ISO		RFC	-95.2440	44.8424	Central and Eastern Ohio	Wind/Rain	168.00	184000	4
2009	Midwest ISO		RFC	-95.2440	44.8424	Central and Eastern Ohio	Wind/Rain	168.00	184000	4
2008	Midwest ISO		RFC	-95.2440	44.8424	East Central Iowa	Wind/Rain	200.00	21000	144
2008	Mirant - Chalk Point	on the Patuxent River	RFC	-76.9963	39.1669	-	Supply Shortage	0.00	0	24
2002	Missouri Public Service Commission	No service area map	SPP	-91.5776	38.8531	Missouri	Snow/Ice Storm	210.00	95000	269
2007	Modesto Irrigation District		WECC	-120.7506	37.7297	Modesto California and the Surrounding Areas	Supply Shortage	180.00	26000	1
2004	National Grid USA - KeySpan Corporation		NPCC	-74.6026	43.0183	Sayreville, New Jersey Long Island, New York	Other External Cause	0.00	0	71

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2004	National Grid USA - New England		NPCC	-71.6425	42.2851	Boston, Massachusetts	Lightning	22700.00	380000	6
2006	National Grid USA - New England		NPCC	-71.6425	42.2851	New England	Lightning	140.00	77000	6
2007	National Grid USA - New England		NPCC	-71.6425	42.2851	Massachusetts, New Hampshire, Rhode Island	Wind/Rain	75.00	70000	2
2008	National Grid USA - New York		NPCC	-75.4586	43.3162	Eastern New York	Snow/Ice Storm	200.00	190000	179
2004	National Grid USA - New York		NPCC	-75.4586	43.3162	Lake Placid/Saranac, New York	Supply Shortage	100.00	18600	52
2004	National Grid USA - New York		NPCC	-75.4586	43.3162	Lake Placid/Saranac, New York	Supply Shortage	100.00	18600	78
2007	National Grid USA - New York		NPCC	-75.4586	43.3162	Eastern New York	Wind/Rain	650.00	300000	43
2008	National Grid USA - New York		NPCC	-75.4586	43.3162	Upstate New York	Wind/Rain	400.00	68000	78
2006	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	Western New York State	Snow/Ice Storm	600.00	250000	246
2004	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	Lake Colby, Lake Placid, Tupper Lake	Supply Shortage	30.00	18600	40
2003	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	New York, Upstate New York	Wind/Rain	275.00	160000	35
2003	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	New York	Wind/Rain	180.00	50280	23
2006	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	Upstate New York	Wind/Rain	250.00	200000	7
2008	National Grid USA - Niagara Mohawk Power Corporation		NPCC	-75.4586	43.3162	Western, New York	Wind/Rain	50.00	54316	60
2006	Nebraska Public Power District		MRO	-99.8295	41.5458	Gosper, Harlan, Franklin, Webster, Clay, Adams, Kearney, Phelps, Dawson, Buffalo, Hall, Hamilton, Sherman, Custer, Valley, Greeley, Howard, Merrick, York, Fillmore, Nance, Boone, Wheeler, Madison, Antelope, Pierce, Platte and Seward Counties in Central Nebraska	Wind/Rain	400.00	15000	160
2006	New York State Electric and Gas		NPCC	-76.2984	42.2795	Western New York State	Snow/Ice Storm	353.00	120000	219
2008	New York ISO	No service area map	NPCC	-75.6945	43.0365	New York State	Equipment Failure	200.00	61000	1
2008	Northern Indiana Public Service Company (NIPSCO)	No service area map	RFC	-86.6022	41.3333	Northwest Indiana	Wind/Rain	0.00	63000	7
2008	NRG Energy - Louisiana Generating, LLC (SERC)	No service area map	SERC	-91.9708	30.8159	Primarily South and Central Louisiana	Hurricane or Tropical Storm	400.00	150000	297
2008	NRG Energy - Louisiana Generating, LLC (SERC)	No service area map	SERC	-91.9708	30.8159	Southwest Louisiana	Hurricane or Tropical Storm	40.00	50000	340
2005	NRG Energy - Louisiana Generating, LLC (SPP)	No service area map	SPP	-92.7691	33.7282	East and Southeast Louisiana	Hurricane or Tropical Storm	300.00	143000	12
2005	NRG Energy - Louisiana Generating, LLC (SPP)	No service area map	SPP	-92.7691	33.7282	West and Southwest Louisiana	Hurricane or Tropical Storm	350.00	125000	313
2002	Oklahoma Gas & Electric		SPP	-97.0476	35.7893	Oklahoma	Snow/Ice Storm	500.00	1881134	198

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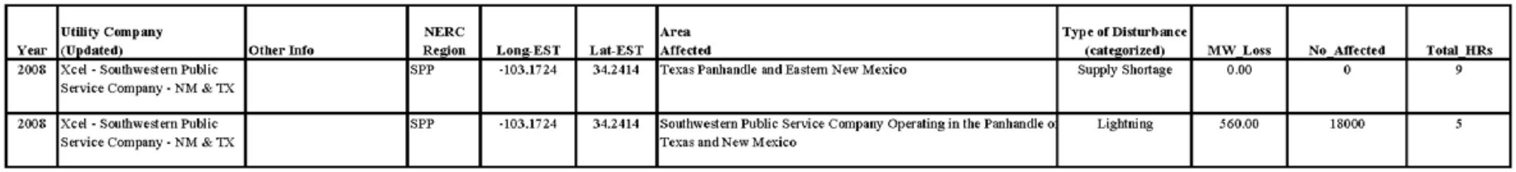
2008	Omaha Public Power District		MRO	-96.1455	41.3806	Omaha, Nebraska (Metro Area)	Wind/Rain	650.00	126000	1
2004	Orlando Utilities Commission	No service area map	FRCC	-81.3794	28.5383	Orlando, Florida	Hurricane or Tropical Storm	200.00	65000	112
2004	Orlando Utilities Commission	No service area map	FRCC	-81.3794	28.5383	Orlando and St. Cloud, Florida	Hurricane or Tropical Storm	350.00	110000	102
2008	Owensboro Municipal Utilities	No service area map	RFC	-87.1133	37.7742	City of Owensboro, Kentucky	Wind/Rain	70.00	18000	175
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Central California Coast	Earthquake	220.00	109750	0
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Equipment Failure	200.00	1	2
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	San Francisco, California	Equipment Failure	150.00	120000	32
2004	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	San Jose, California	Equipment Failure	103.00	59458	3
2006	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	City of Bakersfield area	Equipment Failure	300.00	55655	6
2006	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	California	High Temperatures	200.00	1271893	123
2002	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern and Central California	Snow/Ice Storm	270.00	939000	86
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern and Central California	Snow/Ice Storm	180.00	1500000	125
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern and Central California	Snow/Ice Storm	56.00	385000	59
2003	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	160.00	241000	86
2004	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	170.00	263000	32
2004	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	240.00	505000	34
2005	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	120.00	442000	67
2007	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	110.00	671189	68
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Snow/Ice Storm	500.00	2606931	253
2009	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	East of Fresno California	Supply Shortage	1.00	70	7
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Antioch, California	Supply Shortage	10.00	10008	5
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Near Arnold, California	Supply Shortage	0.00	0	4
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Plumas County, California	Supply Shortage	30.00	10000	0
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	East of Oroville, California	Supply Shortage	1.00	638	5
2004	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Wind/Rain	140.00	407440	35
2004	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Salinas, California and surrounding communitie	Wind/Rain	100.00	95000	3
2005	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern and Central California	Wind/Rain	800.00	1667316	123
2006	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Northern California	Wind/Rain	420.00	850068	129
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Humboldt Area of California	Equipment Failure	5.00	0	186
2008	Pacific Gas & Electric	No service area map	WECC	-122.4195	37.7749	Near Rogers Flat, California	Lightning	3.00	477	4
2008	PacifiCorp		WECC	-122.4348	41.9912	Utah	Supply Shortage	2818.00	74031	3
2008	PacifiCorp		WECC	-122.4348	41.9912	Southern Oregon	Equipment Failure	32.00	3	3
2003	Pepco		RFC	-77.0135	38.9101	Washington, D.C., Montgomery County, Prince Georges County, Maryland	Lightning	1500.00	153000	122
2006	Pepco		RFC	-77.0135	38.9101	Washington DC, Montgomery and Prince Georges Counties MD	Snow/Ice Storm	300.00	60000	66
2003	Pepco		RFC	-77.0135	38.9101	Washington, D.C., Montgomery County, Prince Georges County, Md	Wind/Rain	400.00	104195	20
2003	PJM Interconnection		RFC	-79.1140	38.5598	Maryland/Virginia border	Tornado	350.00	1	1
2006	Portland General Electric		WECC	-122.6615	45.5214	Oregon Counties: Washington, Yamhil	Equipment Failure	350.00	84500	5
2004	PowerSouth Coop	Name change to PowerSouth (Jan 08)	SERC	-85.0535	32.1247	Baldwin County, Alabama, Escambia County, Florida, Washington County, Alabama	Hurricane or Tropical Storm	263.00	75000	8
2005	PowerSouth Coop	Name change to PowerSouth (Jan 08)	SERC	-85.0535	32.1247	Southwest Alabama and Western Panhandle of Florida	Hurricane or Tropical Storm	51.20	50000	29
2003	PPL Electric Utilities		RFC	-76.1508	40.6812	All PPL including: Williamsport, Harrisburg, Lancaster, Scranton and Allentown areas	Hurricane or Tropical Storm	1300.00	425000	68
2003	PPL Electric Utilities		RFC	-76.1508	40.6812	Eastern Pennsylvania	Snow/Ice Storm	250.00	106000	12
2003	PPL Electric Utilities		RFC	-76.1508	40.6812	Pennsylvania	Wind/Rain	750.00	185000	60

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2003	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Eastern North Carolina	Hurricane or Tropical Storm	1655.00	320000	12
2004	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Central and Eastern North Carolina and Northern and Eastern South Carolina	Hurricane or Tropical Storm	500.00	94000	10
2004	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Western North Carolina	Hurricane or Tropical Storm	400.00	112000	32
2005	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Eastern North Carolina	Hurricane or Tropical Storm	215.00	60000	24
2004	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Central and Eastern North Carolina and Northern and Eastern South Carolina	Snow/Ice Storm	475.00	9905	63
2005	Progress Energy - Carolinas	Merged in 2000 to become Progress Energy Inc.	SERC	-78.3728	36.1022	Eastern and Central North Carolina	Wind/Rain	180.00	51600	4
2004	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Florida counties of Hardee, Highlands, Lake, Orange, Osceola, Polk, Seminole, Volusia	Hurricane or Tropical Storm	1300.00	502000	232
2004	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Florida counties of Alachua, Citrus, Columbia, Dixie, Franklin, Gilchrist, Gulf, Hamilton, Hardee, Hernando, Highlands, Jefferson, Lafayette, Lake, Levy, Madison, Marion, Orange, Osceola, Pasco, Pinellas, Polk, Seminole, Sumter, Suwannee, Taylor, Volusia and Wakulla	Hurricane or Tropical Storm	2100.00	832898	161
2004	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Florida counties of Alachua, Bay, Brevard, Citrus, Columbia, Dixie, Flagler, Franklin, Gilchrist, Gulf, Hamilton, Hardee, Hernando, Highlands, Hillsborough, Jefferson, Lafayette, Lake, Leon, Levy, Madison, Marion, Orange, Osceola, Pasco, Pinellas, Polk, Seminole, Sumter, Suwannee, Taylor, Volusia and Wakulla	Hurricane or Tropical Storm	1800.00	722000	114
2005	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Counties of Alachua, Bay, Citrus, Columbia, Dixie, Franklin, Gilchrist, Gulf, Hamilton, Hardee, Hernando, Highlands, Jefferson, Lafayette, Lake, Levy, Madison, Marion, Orange, Osceola, Pasco, Pinellas, Polk, Seminole, Sumter, Suwannee, Taylor, Volusia and Wakulla	Hurricane or Tropical Storm	0.00	0	168
2004	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Florida counties of Gadsden, Wakulla, Leon, and Liberty	Supply Shortage	0.00	16667	60
2008	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	Pinellas County, Florida	Equipment Failure	113.00	32593	7
2008	Progress Energy - Florida	Merged in 2000 to become Progress Energy Inc.	FRCC	-82.7483	29.2740	The entire PEF system was affected, including the following counties: Alachua, Bay, Citrus, Columbia, Dixie, Franklin, Gilchrist, Gulf, Hamilton, Hardee, Hernando, Highlands, Jefferson, Lafayette, Lake, Levy, Madison, Marion, Orange, Osecola, Pasco, Pinellas, Polk, Seminole, Sumter, Suwannee, Taylor, Volusia, Wakulla.	Supply Shortage	500.00	150000	3
2008	Public Service Electric & Gas	Central/Western NJ	RFC	-74.5898	40.0338	Area Around West Orange Switching Station, New Jersey	Equipment Failure	215.00	75654	6
2000	Public Service of NM		WECC	-106.9556	34.3233	New Mexico	Equipment Failure	1040.00	500000	0

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2009	Puget Sound Energy		WECC	-121.9314	48.0861	Skagit County, Washington	Equipment Failure	244.00	93300	8
2004	Puget Sound Energy		WECC	-121.9314	48.0861	King County	Snow/Ice Storm	150.00	145000	89
2003	Puget Sound Energy		WECC	-121.9314	48.0861	Eastern portions of King County and Pierce County	Wind/Rain	175.00	200000	96
2006	Puget Sound Energy		WECC	-121.9314	48.0861	Whatcom and Skagit Counties, Washington	Wind/Rain	50.00	50000	86
2007	Riverside Public Utilities	No service area map	WECC	-117.3961	33.9533	Riverside, California	Supply Shortage	240.00	104000	4
2008	Sacramento Municipal Utility District		WECC	-121.3441	38.5501	Orangevale Area of Sacramento, California	Supply Shortage	110.00	50000	4
2008	Sacramento Municipal Utility District		WECC	-121.3441	38.5501	Sacramento County	Wind/Rain	300.00	150000	9
2007	Salt River Project		WECC	-111.6802	33.5685	Metropolitan Phoenix Area	Supply Shortage	399.00	98700	1
2007	San Diego Gas & Electric Company		WECC	-116.8391	33.0121	San Diego County, California	Fire	199.00	68780	1
2002	San Diego Gas & Electric Company		WECC	-116.8391	33.0121	California	Supply Shortage	300.00	255000	1
2004	SC Electric & Gas Company		SERC	-80.7355	33.3135	Southeastern South Carolina	Hurricane or Tropical Storm	450.00	125000	8
2004	SC Electric & Gas Company		SERC	-80.7355	33.3135	Central South Carolina	Snow/Ice Storm	550.00	150000	46
2008	Seattle City Light		WECC	-122.3228	47.5834	Part of Seattle's Downtown	Supply Shortage	100.00	8000	4
2006	Seattle City Light		WECC	-122.3228	47.5834	City of Seattle, Washington	Wind/Rain	750.00	175000	32
2004	Seminole Electric Cooperative		FRCC	-82.1301	28.4923	Florida counties of Collier, Hendry, Glades, Highlands, Charlotte, Desoto, Lee, Hardee, and Polk	Hurricane or Tropical Storm	700.00	200000	11
2005	Seminole Electric Cooperative		FRCC	-82.1301	28.4923	Florida counties of Collier, Charlotte and Lee	Hurricane or Tropical Storm	280.00	105000	12
2004	Seminole Electric Cooperative		FRCC	-82.1301	28.4923	Florida counties of Gadsden, Wakulla, Leon, and Liberty	Supply Shortage	0.00	16667	60
2008	Seminole Electric Cooperative		FRCC	-82.1301	28.4923	FRCC Region-West Coast Florida	Supply Shortage	120.00	56000	1
2006	Snohomish County PUD #1		WECC	-121.6828	48.0381	Snohomish County, Washington	Snow/Ice Storm	180.00	63992	149
2004	Snohomish County PUD #1		WECC	-121.6828	48.0381	Snohomish County Washington	Wind/Rain	300.00	187000	71
2006	Snohomish County PUD #1		WECC	-121.6828	48.0381	Snohomish County, Washington	Wind/Rain	150.00	123827	46
2006	Snohomish County PUD #1		WECC	-121.6828	48.0381	Snohomish County, Washington	Wind/Rain	360.00	172060	161
2007	Snohomish County PUD #1		WECC	-121.6828	48.0381	Snohomish County, Washington	Wind/Rain	260.00	110433	22
2004	Southern California Edison		WECC	-116.3203	34.9027	Northwest Orange County, California	Equipment Failure	480.00	182000	1
2004	Southern California Edison		WECC	-116.3203	34.9027	Soledad Canyon near Acton, California	Fire	214.00	50000	12
2007	Southern California Edison		WECC	-116.3203	34.9027	Southern California	Fire	451.00	90323	0
2007	Southern California Edison		WECC	-116.3203	34.9027	Southern Califonia	Fire	280.00	20345	4
2004	Southern California Edison		WECC	-116.3203	34.9027	Central and Southern California	High Temperatures	662.00	940	5
2001	Southern California Edison		WECC	-116.3203	34.9027	California	Supply Shortage	159.00	56718	2
2001	Southern California Edison		WECC	-116.3203	34.9027	California	Supply Shortage	225.00	70848	2
2004	Southern California Edison		WECC	-116.3203	34.9027	Southern California not including LA	Supply Shortage	300.00	70000	1

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2005	Southern California Edison		WECC	-116.3203	34.9027	Southern California	Supply Shortage	197.00	128050	3
2005	Southern California Edison		WECC	-116.3203	34.9027	Southern California	Supply Shortage	206.00	133900	4
2005	Southern California Edison		WECC	-116.3203	34.9027	Southern California	Supply Shortage	864.00	409000	4
2006	Southern California Edison		WECC	-116.3203	34.9027	Newhall, San Frenando, Saugus, and Santa Clarita, California	Supply Shortage	308.00	130000	6
2009	Southern California Edison		WECC	-116.3203	34.9027	Communities of Elsinore, Hemet, Moreno Valley, Perris, San Jacinto and Temecula in the southeastern area of Riverside County in California	Supply Shortage	512.00	280000	2
2008	Southern California Edison		WECC	-116.3203	34.9027	Goleta and Santa Barbara Areas of Southern California	Supply Shortage	250.00	140000	1
2008	Southern California Edison		WECC	-116.3203	34.9027	Goleta and Santa Barbara Areas of Southern California	Fire	119.00	37784	6
2004	Southern Company		SERC	-84.0169	32.9565	Florida, Mississippi, Alabama, Georgia	Hurricane or Tropical Storm	3000.00	99000	95
2004	Southern Company		SERC	-84.0169	32.9565	Florida, Mississippi, Alabama, Georgia	Hurricane or Tropical Storm	916.00	916316	48
2004	Southern Company		SERC	-84.0169	32.9565	Georgia	Hurricane or Tropical Storm	854.00	85455	6
2005	Southern Company		SERC	-84.0169	32.9565	Alabama, Mississippi, Florida, Georgia	Hurricane or Tropical Storm	45.00	228102	48
2005	Southern Company		SERC	-84.0169	32.9565	Alabama, Florida, Mississippi	Hurricane or Tropical Storm	5120.00	512049	15
2003	Southern Company		SERC	-84.0169	32.9565	Alabama	Lightning	130.00	12897	12
2003	Southern Company		SERC	-84.0169	32.9565	Central Georgia	Lightning	130.00	102842	12
2004	Southern Company		SERC	-84.0169	32.9565	Georgia and Alabama	Lightning	50.00	50595	1
2004	Southern Company		SERC	-84.0169	32.9565	Georgia	Lightning	100.00	83450	6
2005	Southern Company		SERC	-84.0169	32.9565	Alabama and Georgia	Lightning	100.00	51808	2
2009	Southern Company		SERC	-84.0169	32.9565	Georgia	Lightning	290.00	102000	20
2008	Southern Company		SERC	-84.0169	32.9565	Georgia	Lightning	100.00	80539	32
2008	Southern Company		SERC	-84.0169	32.9565	Georgia and Alabama	Lightning	400.00	131115	9
2008	Southern Company		SERC	-84.0169	32.9565	Southern Service Area/Alabama and Georgi	Lightning	484.00	145380	10
2004	Southern Company		SERC	-84.0169	32.9565	North and Central area of Georgia	Snow/Ice Storm	150.00	30689	30
2005	Southern Company		SERC	-84.0169	32.9565	Parts of Alabama and Georgia	Snow/Ice Storm	100.00	150000	48
2005	Southern Company		SERC	-84.0169	32.9565	Northeast Georgia	Snow/Ice Storm	75.00	52659	31
2006	Southern Company		SERC	-84.0169	32.9565	North and Central Alabama and Northern Georgia area	Tornado	300.00	115589	7
2000	Southern Company		SERC	-84.0169	32.9565	Alabama	Wind/Rain	0.00	75000	20
2004	Southern Company		SERC	-84.0169	32.9565	Georgia	Wind/Rain	10.00	47165	2
2004	Southern Company		SERC	-84.0169	32.9565	Georgia, Alabama, Florida panhandle, Southern Mississippi	Wind/Rain	61.00	61004	1
2006	Southern Company		SERC	-84.0169	32.9565	Georgia	Wind/Rain	363.00	109000	2
2007	Southern Company		SERC	-84.0169	32.9565	Parts of Alabama, Mississippi, Georgia, Florid	Wind/Rain	95.00	25445	26
2009	Southern Company		SERC	-84.0169	32.9565	Southern Balancing Area	Wind/Rain	75.00	60000	7
2008	Southern Company		SERC	-84.0169	32.9565	Parts of Alabama and Georgia	Wind/Rain	200.00	157744	24
2008	Southern Company		SERC	-84.0169	32.9565	Georgia and Alabama	Hurricane or Tropical Storm	110.00	87390	10
2006	Tacoma Power		WECC	-122.4435	47.2528	Greater Tacoma area (City of Fircrest, University Place, City of Lakeland) and portions of South Pierce County in State of Washington	Wind/Rain	280.00	75000	47
2004	Tallahassee Electric	No service area map	FRCC	-84.2807	30.4383	Leon County, Florida	Equipment Failure	283.00	42124	4
2004	Tallahassee Electric	No service area map	FRCC	-84.2807	30.4383	Florida counties of Gadsden, Wakulla, Leon, and Liberty	Supply Shortage	0.00	16667	60

Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2004	Tampa Electric	No service area map	FRCC	-82.4585	27.9475	Eastern Hillsborough, Polk County, Florida	Hurricane or Tropical Storm	250.00	78000	4
2004	Tampa Electric	No service area map	FRCC	-82.4585	27.9475	Hillsborough, Pasco, and Polk County, Florida	Hurricane or Tropical Storm	1,100	268000	201
2004	Tampa Electric	No service area map	FRCC	-82.4585	27.9475	Hillsborough, Pasco, and Polk County, Florida	Hurricane or Tropical Storm	1250.00	285300	22
2008	Tampa Electric	No service area map	FRCC	-82.4585	27.9475	Tampa Electric Service Territory	Supply Shortage	318.00	53965	2
2005	Tennessee Valley Authority		SERC	-86.7430	36.8587	Alabama, Mississippi, Tennessee	Hurricane or Tropical Storm	118.50	323529	284
2009	Tennessee Valley Authority		SERC	-86.7430	36.8587	TVA Service Territory	Snow/Ice Storm	850.00	1	1
2009	Tennessee Valley Authority		SERC	-86.7430	36.8587	Chattanooga, Tennessee	Wind/Rain	860.00	136000	2
2008	Texas - New Mexico Power Company	No service area map of NM	TRE	-95.1817	29.3749	Galveston and Brazoria Counties	Hurricane or Tropical Storm	650.00	113247	359
2006	Texas Regional Entity	No service area map	TRE	-99.7031	31.3362	ERCOT Region of Texas	Supply Shortage	1000.00	200000	4
2006	Texas Regional Entity	No service area map	TRE	-99.7031	31.3362	Grimes, Robertson, Fort Bend, Brazos, Burleson and Walker Counties	Supply Shortage	339.00	100308	5
2004	Texas Regional Entity	No service area map	TRE	-99.7031	31.3362	North Texas	Wind/Rain	300.00	63000	298
2009	The Empire District Electric Company		SERC	-94.4736	36.7912	SW Missouri	Lightning	266.00	83000	2
2000	Tucson Electric Power		WECC	-110.8465	32.1594	Arizona	Equipment Failure	138.00	40911	1
2005	TXU Energy	Region is TRE	TRE	-98.3205	31.0572	Nacogdoches, Lufkin, Tyler, Jacksonville, Rusk, Paris, Commerce, Huntington	Hurricane or Tropical Storm	260.00	200000	203
2001	TXU Energy	Region is TRE	TRE	-98.3205	31.0572	Rio Grand Valley of Texas	Supply Shortage	350.00	24506	5
2006	TXU Energy	Region is TRE	TRE	-98.3205	31.0572	North and East Texas	Supply Shortage	380.00	489478	3
2004	TXU Energy	Region is TRE	TRE	-98.3205	31.0572	Collin, Dallas, Denton, Ellis, Parker, and Tarrant Counties, Texas	Wind/Rain	1900.00	500000	8
2003	Upper Peninsula Power Company		MRO	-87.4223	46.4329	Northeast Wisconsin and Central/Western Upper Peninsula of Michigan	Equipment Failure	14.00	2	13
2004	Utilities Commission, City of New Smyrna Beach	No service area map	FRCC	-80.9216	29.0184	New Smyrna Beach, Florida	Hurricane or Tropical Storm	65.00	23000	18
2000	Vectren Energy	No service area map	RFC	-85.8197	39.7347	Indiana	Equipment Failure	15.00	124000	1
2009	Vectren Energy	No service area map	RFC	-85.8197	39.7347	Indiana, Evansville, Metro Area	Snow/Ice Storm	506.00	75000	204
2009	WAPA - Upper Great Plains Region		MRO	-95.5498	46.4224	Western South Dakota	Supply Shortage	373.00	18	3
2003	We Energies		RFC	-88.5698	44.2400	Upper Peninsula of Michigan and Northeastern Wisconsin	Equipment Failure	500.00	36000	82
2003	We Energies		RFC	-88.5698	44.2400	Southeast Wisconsin	Lightning	150.00	52000	4
2005	We Energies		RFC	-88.5698	44.2400	Southeast Wisconsin	Lightning	10.00	48000	50
2003	We Energies		RFC	-88.5698	44.2400	Upper Michigan Peninsula	Wind/Rain	240.00	2	768
2005	We Energies		RFC	-88.5698	44.2400	Southeast Wisconsin and Fox Valley	Wind/Rain	600.00	110000	74
2005	Westar Energy		SPP	-96.1817	38.4039	Eastern one third of the state of Kansas	Snow/Ice Storm	200.00	211000	234
2007	Westar Energy		SPP	-96.1817	38.4039	Eastern half of the State of Kansas	Snow/Ice Storm	500.00	95000	228
2005	Xcel - Northern States Power Company - MN	Merged with Xcel	MRO	-96.5849	45.0008	Minnesota	Lightning	75.00	300000	66
2007	Xcel - Northern States Power Company - MN	Merged with Xcel	MRO	-96.5849	45.0008	Minnesota, Wisconsin, North Dakota, South Dakota and Michigan	Supply Shortage	16.00	6000	1
2009	Xcel - Public Service Company of Colorado		WECC	-105.8557	39.0032	Metro Denver (Jefferson, Adams, and Arapahoe Counties)	Lightning	150.00	86058	45
2006	Xcel - Public Service Company of Colorado		WECC	-105.8557	39.0032	Colorado	Supply Shortage	428.00	323000	7



Year	Utility Company (Updated)	Other Info	NERC Region	Long-EST	Lat-EST	Area Affected	Type of Disturbance (categorized)	MW_Loss	No_Affected	Total_HRs
2008	Xcel - Southwestern Public Service Company - NM & TX		SPP	-103.1724	34.2414	Texas Panhandle and Eastern New Mexico	Supply Shortage	0.00	0	9
2008	Xcel - Southwestern Public Service Company - NM & TX		SPP	-103.1724	34.2414	Southwestern Public Service Company Operating in the Panhandle o Texas and New Mexico	Lightning	560.00	18000	5

APPENDIX D. ArcGIS Procedural Log

METADATA:

Description:

Status of the data: Complete (Update Frequency: None Planned)
Time Period for which the data is relevant: 3/25/2010 at time 1900
Data storage and access information:
File Name: FINAL_Vulnerability Map (2009_03Mar_10).mxd
Data Processing Environment: Microsoft Windows Vista Version 6.0, ESRI ArcCatalog 9.3.1.3000
Standards used to create this document:
Standard Name: FGDC Content Standards for Digital Geospatial Metadata
Standard Version: FGDC-STD-001-1998
Time Convention used in this document: Local Time

Spatial:

Horizontal Coordinate System:
Geographic Coordinate System Name: World Geodetic System 1984
Horizontal Datum Name: North American Datum of 1983
Bounding Coordinates:
West: -125.378747664 digital degrees
East: -66.184089108 digital degrees
North: 59.957198096 digital degrees
South: 19.149255297 digital degrees
Sources: Electric Disturbance Events – Monthly and Annual Summaries (EIA)

Attributes:

Overview Description:

A unique characteristic of electric power is that it cannot be stored for future use. Electric energy suppliers, therefore, must build and maintain generating and transmission facilities capable of meeting the demand levels for electric power at all times. Tracking disturbances that impact the integrated generating and transmission facilities is an important Federal task along with examining issues associated with insufficient capacity reserves.

Software requirement:

Microsoft Excel, ArcGIS 9.3 (Extensions: Data Management & Spatial Analyst Tools)

1) **Download Census Data to working folder**
    - a) Access http://nationalatlas.gov/atlasftp.html
    - b) Download County Boundaries
        - i) Boundaries ➔ County Boundaries, 2001 ➔ Download countyp020.tar.gz ➔ Save File
        - ii) Extract data using a Zipping software within the main directory
    - c) Download Water Bodies
        - i) Water ➔ Streams and Waterbodies ➔ Download hydrogm020.tar.gz ➔ Save File
        - ii) Extract data using a Zipping software within the main directory
    - d) Download State Boundaries
        - i) Boundaries ➔ State Boundaries ➔ Download statesp020.tar.gz ➔ Save File
        - ii) Extract data using a Zipping software within the main directory
    - e) Access http://www2.census.gov/geo/tiger/TIGER2009/
    - f) Download Federal Lands
        - i) Download tl_2009_us_mil ➔ Save File
        - ii) Extract data using a Zipping software within the main directory

2) **Define downloaded layer coordinate systems**
    - a) Open ArcCatalog
    - b) Locate the downloaded layers ➔ select the files
        - i) In the right window, right click ‘statesp020’ ➔ Properties
            - (1) Select ➔ Geographic Coordinate Systems ➔ North America ➔ ‘North American Datum 1983.prj’
            - (2) Click ‘Add’
        - ii) In the right window, right click ‘countyp020’ ➔ Properties
            - (1) Select ➔ Geographic Coordinate Systems ➔ North America ➔ ‘North American Datum 1983.prj’
            - (2) Click ‘Add’
        - iii) In the right window, right click ‘hydrogm020’ ➔ Properties
            - (1) Select ➔ Geographic Coordinate Systems ➔ North America ➔ ‘North American Datum 1983.prj’
            - (2) Click ‘Add’
        - iv) In the right window, right click ‘tl_2009_us_mil’ ➔ Properties
            - (1) Select ➔ Geographic Coordinate Systems ➔ North America ➔ ‘North American Datum 1983.prj’
            - (2) Click ‘Add’

3) Create personal geodatabase (GDB) file in ArcGIS

- a) ArcToolbox ➔ Data Management Tools ➔ Workspace ➔ Create Personal GDB
- b) Create the file within the same direction (but a sub-folder) to the ArcGIS Map file
- c) Name the file to something relevant such at ‘PowerOutageAnalysis’

4) Add Downloaded data layers and add to GDB

- **a) County Data**
  - i) Add data ➔ County Data (shape file)
  - ii) Filter Data such that only counties for the continental United States are shown
    - (1) Right Click Layer ➔ Properties ➔ Definition Query ➔ Query Builder
    - (2) Paste into field ➔ NOT("STATE" = 'AK') AND NOT("STATE" = 'HI') AND NOT("STATE" = 'PR') AND NOT("STATE" = 'VI')
  - iii) Project Data from GCS_North_American_1983 to GSC_WGS_1984
    - (1) ArcToolbox ➔ Data Management Tools ➔ Projections and Transformations ➔ Feature ➔ Project
      - (a) Input Dataset of Feature Class = County layer added
      - (b) Output Dataset or Feature Class = County_Layer (save within GDB created earlier)
      - (c) Output Coordinate System = GCS_WGS_1984
      - (d) Geographic Transformation ➔ NAD_1983_To_WGS_1984_1
      - (e) Click OK
    - (2) Rename new layer to something that describes it (i.e. County Boundaries, 2001)
    - (3) Remove original countyp020 file from layers
- **b) State Data**
  - i) Add data ➔ State Data (shape file)
  - ii) Filter Data such that only counties for the continental United States are shown
    - (1) Right Click Layer ➔ Properties ➔ Definition Query ➔ Query Builder
    - (2) Paste into field ➔ NOT ("STATE" = 'Alaska') AND NOT ("STATE" = 'Hawaii') AND NOT ("STATE" = 'Puerto Rico') AND NOT ("STATE" = 'U.S. Virgin Islands')
  - iii) Project Data from GCS_North_American_1983 to GSC_WGS_1984
    - (1) ArcToolbox ➔ Data Management Tools ➔ Projections and Transformations ➔ Feature ➔ Project
      - (a) Input Dataset of Feature Class = State layer added
      - (b) Output Dataset or Feature Class = State_Layer (save within GDB created earlier)
      - (c) Output Coordinate System = GCS_WGS_1984
      - (d) Geographic Transformation ➔ NAD_1983_To_WGS_1984_1
      - (e) Click OK
    - (2) Rename new layer to something that describes it (i.e. State Boundaries, 2005)
    - (3) Remove original statep020 file from layers

c) **Steams and Waterbodies Data**

i) Add data ➔ Steams and Waterbodies Data (shape file)

ii) Filter Data such that only the Great Lakes are shown

(1) Right Click Layer ➔ Properties ➔ Definition Query ➔ Query Builder

(2) Paste into field ➔ "NAME" = 'Lake Huron' OR "NAME" = 'Lake Michigan' OR "NAME" = 'Lake Ontario' OR "NAME" = 'Lake Superior' OR "NAME" = 'Lake Erie'

iii) Project Data from GCS_North_American_1983 to GSC_WGS_1984

(1) ArcToolbox ➔ Data Management Tools ➔ Projections and Transformations ➔ Feature ➔ Project

(a) Input Dataset of Feature Class = Water layer added

(b) Output Dataset or Feature Class = Water_Layer (save within GDB created earlier)

(c) Output Coordinate System = GCS_WGS_1984

(d) Geographic Transformation ➔ NAD_1983_To_WGS_1984_1

(e) Click OK

(2) Rename new layer to something that describes it (i.e. Great Lakes, 2006)

(3) Remove original hydrogm020 from layers

d) **Federal Land Data**

i) Add data ➔ Federal Land Data (shape file)

ii) Filter Data such that only counties for the continental United States are shown

(1) Right Click Layer ➔ Properties ➔ Definition Query ➔ Query Builder

(2) Paste into field ➔ "FULLNAME" = 'Altus AFB' OR "FULLNAME" = 'Andrews AFB' OR "FULLNAME" = 'Arnold AFB' OR "FULLNAME" = 'Barksdale AFB' OR "FULLNAME" = 'Beale AFB' OR "FULLNAME" = 'Bolling AFB' OR "FULLNAME" = 'Buckley AFB' OR "FULLNAME" = 'Cannon AFB' OR "FULLNAME" = 'Charleston AFB' OR "FULLNAME" = 'Columbus AFB' OR "FULLNAME" = 'Creech AFB' OR "FULLNAME" = 'Davis- Monthan AFB' OR "FULLNAME" = 'Dover AFB' OR "FULLNAME" = 'Dyess AFB' OR "FULLNAME" = 'Edwards AFB' OR "FULLNAME" = 'Eglin AFB' OR "FULLNAME" = 'Ellsworth AFB' OR "FULLNAME" = 'F E Warren AFB' OR "FULLNAME" = 'Fairchild AFB' OR "FULLNAME" = 'Goodfellow AFB' OR "FULLNAME" = 'Grand Forks AFB' OR "FULLNAME" = 'Hanscom AFB' OR "FULLNAME" = 'Hill AFB' OR "FULLNAME" = 'Holloman AFB' OR "FULLNAME" = 'Hurlburt Fld' OR "FULLNAME" = 'Keesler AFB' OR "FULLNAME" = 'Kirtland AFB' OR "FULLNAME" = 'Lackland AFB' OR "FULLNAME" = 'Langley AFB' OR "FULLNAME" = 'Laughlin AFB' OR "FULLNAME" = 'Little Rock AFB' OR "FULLNAME" = 'Los Angeles Air Force Base (Area A)' OR "FULLNAME" = 'Luke AFB' OR "FULLNAME" = 'Macdill AFB' OR "FULLNAME" = 'Malmstrom AFB' OR "FULLNAME" = 'Maxwell AFB' OR "FULLNAME" = 'Maxwell Air Force Base (Gunter Annex)' OR "FULLNAME" = 'McChord AFB' OR "FULLNAME" = 'McConnell AFB' OR "FULLNAME" = 'McGuire

AFB' OR "FULLNAME" = 'Minot AFB' OR "FULLNAME" = 'Moody AFB' OR "FULLNAME" = 'Mountain Home AFB' OR "FULLNAME" = 'Nellis AFB' OR "FULLNAME" = 'Offutt AFB' OR "FULLNAME" = 'Patrick AFB' OR "FULLNAME" = 'Peterson AFB' OR "FULLNAME" = 'Pope AFB' OR "FULLNAME" = 'Randolph AFB' OR "FULLNAME" = 'Robins AFB' OR "FULLNAME" = 'Scott AFB' OR "FULLNAME" = 'Seymour Johnson AFB' OR "FULLNAME" = 'Shaw AFB' OR "FULLNAME" = 'Sheppard AFB' OR "FULLNAME" = 'Tinker AFB' OR "FULLNAME" = 'Travis AFB' OR "FULLNAME" = 'Tyndall AFB' OR "FULLNAME" = 'Vance AFB' OR "FULLNAME" = 'Vandenberg AFB' OR "FULLNAME" = 'Whiteman AFB' OR "FULLNAME" = 'Wright-Patterson AFB'

iii) Create Centroid of Base Areas
  (1) Right Click on Layer ➔ Open Attribute Table
  (2) Options ➔ Add Field (Latitude)
    (a) Latitude
      (i) Name = Centrd_Lat
      (ii) Type = Double
    (b) Longitude
      (i) Name = Centrd_Lon
      (ii) Type = Double
  (3) Field Calculations
    (a) Right Click "Centroid_Lat" ➔ Field Calculator… ➔ Click YES
    (b) Check the box for Advanced ➔ Paste:

```
Dim Output As Double
Dim pArea As IArea
Set pArea = [Shape]
Output = pArea.Centroid.Y
```

    (c) In the box on the bottom, type OUTPUT
    (d) Click OK
    (e) Right Click "Centroid_Lon" ➔ Field Calculator… ➔ Click YES
    (f) Check the box for Advanced ➔ Paste:

```
Dim Output As Double
Dim pArea As IArea
Set pArea = [Shape]
Output = pArea.Centroid.X
```

    (g) In the box on the bottom, type OUTPUT
    (h) Click OK

iv) Project Data from GCS_North_American_1983 to GSC_WGS_1984
  (1) Arc Toolbox ➔ Data Management Tools ➔ Projections and Transformations ➔ Feature ➔ Project
    (a) Input Dataset of Feature Class = Federal Land layer added
    (b) Output Dataset or Feature Class = AF_Installations_Layer (save within GDB created earlier)
    (c) Output Coordinate System = GCS_WGS_1984

- (d) Geographic Transformation ➔ NAD_1983_To_WGS_1984_1
- (e) Click OK

- (2) Rename new layer to something that describes it (i.e. AF Installations, 2009)
- (3) Remove original tl_2009_us_mil from layers

- v) Create XY Data for Installation Centroids
  - (1) Right Click Projected layer from [iv) (2)]’ ➔ Open Attribute Table
    - (a) Options ➔ Export… (save within GDB file)
    - (b) Click YES to add it to the current file
  - (2) Source Tab ➔ Right Click New Table (from above) ➔ Display XY Data…
    - (a) X Field = Centrd_Lon
    - (b) Y Field = Centrd_Lat
    - (c) Click Edit… ➔ Select… ➔ Geographic Coordinate Systems ➔ World ➔ WGS 1984.prj (click ADD)
    - (d) Click OK ➔ Click OK
  - (3) Rename new layer to something that describes it (i.e. AF Installations Points, 2009)

5) Enable ArcToolbox & setup Environments

- a) Right click on the ArcToolbox Area ➔ Environments…
- b) General Settings
  - i) Current Workspace ➔ “PowerOutageAnalysis”
  - ii) Scratch Workspace ➔ “PowerOutageAnalysis”
  - iii) Output Coordinate System ➔ As Specified Below ➔ GCS_WGS_1984
  - iv) Output has Z Values ➔ same as input
  - v) Output has M Values ➔ same as input
  - vi) Extent ➔ Same as layer “State Boundaries, 2005”
- c) Raster Analysis Settings
  - i) Cell Size ➔ As specified below ➔ 0.04
  - ii) Mask ➔ “State Boundaries, 2005”
- d) Click OK

6) Data Collected from EIA necessary to perform the Analysis (for the purpose of this thesis, all data has been collected and scrubbed within the Excel file ‘GIS Data – Power Outages.xls’

- a) Add Data ➔ Find ‘GIS Data – Power Outages.xls’ ➔ Select tab/file 'Outage Data-GIS Rdy$' ➔ Click Add
- b) Source Tab ➔ Right Click 'Outage Data-GIS Rdy$' ➔ Display XY Data…
  - i) X Field = Long-EST
  - ii) Y Field = Lat-EST
  - iii) Click Edit… ➔ Select… ➔ Geographic Coordinate Systems ➔ World ➔ WGS 1984.prj (click ADD)

        iv) Display Tab ➔ Right click the outputted layer from above ➔ Data… ➔ Export Data…
        v) Save within GDB file (created earlier) ➔ Change name to ‘PowerOutage_Output’
        vi) Click YES to add it to the map as a new layer file
        vii) Right click the old file ➔ Remove
    c) Right click (new layer) ➔ Rename: EIA Complete Power Outages_2009

7) Add in Consolidated data (similar to above)
    a) Add Data ➔ Find ‘GIS Data – Power Outages.xls’ ➔ Select tab/file ‘Summary_ByElecComp$' ➔ Click Add
    b) Source Tab ➔ Right Click Summary_ByElecComp $' ➔ Display XY Data…
        i) X Field = Long-EST
        ii) Y Field = Lat-EST
        iii) Click Edit… ➔ Select… ➔ Geographic Coordinate Systems ➔ World ➔ WGS 1984.prj (click ADD)
        iv) Display Tab ➔ Right click the outputted layer from above ➔ Data… ➔ Export Data…
        v) Save within GDB file (created earlier) ➔ Change name to ‘PowerOutageCons_Output’
        vi) Click YES to add it to the map as a new layer file
        vii) Right click the old file ➔ Remove
    c) Right click (new layer) ➔ Rename: EIA Consolidated Power Outages_2009

8) FORMATTING:
    a) Display Tab ➔ Highlight the following layers (downloaded/modified layers):
        i) AF Installation Pts, 2009
        ii) AF Installations, 2009
        iii) Great Lakes, 2006
        iv) County Boundaries, 2006
        v) State Boundaries, 2005
        vi) Right click ➔ Group (change the name to ‘Existing Layers’)
    b) Display Tab ➔ Highlight the following layers (downloaded/modified layers):
        i) EIA Complete Power Outages_2009
        ii) EIA Consolidated Power Outages_2009
        iii) Right click ➔ Group (change the name to ‘EIA Power Outages’)

9) Analysis (Individual Outages) – Include all changes done to the maps as well
    a) Inverse Distance Weighted (MW Loss)
        i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
            (1) Input point features = EIA Complete Power Outages_2009
            (2) Z value field = MW_Loss

        - (3) Output Raster = IDW_Ind_MW_Loss (save within GDB created earlier)
        - (4) Output cell size (optional) = 0.04
        - (5) Power = 2
        - (6) Search Radius (option) = Variable
            - (a) Number of points = 12
            - (b) Maximum Distance = (BLANK)
        - (7) Input barrier polyline features (optional) = (BLANK)
    - ii) Right click the added layer ➔ Properties…
        - (1) Display (TAB) ➔ Transparency = 45%
        - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
            - (a) Classification ➔ Classes = 5
            - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
            - (c) Color Ramp ➔ GREEN to RED (left to right)
    - iii) Click OK
- b) Inverse Distance Weighted (Number of people affected)
    - i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
        - (1) Input point features = EIA Complete Power Outages_2009
        - (2) Z value field = No_Affecte
        - (3) Output Raster = IDW_Ind_No_Affected (save within GDB created earlier)
        - (4) Output cell size (optional) = 0.04
        - (5) Power = 2
        - (6) Search Radius (option) = Variable
            - (a) Number of points = 12
            - (b) Maximum Distance = (BLANK)
        - (7) Input barrier polyline features (optional) = (BLANK)
    - ii) Right click the added layer ➔ Properties…
        - (1) Display (TAB) ➔ Transparency = 45%
        - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
            - (a) Classification ➔ Classes = 5
            - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
            - (c) Color Ramp ➔ GREEN to RED (left to right)
    - iii) Click OK
- c) Inverse Distance Weighted (Outage Total Duration)
    - i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
        - (1) Input point features = EIA Complete Power Outages_2009
        - (2) Z value field = Total_HRs
        - (3) Output Raster = IDW_Ind_Hours_Off (save within GDB created earlier)
        - (4) Output cell size (optional) = 0.04
        - (5) Power = 2
        - (6) Search Radius (option) = Variable
            - (a) Number of points = 12

            - (b) Maximum Distance = (BLANK)
        - (7) Input barrier polyline features (optional) = (BLANK)
    - ii) Right click the added layer ➔ Properties…
        - (1) Display (TAB) ➔ Transparency = 45%
        - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
            - (a) Classification ➔ Classes = 5
            - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
            - (c) Color Ramp ➔ GREEN to RED (left to right)
    - iii) Click OK
- d) Raster Calculator (Individual Outage Calculated Vulnerability)
    - i) Ensure the Spatial Analyst Toolbar is enabled. If not:
        - (1) View ➔ Toolbars ➔ Spatial Analyst
        - (2) Dock the toolbar
    - ii) Spatial Analyst ➔ Raster Calculator
        - (1) Copy the following expression to the open space ➔ (([IDW_Cons_Hours_Off] / 52.59) * 0.4) + (([IDW_Cons_MW_Loss] / 598.78) * 0.5) + (([IDW_Cons_No_Affected] / 195553.13) * 0.1)
        - (2) Click Evaluate (it might take up to an hour to complete the analysis, depending on computer speeds)
    - iii) Right click the added layer ➔ Properties…
        - (1) General (TAB) ➔ Layer Name = 'IDW_Ind_Calculated_Vulnerability'
        - (2) Display (TAB) ➔ Transparency = 45%
        - (3) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
            - (a) Classification ➔ Classes = 5
            - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
            - (c) Color Ramp ➔ GREEN to RED (left to right)
    - iv) Click OK

10) Analysis (Consolidated Outages)

- a) Inverse Distance Weighted (MW Loss)
    - i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
        - (1) Input point features = EIA Complete Power Outages_2009
        - (2) Z value field = MW_Loss
        - (3) Output Raster = IDW_Cons_MW_Loss (save within GDB created earlier)
        - (4) Output cell size (optional) = 0.04
        - (5) Power = 2
        - (6) Search Radius (option) = Variable
            - (a) Number of points = 12
            - (b) Maximum Distance = (BLANK)
        - (7) Input barrier polyline features (optional) = (BLANK)

- ii) Right click the added layer ➔ Properties…
  - (1) Display (TAB) ➔ Transparency = 45%
  - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
    - (a) Classification ➔ Classes = 5
    - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
    - (c) Color Ramp ➔ GREEN to RED (left to right)
- iii) Click OK

b) Inverse Distance Weighted (Number of people affected)

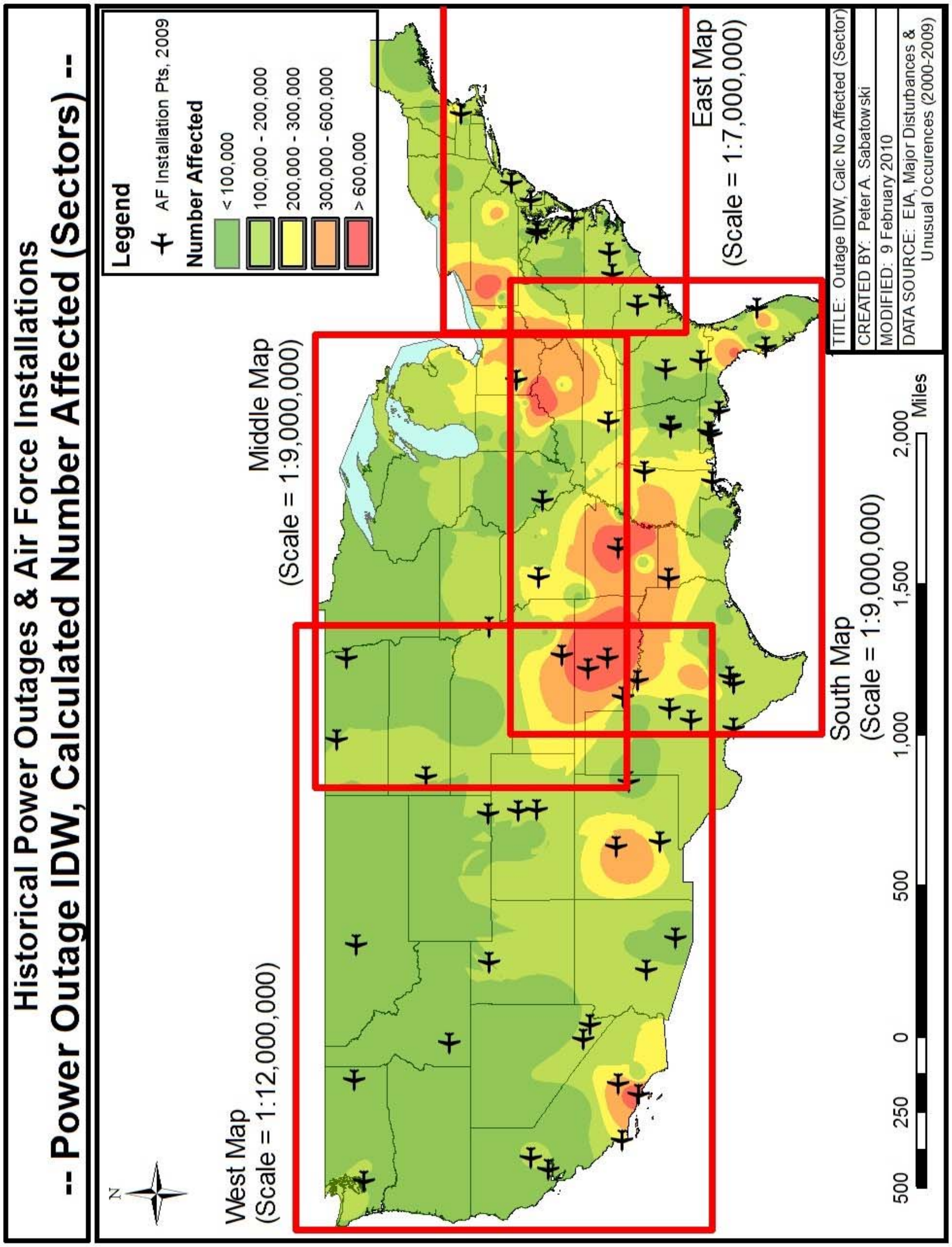
- i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
  - (1) Input point features = EIA Complete Power Outages_2009
  - (2) Z value field = No_Affected
  - (3) Output Raster = IDW_Cons _No_Affected (save within GDB created earlier)
  - (4) Output cell size (optional) = 0.04
  - (5) Power = 2
  - (6) Search Radius (option) = Variable
    - (a) Number of points = 12
    - (b) Maximum Distance = (BLANK)
  - (7) Input barrier polyline features (optional) = (BLANK)
- ii) Right click the added layer ➔ Properties…
  - (1) Display (TAB) ➔ Transparency = 45%
  - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
    - (a) Classification ➔ Classes = 5
    - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
    - (c) Color Ramp ➔ GREEN to RED (left to right)
- iii) Click OK

c) Inverse Distance Weighted (Outage Total Duration)

- i) ArcToolbox ➔Spatial Analyst Tools ➔ Interpolation ➔ IDW
  - (1) Input point features = EIA Complete Power Outages_2009
  - (2) Z value field = Total_HRs
  - (3) Output Raster = IDW_Cons_Hours_Off (save within GDB created earlier)
  - (4) Output cell size (optional) = 0.04
  - (5) Power = 2
  - (6) Search Radius (option) = Variable
    - (a) Number of points = 12
    - (b) Maximum Distance = (BLANK)
  - (7) Input barrier polyline features (optional) = (BLANK)
- ii) Right click the added layer ➔ Properties…
  - (1) Display (TAB) ➔ Transparency = 45%
  - (2) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
    - (a) Classification ➔ Classes = 5
    - (b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click

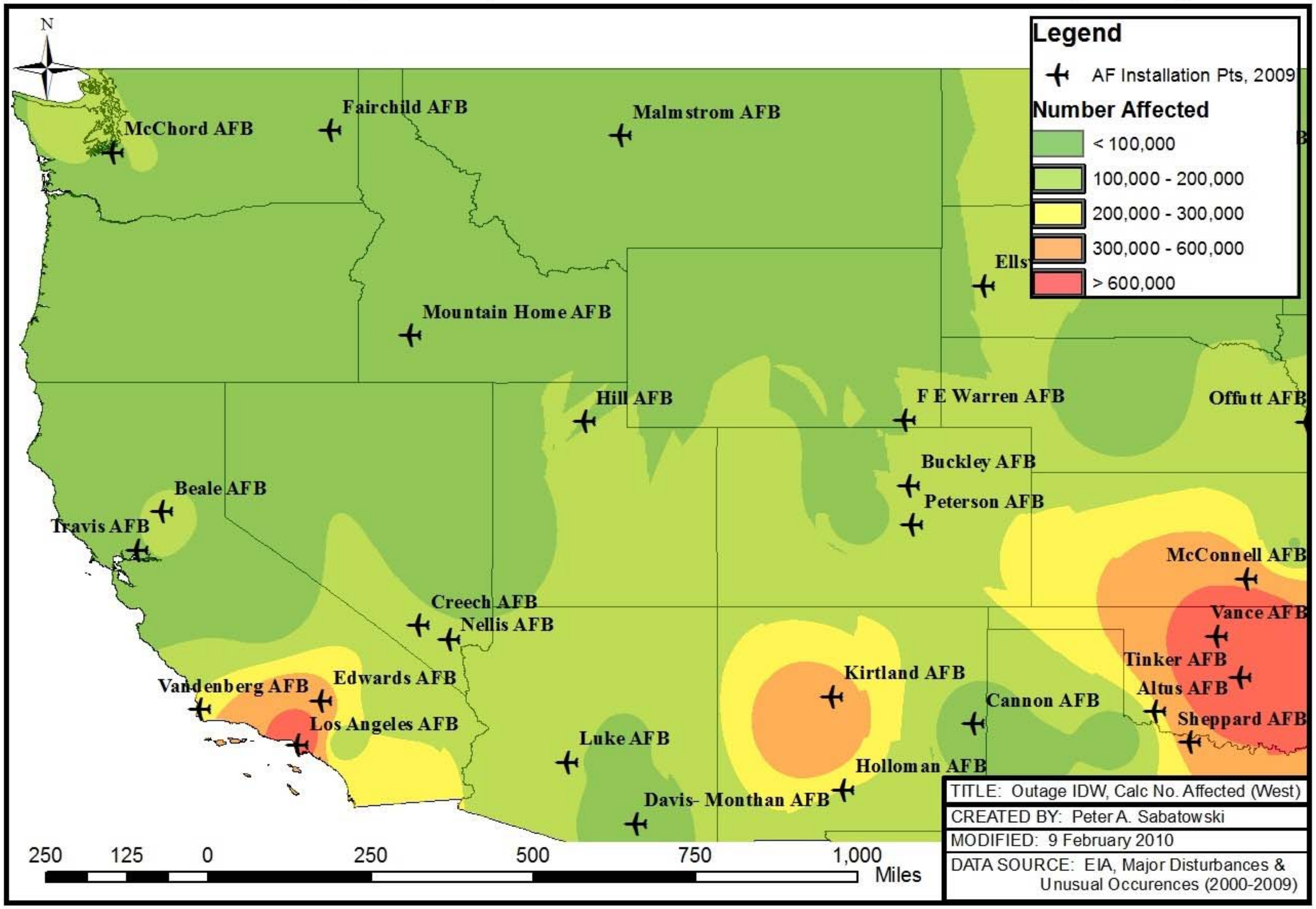
OK
(c) Color Ramp ➔ GREEN to RED (left to right)
iii) Click OK
d) Raster Calculator (Consolidated Outage Calculated Vulnerability)
i) Ensure the Spatial Analyst Toolbar is enabled. If not:
(1) View ➔ Toolbars ➔ Spatial Analyst
(2) Dock the toolbar
ii) Spatial Analyst ➔ Raster Calculator
(1) Copy the following expression to the open space ➔ (([IDW_Cons_Hours_Off] / 212.966) * 0.4) + (([IDW_Cons_MW_Loss] / 2375.012) * 0.5) + (([IDW_Cons_No_Affected] / 754639.069) * 0.1)
(2) Click Evaluate (it might take up to an hour to complete the analysis, depending on computer speeds)
iii) Right click the added layer ➔ Properties…
(1) General (TAB) ➔ Layer Name = 'IDW_Cons_Calculated_Vulnerability'
(2) Display (TAB) ➔ Transparency = 45%
(3) Symbology (TAB) ➔ Show (Left side) ➔ Click CLASSIFIED ➔ Click YES
(a) Classification ➔ Classes = 5
(b) Classification ➔ Classify ➔ Method = Natural Breaks (Jenks) ➔ Click OK
(c) Color Ramp ➔ GREEN to RED (left to right)
iv) Click OK

APPENDIX E. Calculated IDW (Number Affected)

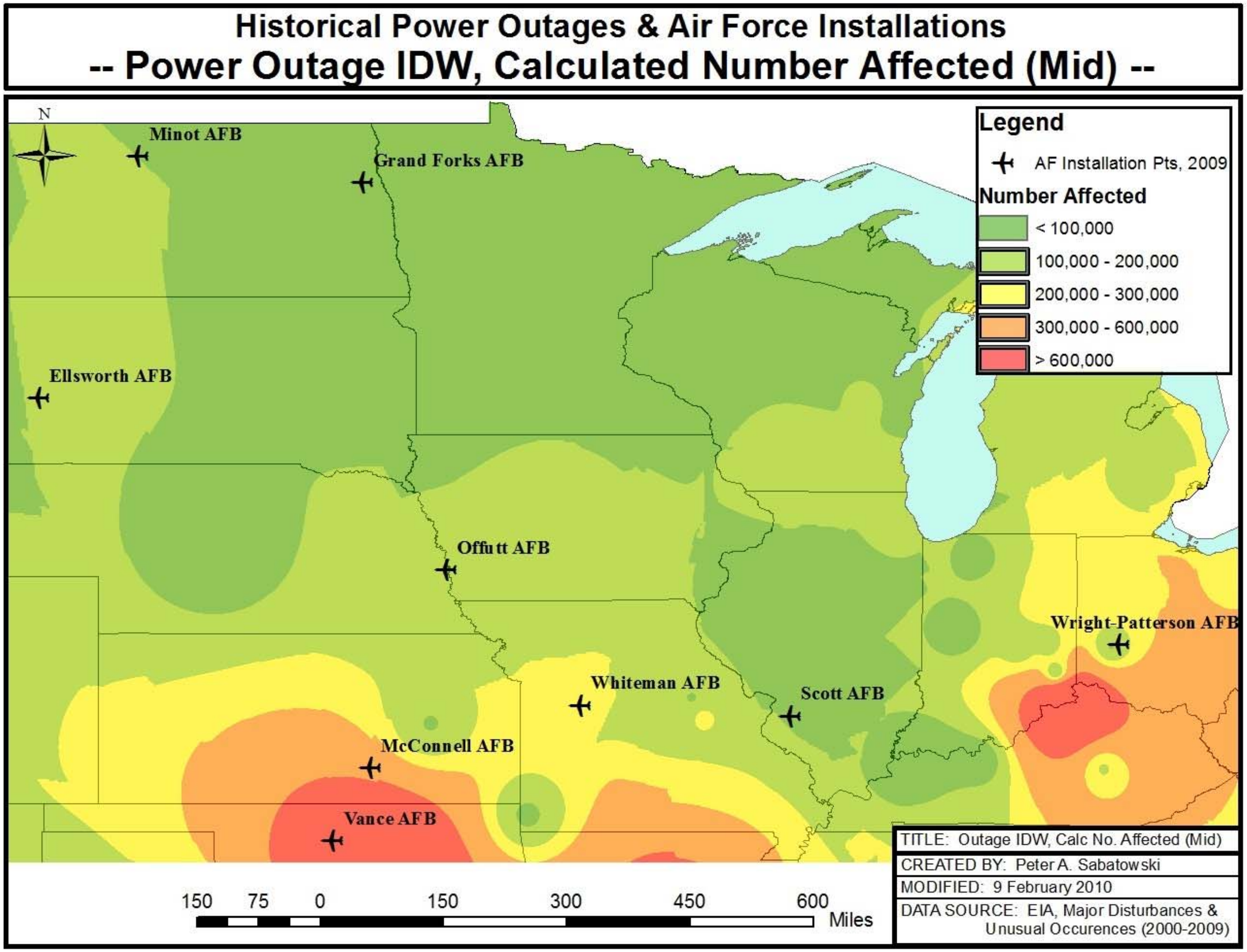


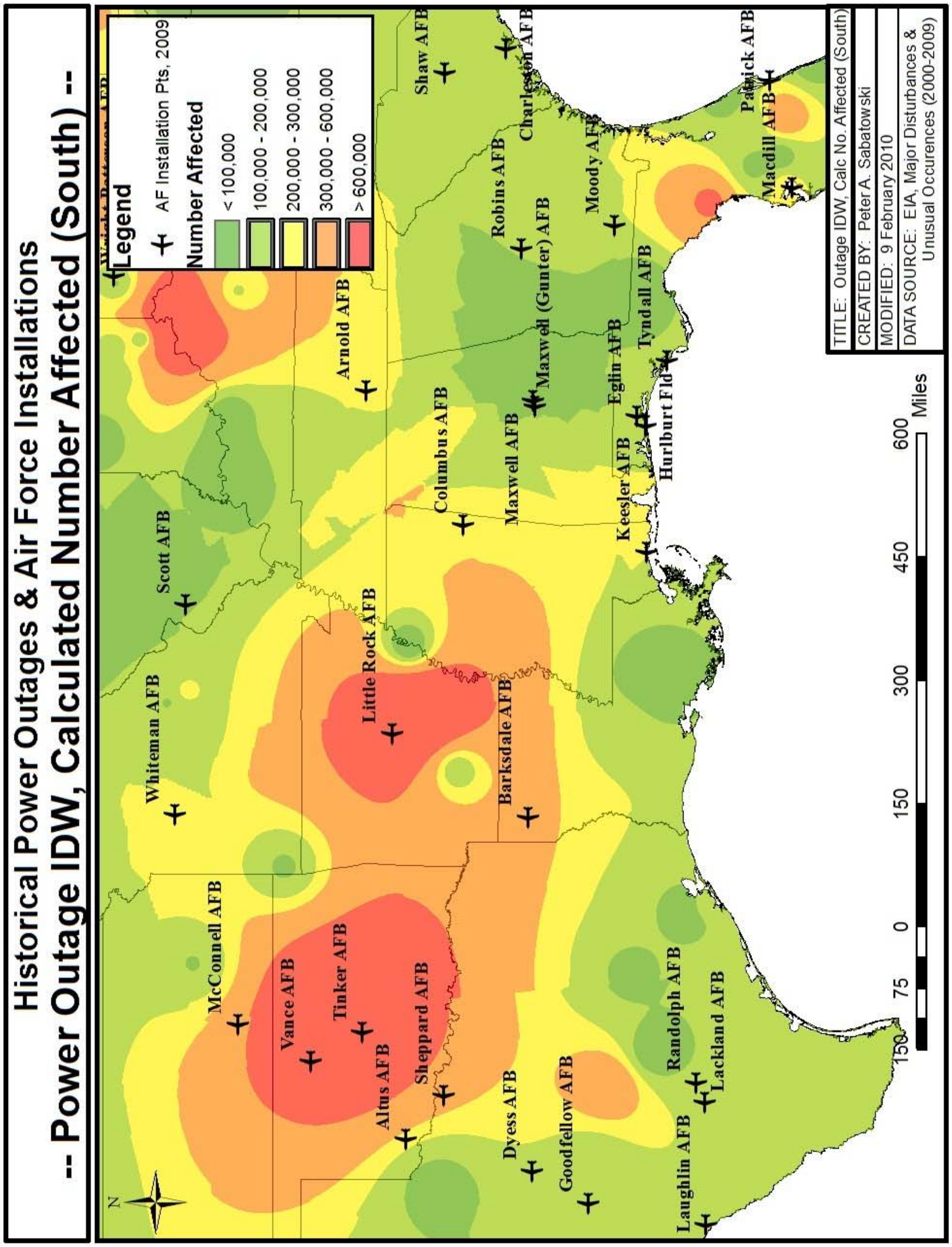
Historical Power Outages & Air Force Installations

-- Power Outage IDW, Calculated Number Affected (West) --



TITLE: Outage IDW, Calc No. Affected (West)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)

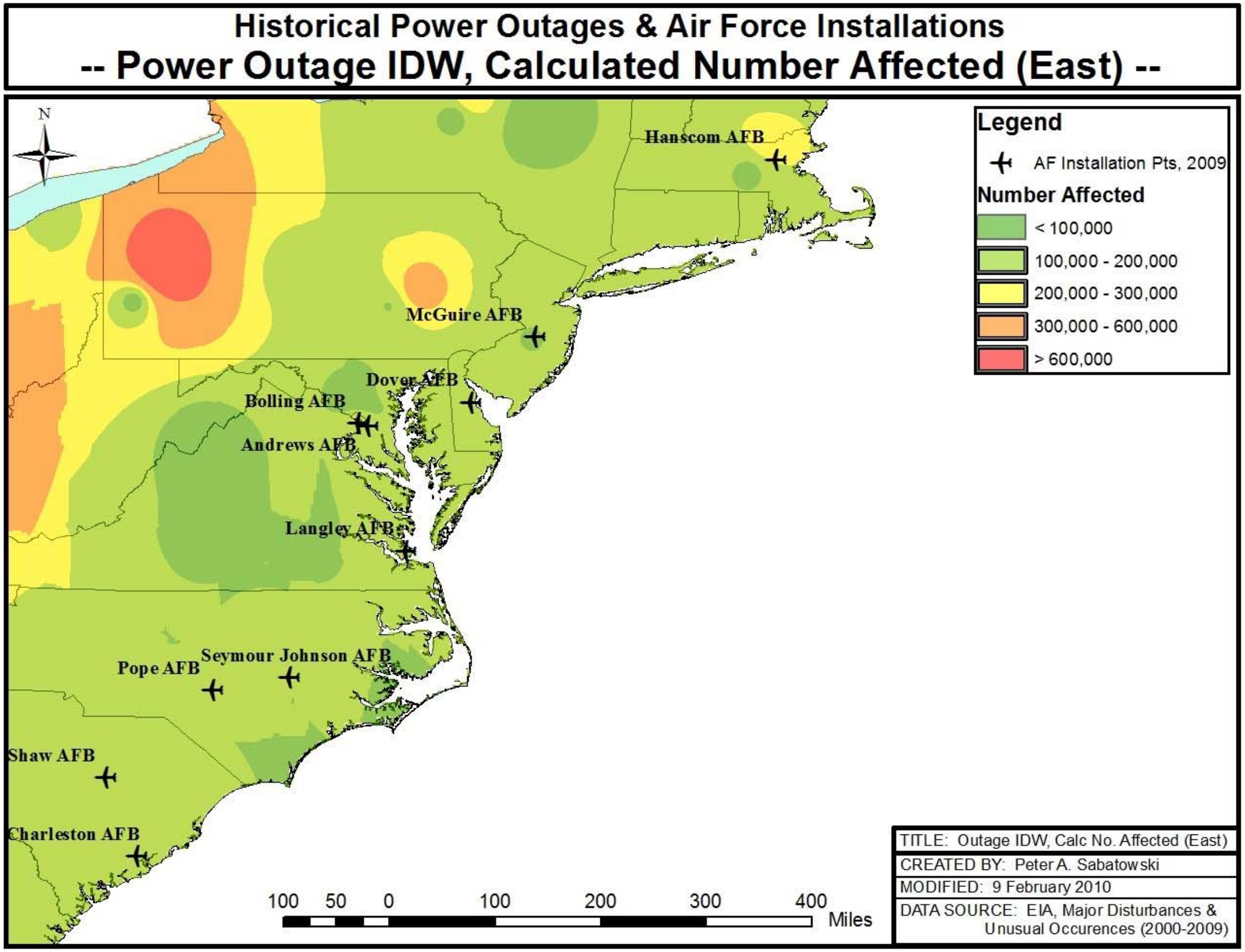

Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Number Affected (Mid) --
N
Minot AFB
Grand Forks AFB
Ellsworth AFB
Offutt AFB
Whiteman AFB
Scott AFB
McConnell AFB
Vance AFB
Wright-Patterson AFB
Legend
AF Installation Pts, 2009
Number Affected
< 100,000
100,000 - 200,000
200,000 - 300,000
300,000 - 600,000
> 600,000
150 75 0 150 300 450 600
Miles
TITLE: Outage IDW, Calc No. Affected (Mid)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)



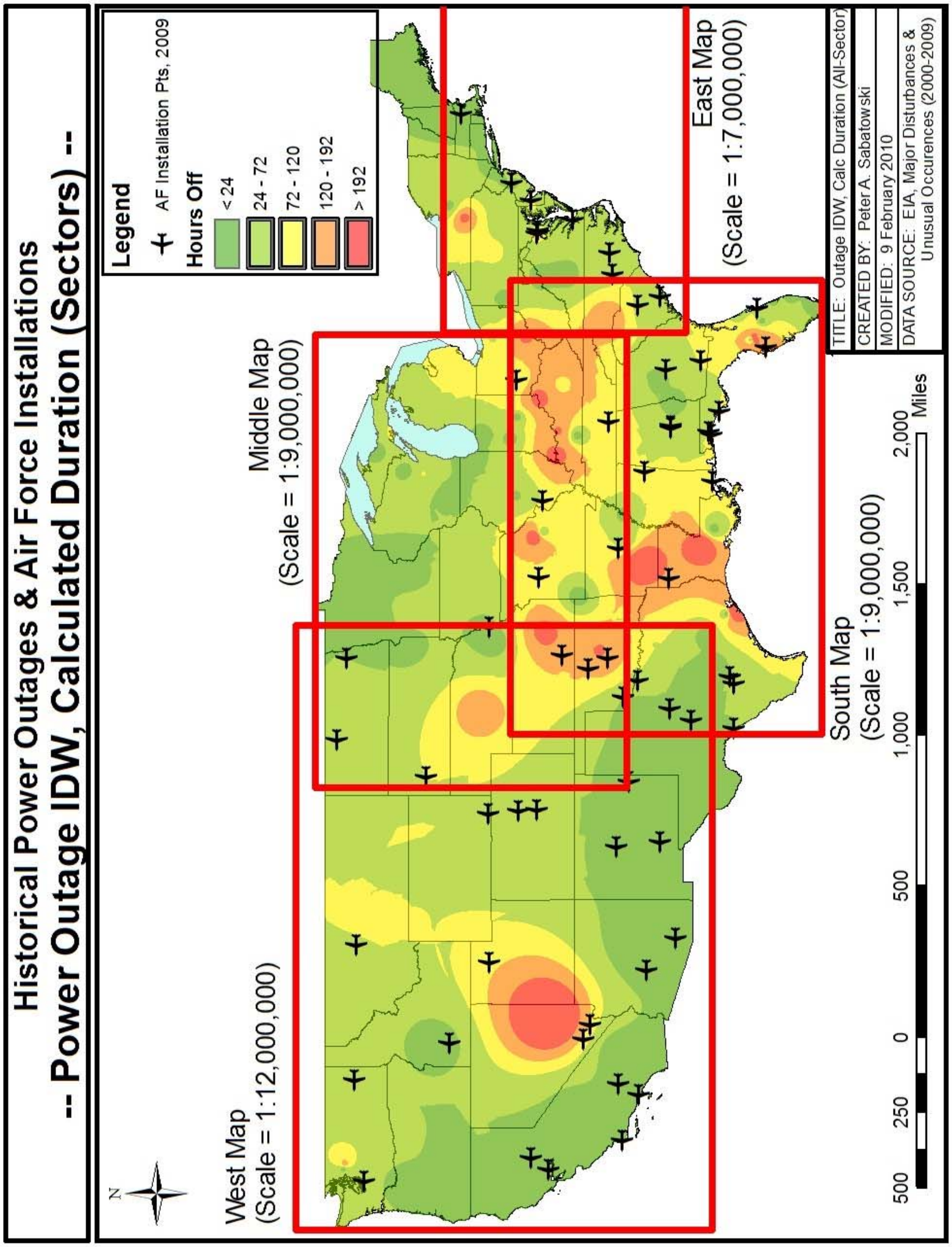
Historical Power Outages & Air Force Installations

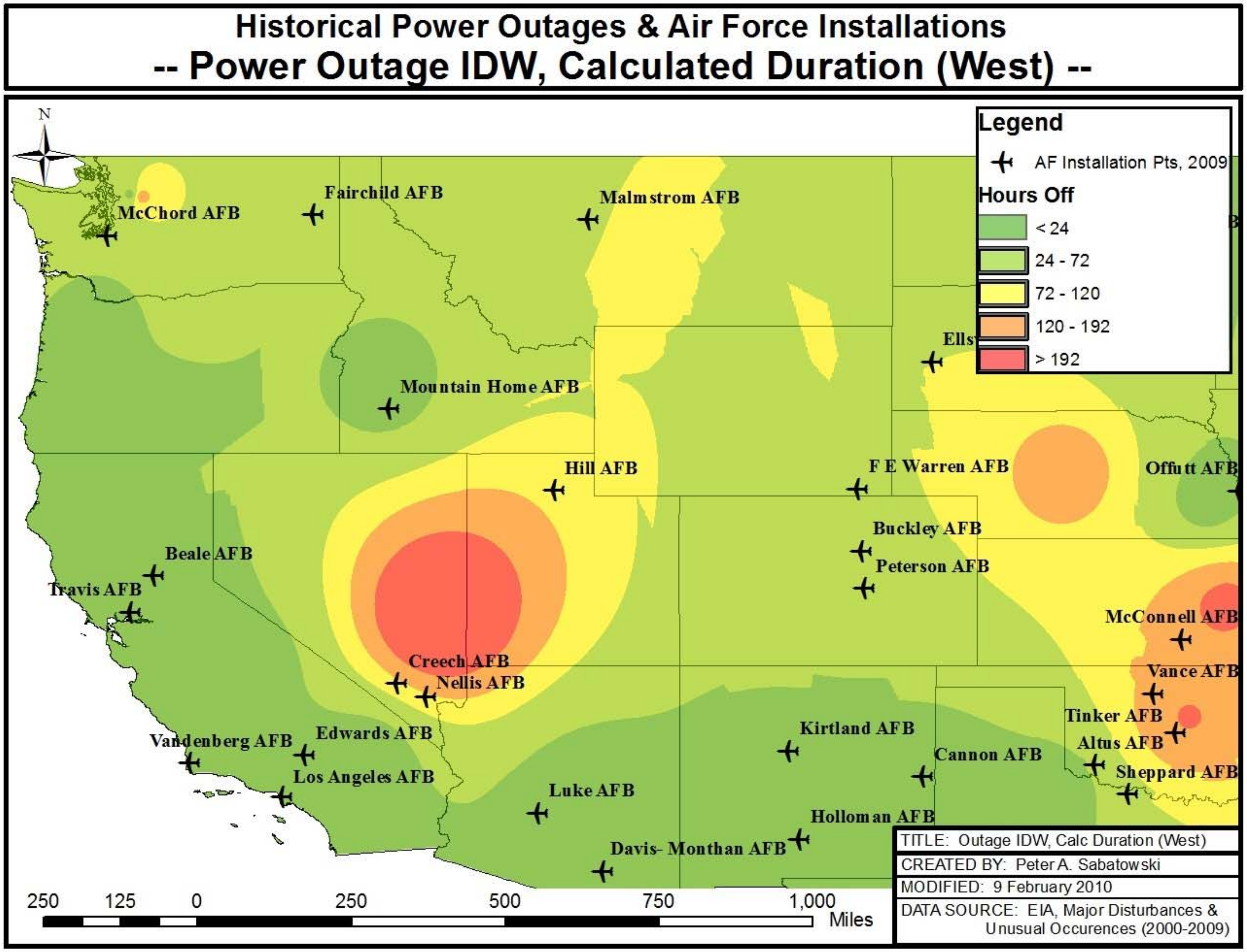
-- Power Outage IDW, Calculated Number Affected (South) --

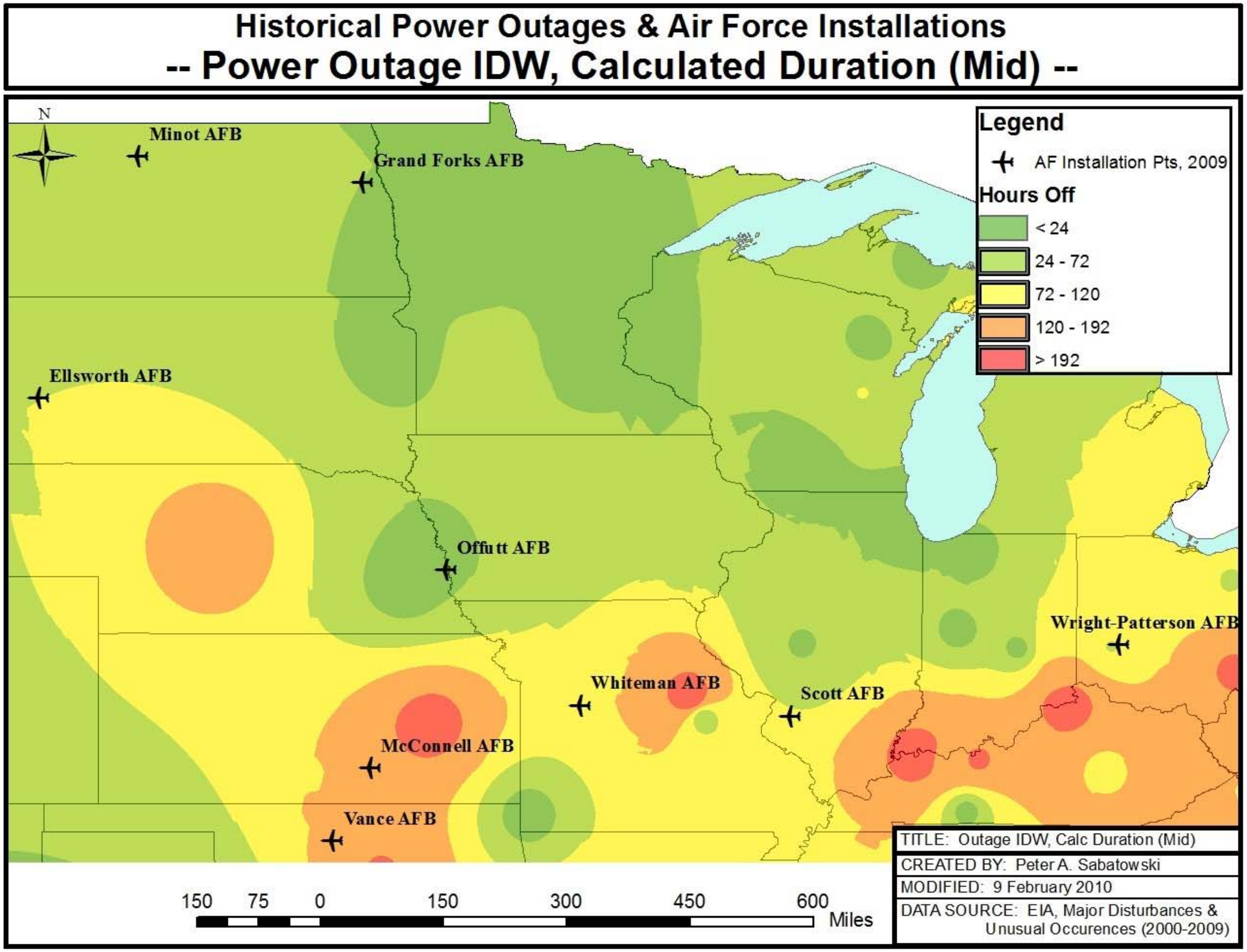
TITLE: Outage IDW, Calc No. Affected (South)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)


Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Number Affected (East) --
N
Hanscom AFB
McGuire AFB
Dover AFB
Bolling AFB
Andrews AFB
Langley AFB
Seymour Johnson AFB
Pope AFB
Shaw AFB
Charleston AFB
Legend
AF Installation Pts, 2009
Number Affected
< 100,000
100,000 - 200,000
200,000 - 300,000
300,000 - 600,000
> 600,000
100 50 0 100 200 300 400
Miles
TITLE: Outage IDW, Calc No. Affected (East)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)

APPENDIX F. Calculated IDW (Duration)



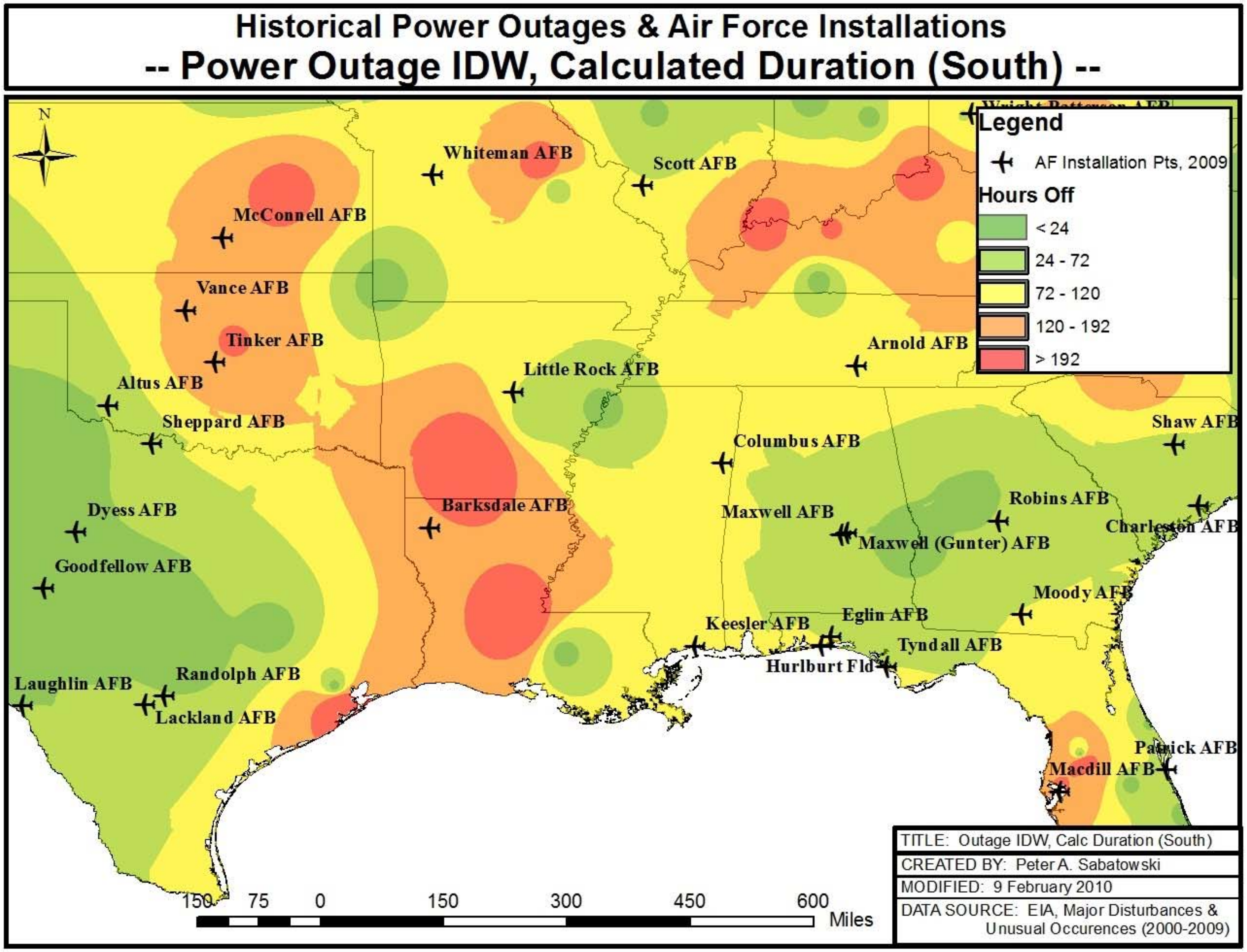

Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Duration (West) --
N
Legend
AF Installation Pts, 2009
Hours Off
< 24
24 - 72
72 - 120
120 - 192
> 192
McChord AFB
Fairchild AFB
Malmstrom AFB
Ells
Mountain Home AFB
Hill AFB
F E Warren AFB
Offutt AFB
Buckley AFB
Peterson AFB
Beale AFB
Travis AFB
McConnell AFB
Creech AFB
Nellis AFB
Vance AFB
Tinker AFB
Altus AFB
Kirtland AFB
Cannon AFB
Sheppard AFB
Vandenberg AFB
Edwards AFB
Los Angeles AFB
Luke AFB
Holloman AFB
Davis- Monthan AFB
250 125 0 250 500 750 1,000
Miles
TITLE: Outage IDW, Calc Duration (West)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)



Historical Power Outages & Air Force Installations

-- Power Outage IDW, Calculated Duration (Mid) --

TITLE: Outage IDW, Calc Duration (Mid)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)

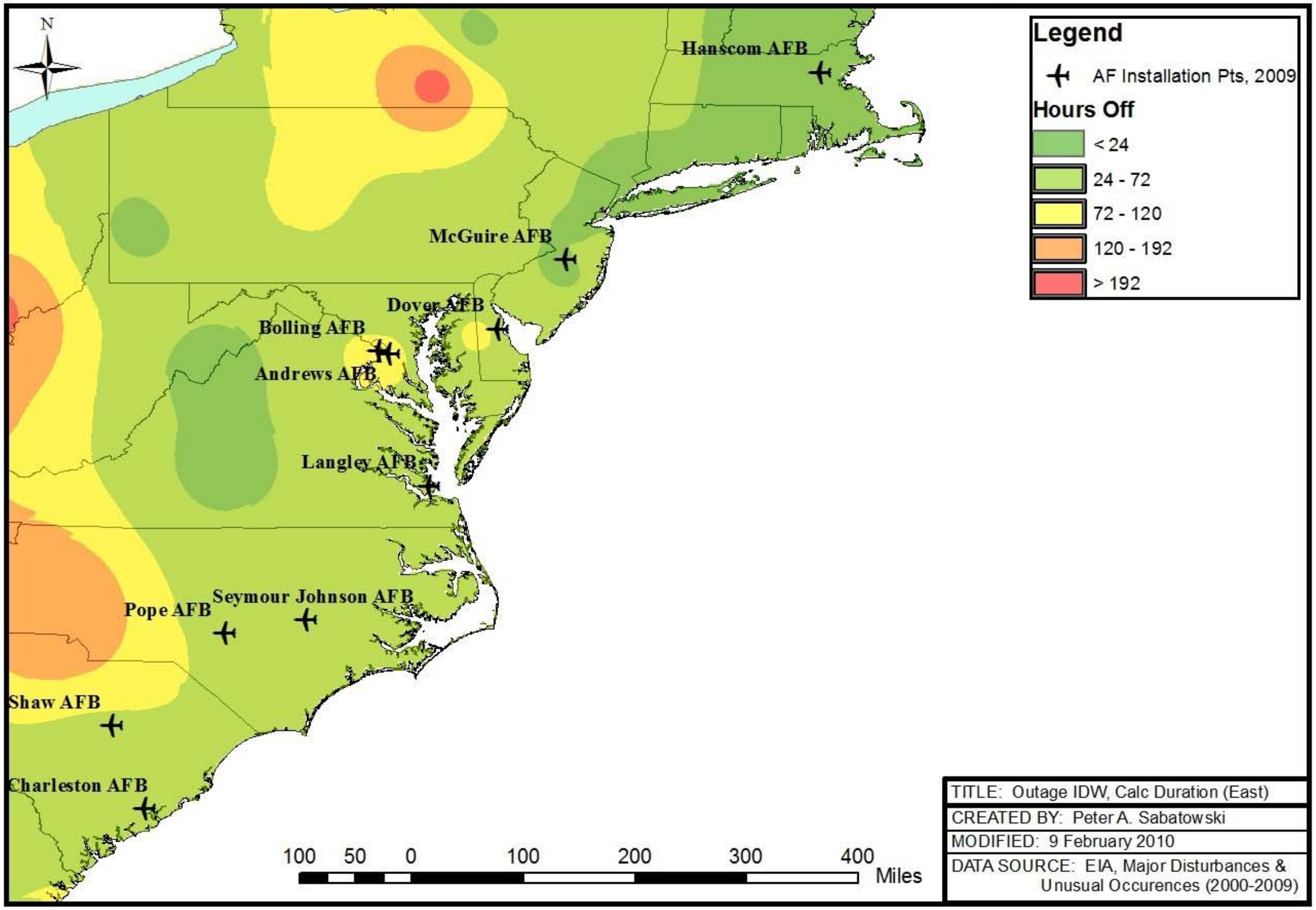


Historical Power Outages & Air Force Installations

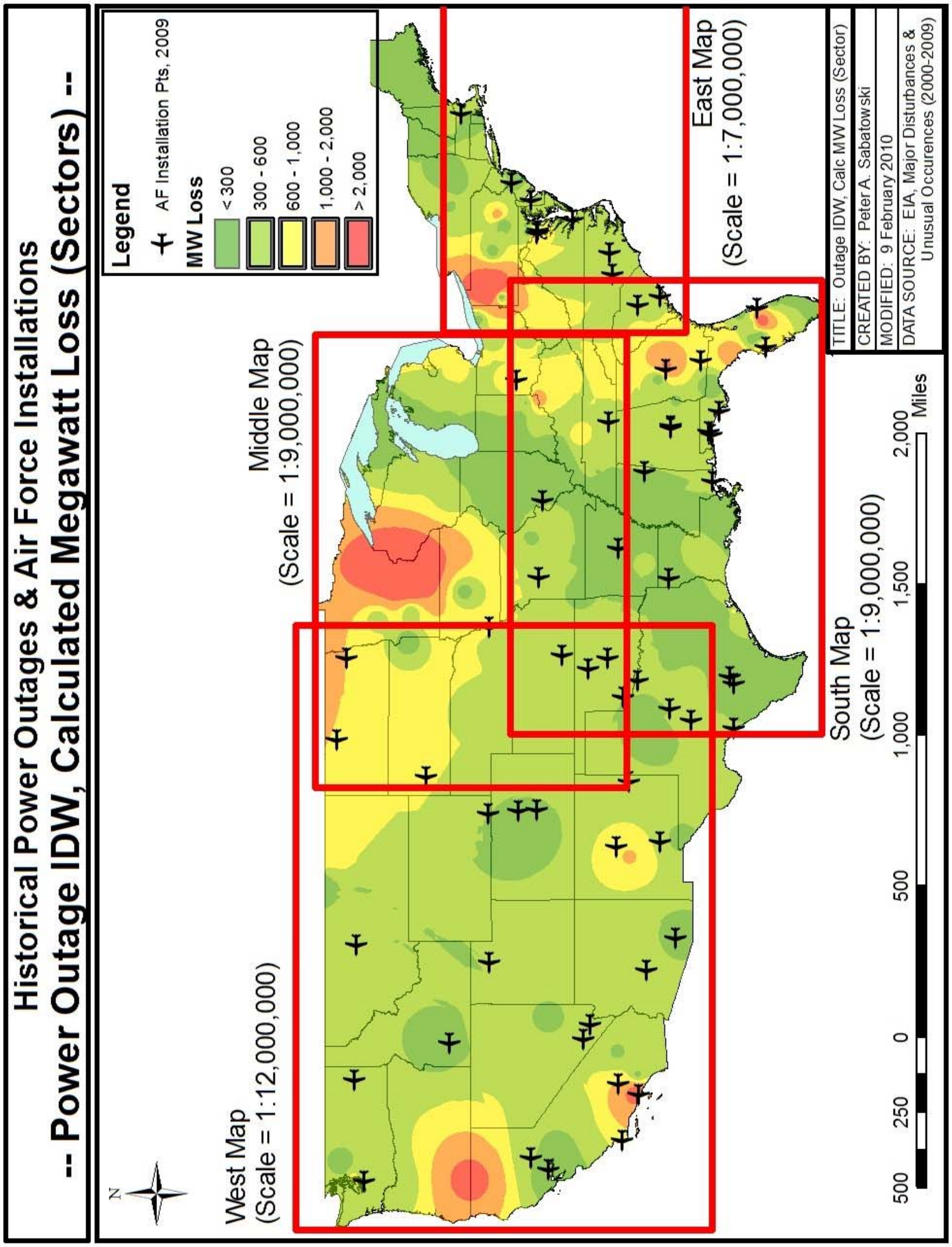
-- Power Outage IDW, Calculated Duration (South) --

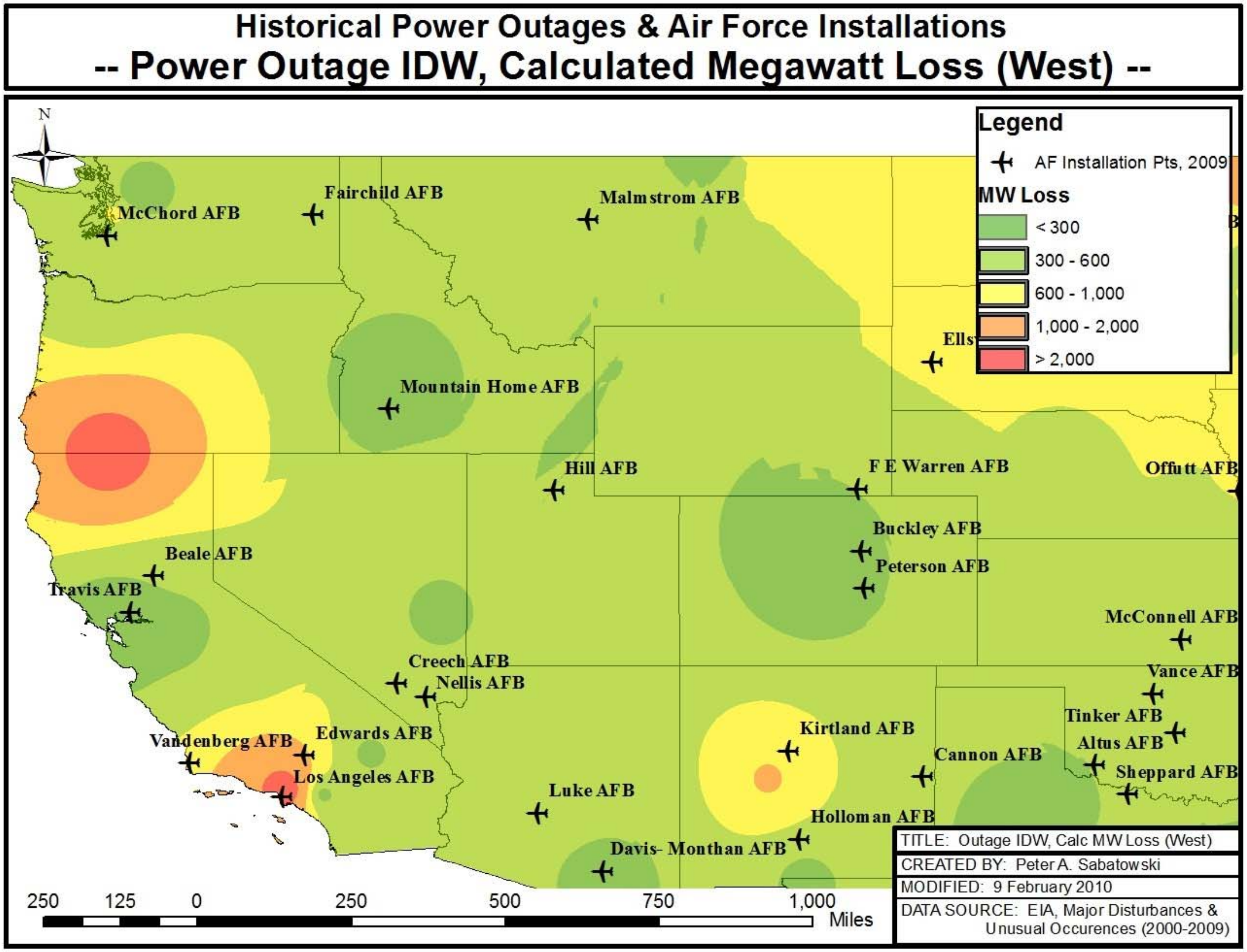
Historical Power Outages & Air Force Installations

-- Power Outage IDW, Calculated Duration (East) --



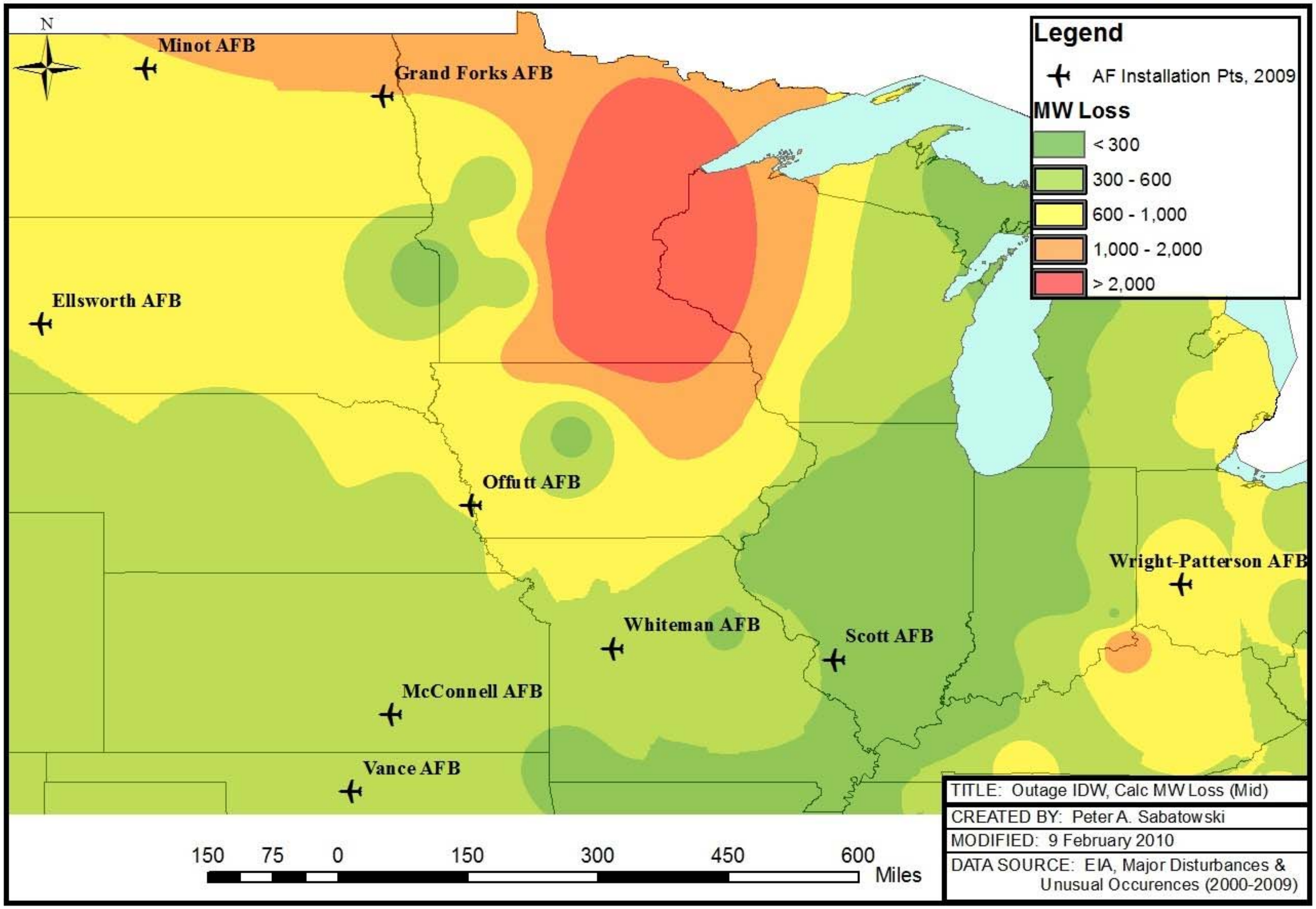
APPENDIX G. Calculated IDW (Power Loss)



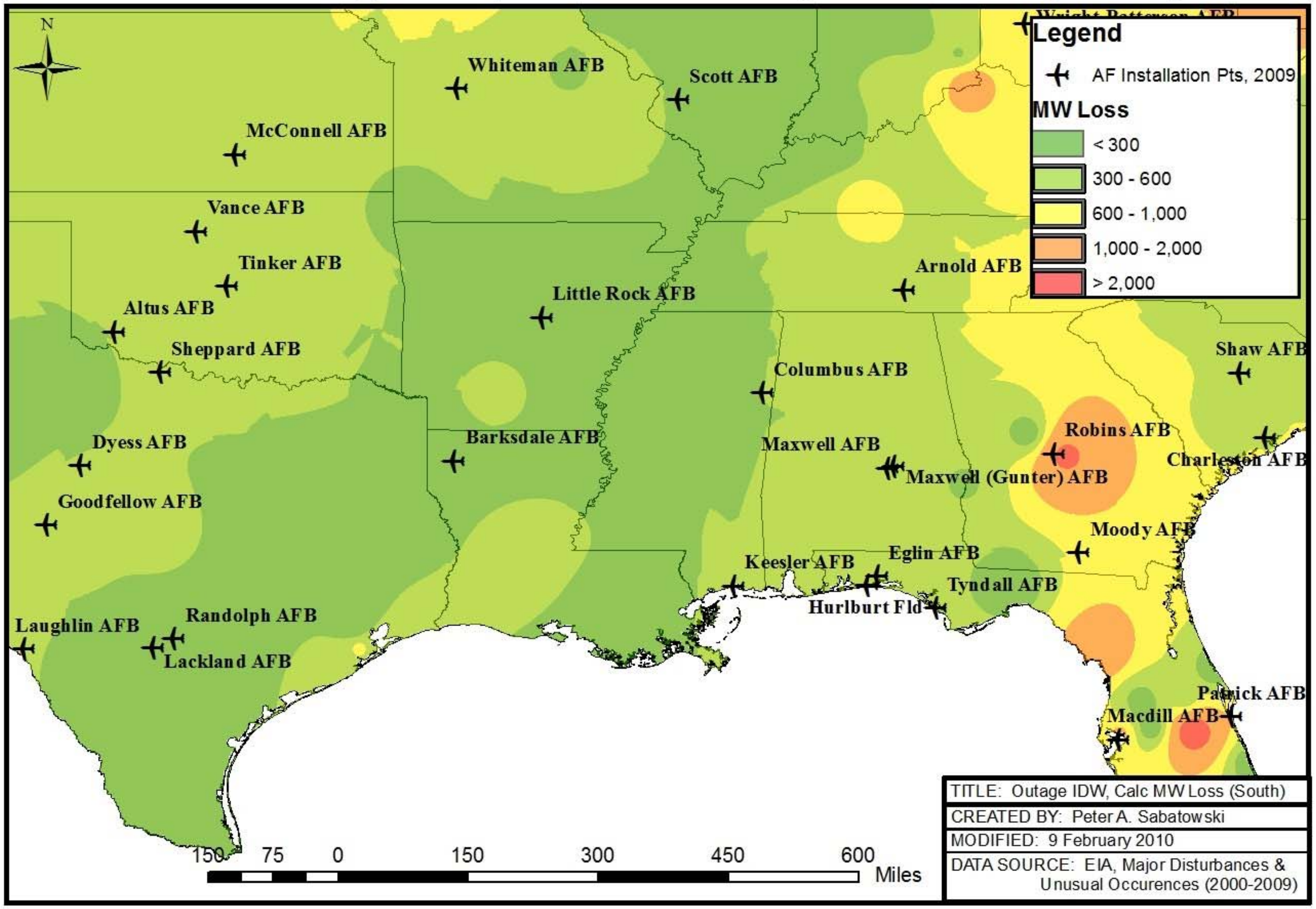

Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Megawatt Loss (West) --
N
Legend
AF Installation Pts, 2009
MW Loss
< 300
300 - 600
600 - 1,000
1,000 - 2,000
> 2,000
McChord AFB
Fairchild AFB
Malmstrom AFB
Ells
Mountain Home AFB
Hill AFB
F E Warren AFB
Offutt AFB
Buckley AFB
Peterson AFB
Beale AFB
Travis AFB
McConnell AFB
Creech AFB
Nellis AFB
Vance AFB
Tinker AFB
Altus AFB
Kirtland AFB
Cannon AFB
Sheppard AFB
Vandenberg AFB
Edwards AFB
Los Angeles AFB
Luke AFB
Holloman AFB
Davis- Monthan AFB
250
125
0
250
500
750
1,000
Miles
TITLE: Outage IDW, Calc MW Loss (West)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)

Historical Power Outages & Air Force Installations

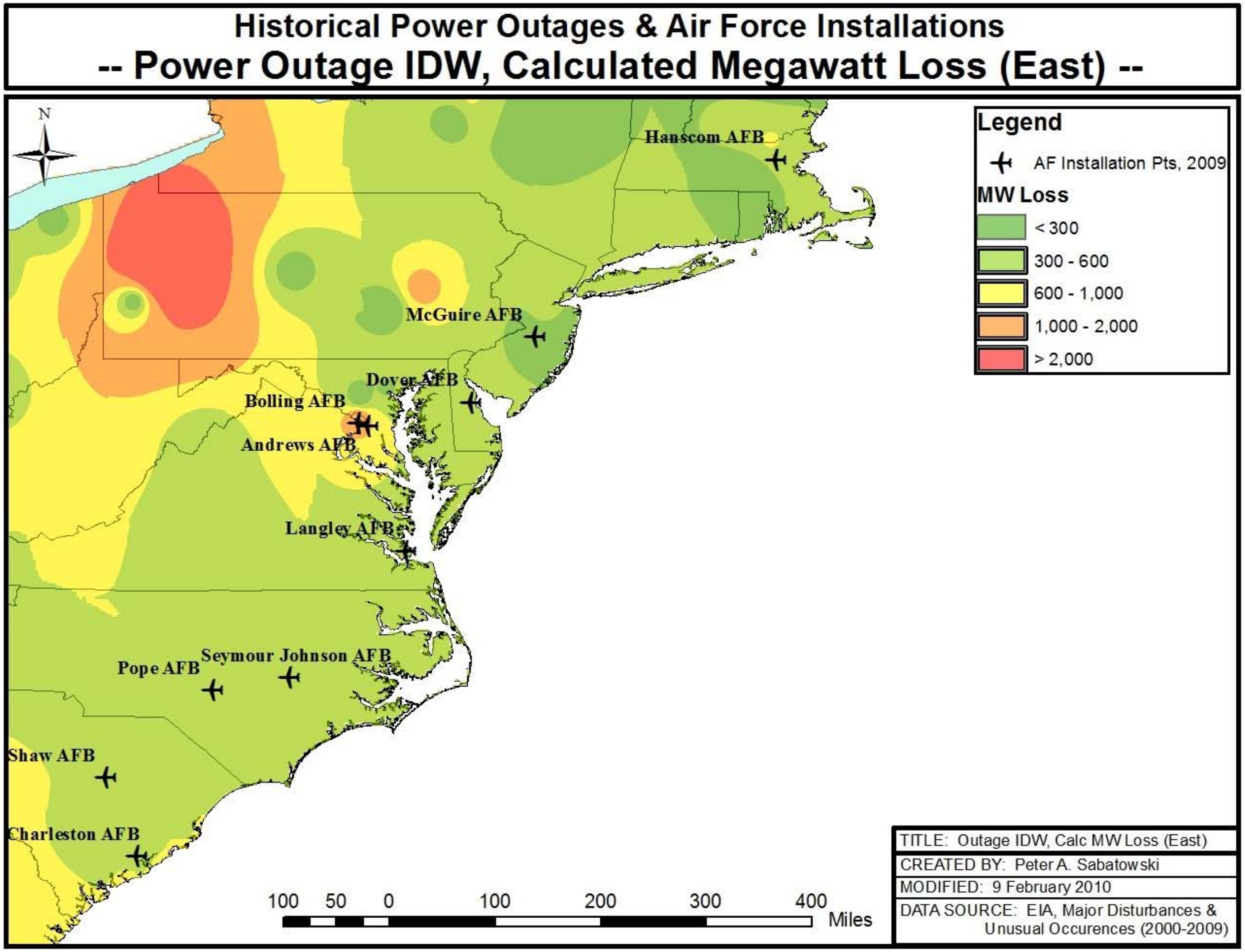
-- Power Outage IDW, Calculated Megawatt Loss (Mid) --



Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Megawatt Loss (South) --

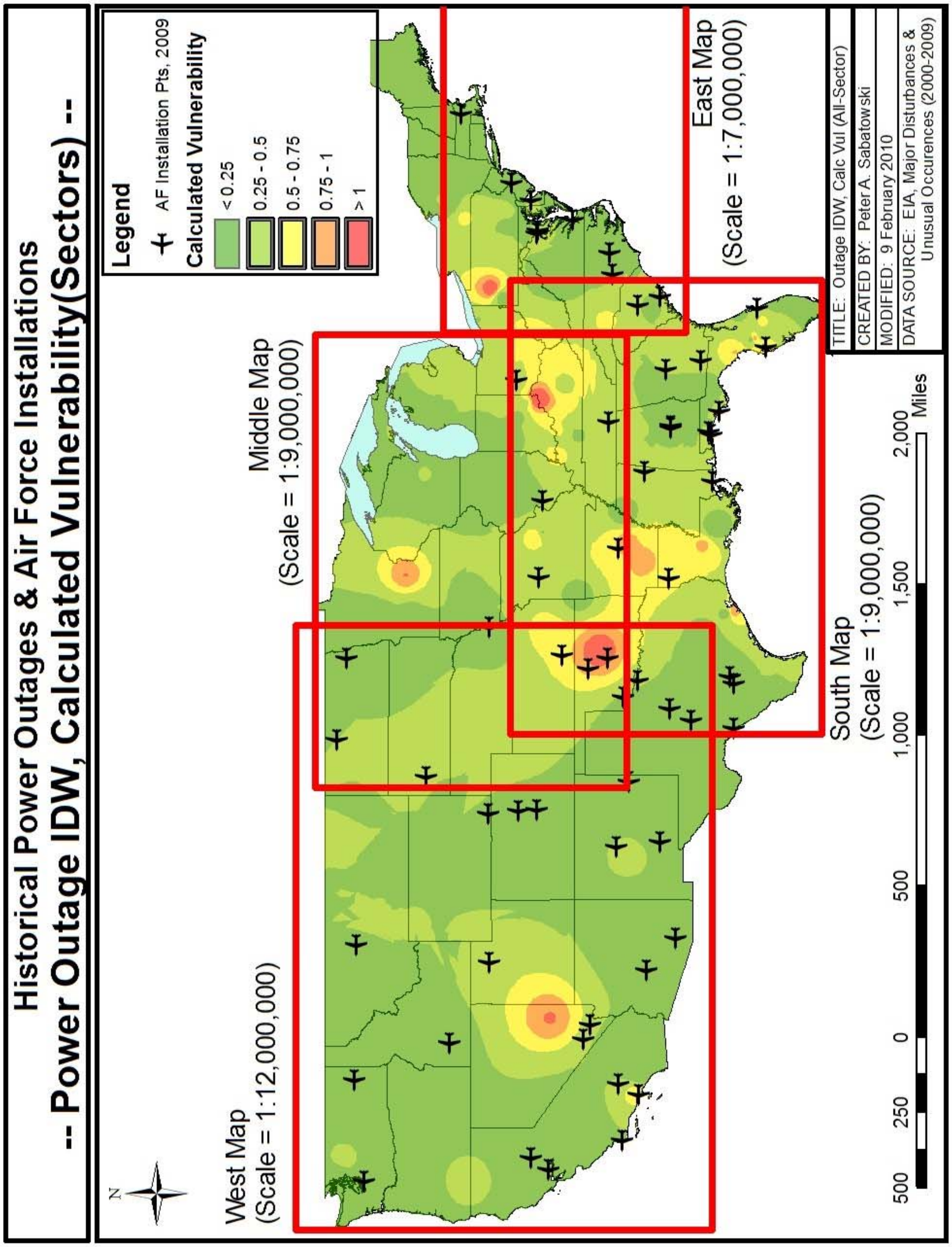


TITLE: Outage IDW, Calc MW Loss (South)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)


Historical Power Outages & Air Force Installations

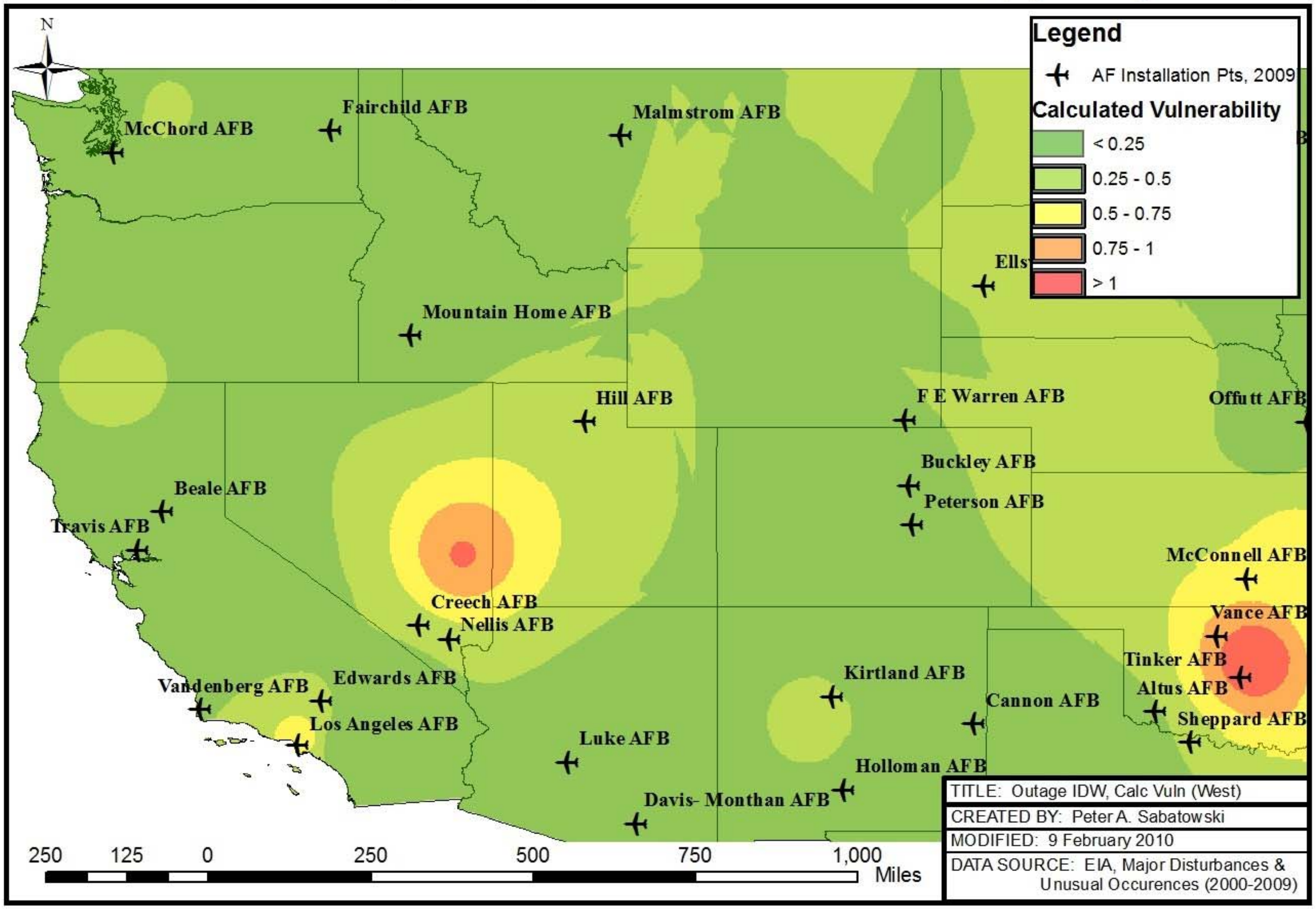
-- Power Outage IDW, Calculated Megawatt Loss (East) --

APPENDIX H. Calculated Weighted Vulnerability



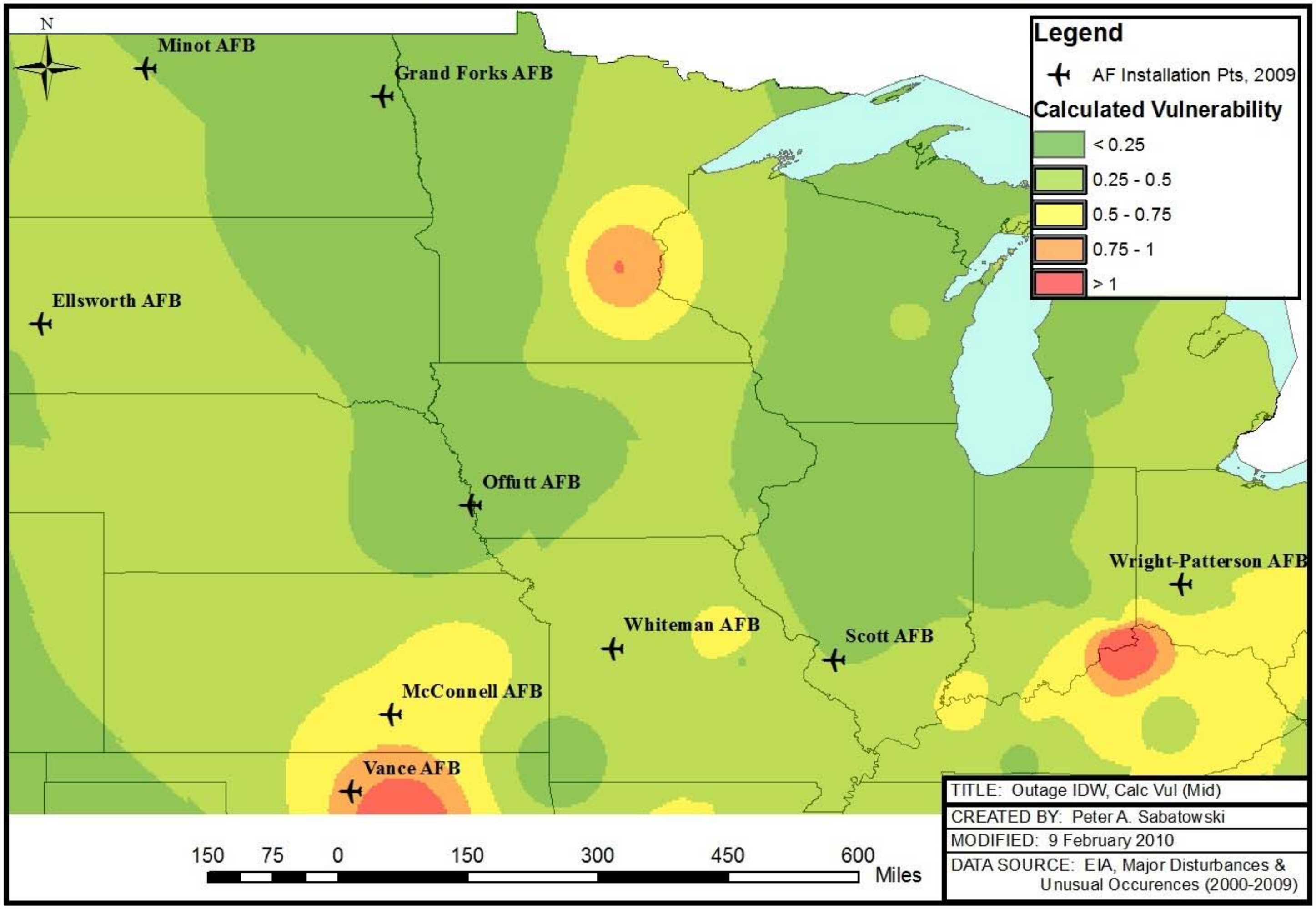
Historical Power Outages & Air Force Installations

-- Power Outage IDW, Calculated Vulnerability (West) --



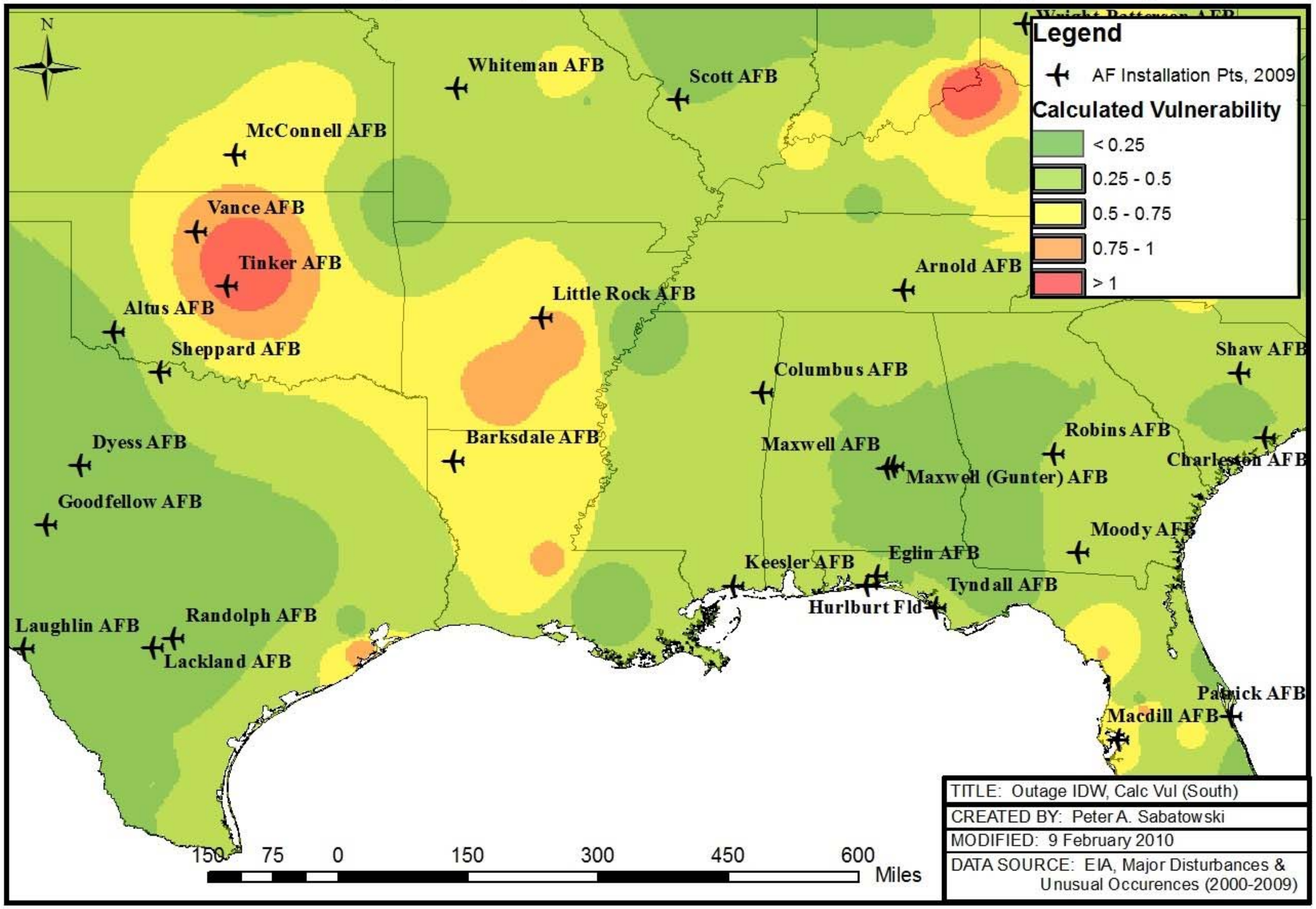
Historical Power Outages & Air Force Installations

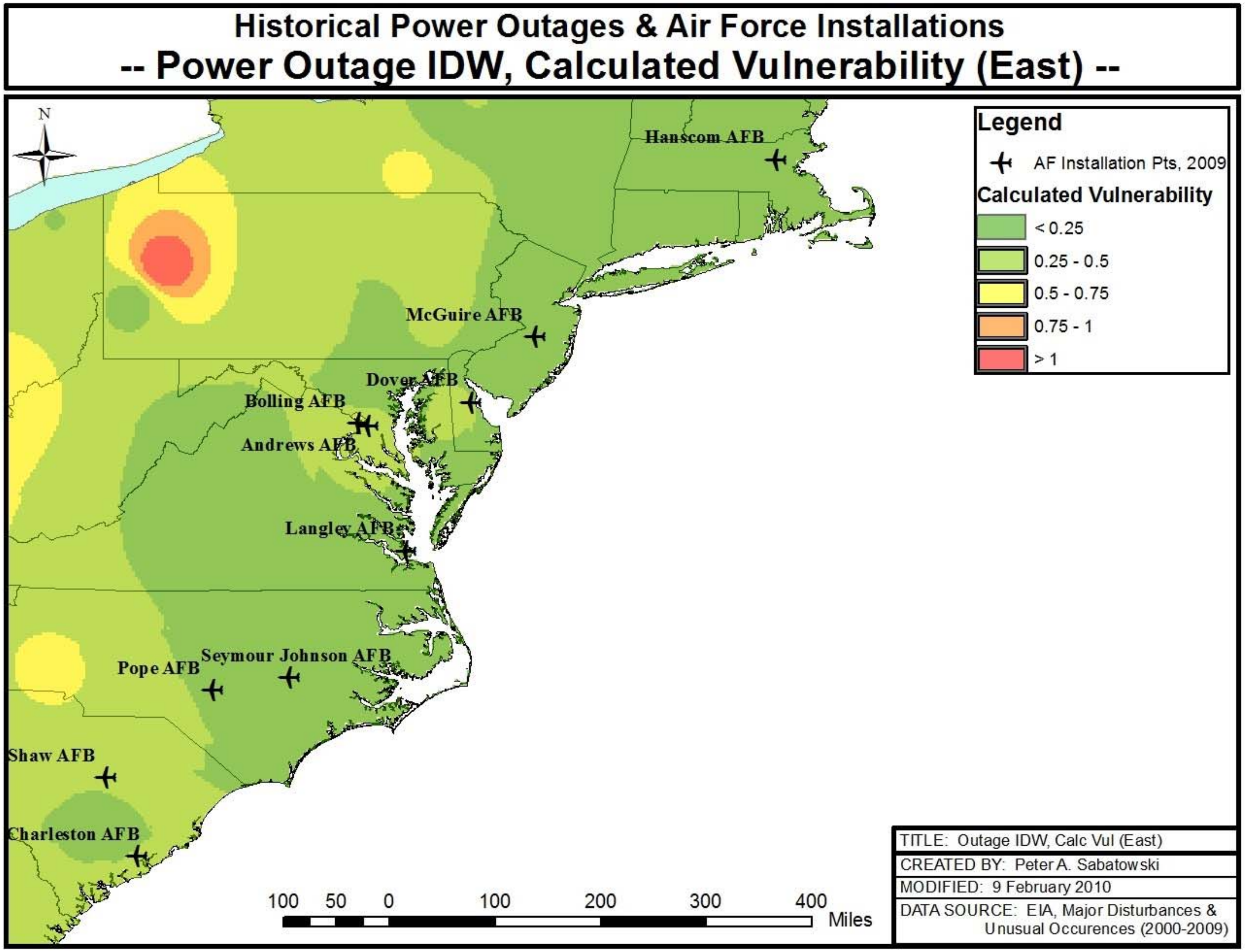
-- Power Outage IDW, Calculated Vulnerability (Mid) --



Historical Power Outages & Air Force Installations

-- Power Outage IDW, Calculated Vulnerability (South) --




Historical Power Outages & Air Force Installations
-- Power Outage IDW, Calculated Vulnerability (East) --
N
Hanscom AFB
McGuire AFB
Dover AFB
Bolling AFB
Andrews AFB
Langley AFB
Seymour Johnson AFB
Pope AFB
Shaw AFB
Charleston AFB
Legend
AF Installation Pts, 2009
Calculated Vulnerability
< 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
> 1
100 50 0 100 200 300 400
Miles
TITLE: Outage IDW, Calc Vul (East)
CREATED BY: Peter A. Sabatowski
MODIFIED: 9 February 2010
DATA SOURCE: EIA, Major Disturbances & Unusual Occurences (2000-2009)

References

About FERC. (2009, March 20). Retrieved May 7, 2009, from Federal Energy Regulatory Commission: http://www.ferc.gov/about/about.asp

About NERC. (2010). Retrieved January 10, 2010, from North American Electric Reliability Corporation: http://www.nerc.com/page.php?cid=1|15

Abshier, J. (2007, August 31). Becoming NERC CIP-Compliant: What you need to know to be compliant with the new mandatory compliance standards. *Process Automation Technologies* , p. 5.

Aimone, M. A. (2009, January). Cyber Warfare and the U.S. Electric Grid: Implications for National Security.

Albert, R., Albert, I., & Nakarado, G. (2004). Structural vulnerability of the North American power grid. *Physical Review , 69*, 1-4.

Amin, M. (2005). Scanning the Technology: Energy Infrastructure Defense Systems. *IEEE. 93,* pp. 861-875. IEEE.

Anjia, M., Jiaxi, Y., & Zhizhong, G. (2006). Electric Power Grid Structural Vulnerability. *Power Engineering Society General Meeting* (p. 6). Montreal, Quebec: IEEE.

Apt, J., Lave, L., & Morgan, M. G. (2006). Power Play, a more reliable U.S. electric system. *Issues in Science and Technology* , 51-58.

Arrillaga, J., Bollen, M. H., & Watson, N. R. (2000). Power Quality Following Deregulation. *Proceedings of the IEEE* , 246-261.

Ayres, R. U., Ayres, L. W., & Pokrovsky, V. (2005). On the efficiency of US electricity usage since 1900. *Energy , 30*, 1092-1145.

Baker, E. (2008). Responding to critical infrastructure threats of reliability and security: economic, organizational, and technical perspectives for a next generation U.S. electric grid. *Journal of Information Privacy and Security , 4* (1), 3-20.

Blankinship, S. (2001). Mission critical systems highlight need for reliable power protection. *Power Engineering , 105* (4), 54.

Bradbury, D. (2009, May). U.S. prepares law to increase electrical grid security. *Computer Fraud & Security* , pp. 1-2.

Brayley, H., Redfern, M., & Bo, Q. (2005). The public perception of power blackouts. *IEEE/PES Transmission and Distribution Conference & Exhibition* (pp. 1-5). Dalian, China: IEEE.

Brown, C. B. (2005). Learning from the Fed: Lessons for Federal Electricity Regulation. *The Electricity Journal , 18* (3), 15-46.

Bruce, J. (2002, Jan/Feb). Protecting power: an interview with Erle Nye. *Electric Perspectives , 27* (1), pp. 32-33.

Chassin, D., & Posse, C. (2005). Evaluating North American electric grid reliability using the Barabasi-Albert network model. *Physica A 255* , 667-677.

Childs, C. (2004, July-September). Interpolating Surfaces in ArcGIS Spatial Analyst. *ArcUser* , p. 4.

Cieslewicz, J. (2004). *Attacks & accidents: Policy to protect the power grid's critical computing and communication needs.* Leland Stanford Junior University.

De la Ree, J., Liu, Y., Mili, L., Phadke, A., & DaSilva, L. (2005). Catastrophic failures in power systems: causes, analyses, and countermeasures. *Proceedings of the IEEE , 93* (5), 956-964.

Defense Science Board Task Force. (2008). *DoD Energy Strategy: "More Fight - Less Fuel".* Washington, D.C.: Office of the Under Secretary of Defense.

Dix, J. (2006, April 28). Air Force Critical Infrastructure Program (CIP). *AFPD 10-24* .

Dobson, I. (2007). Where is the edge for cascading failure?: challenges and opportunities for quantifying blackout risk. *IEEE Power Engineering Society General Meeting* (pp. 1-8). Tampa, FL: IEEE.

Earls, J., & Dixon, B. (2007). Spatial Interpolation of Rainfall Data using ArcGIS: A Comparative Study. *ESRI User Conference 2007 Proceedings,* (pp. 1-9).

EIA. (2009, December 16). *Major Disturbances and Unusual Occurences.* Retrieved December 20, 2009, from Electric Disturbance Events - Monthly and Annual Summaries: http://www.eia.doe.gov/cneaf/electricity/page/disturb_events.html

ESRI. (2006, November 22). *An Overview of the Raster Interpolation Toolset.* Retrieved December 12, 2009, from ArcGIS 9.2 Webhelp Topic: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=An_overview_of_the_Raster_interpolation_toolset

ESRI. (2007, May 2). *Implementing Inverse Distance Weighted (IDW).* Retrieved December 13, 2009, from ArcGIS 9.2 Webhelp Topic: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?id=4792&pid=4790&topicname=Implementing_Inverse_Distance_Weighted_(IDW)

Eto, J. H., & LaCommare, K. H. (2008). *Tracking the reliability of the U.S. electric power system: An assessment of publicly available information reported to state* *public commissions.* Berkely, Ernest Orlando Lawrence Berkeley National Laboratory. CA: Berkely Lab.

Fox-Penner, P. (2005). Rethinking the grid: avoiding more blackouts and modernizing the power grid will be harder than you think. *The Electricity Journal* , 28-42.

Hauer, J., & Dagle, J. (1999). *Review of recent reliability issues and system events.* Washington D.C.: U.S. Department of Energy.

Hines, P., Apt, J., & Talukdar, S. (2008). Trends in the history of large blackouts in the United States. *IEEE* , 1-8.

History of FERC. (2009). Retrieved May 07, 2009, from Federal Energy Regulatory Commission: http://www.ferc.gov/students/whatisferc/history.htm

HQ AFCESA/CEOA. (2009, June 5). Interim Change-1 to AFI32-1063: Electric Power Systems. AFCESA.

HQ AFCESA/CES. (2005, June 1). AFI32-1062: Electrical Power Plants and Generators. AFCESA.

Karydas, C. G., Gitas, L. Z., Koutsogiannaki, E., Lydakis-Simantiris, N., & Silleos, G. N. (2009). Evaluation of Spatial Interpolation Techniques for Mapping Agricultural Topsoil Properties in Crete. *EARSeL eProceedings*, (pp. 26-39).

LaCommare, K. H., & Eto, J. H. (2004). *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers.* Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory.

Lerner, E. J. (2003, October). What's wrong with the electric grid? *Industrial Physicist* , 8-13.

Masse, T., O'Neill, S., & Rollins, J. (2007). *The Department of Homeland Security's Risk Assessment Methodology: Evolution, Issues, and Options for Congress.* Department of Homeland Security. Washington D.C.: Congressional Research Service.

McClelland, J. (2009, July 21). Testimony of Joseph McClelland, Director, Office of Electric Reliability, FERC. *Emerging threats, cybersecurity, and science and technology* . Washington D.C.: U.S. House of Representatives.

McDonald, R. (2008). *New Considerations for Security Compliance, Reliability and Business Continuity.* IEEE.

Merriam-Webster. (2009). Retrieved December 20, 2009, from Merriam-Webster: http://www.merriam-webster.com/dictionary/risk

Mertz, M. (2008). NERC CIP Compliance: We've Identified Our Critical Assets, Now What? *IEEE* .

Mili, L., Qiu, Q., & Phadkey, A. G. (2004). Risk assessment of catastrophic failures in electric power systems. *International Journal of Critical Infrastructures* , *1* (1), 38-63.

MRO. (2009). *About Us.* Retrieved January 18, 2010, from Midwest Reliability Organization: http://www.midwestreliability.org/about_mro.html

NERC. (2008). *NERC History*. Retrieved May 7, 2009, from North American Electric Reliability Corporation: http://www.nerc.com/page.php?cid=1%7C7%7C11

NPCC. (2007, October). *2007 NPCC Statistical Brochure.* Retrieved January 18, 2010, from Northeast Power Coordinating Council: http://www.npcc.org/viewDoc.aspx?name=statisticalBrochure%5b1%5d.pdf&cat=general

Office of the Air Force Civil Engineer. (2008). *U.S. Air Force Infrastructure Energy Strategy.* Washington D.C.: Air Force Civil Engineer Support Agency.

Rietz, R. K. (2008). Move with the Times. *IEEE Industrial Applications Magazine* , 14-18.

Salmeron, J., Wood, K., & Baldick, R. (2004). Analysis of electric grid security under terrorist threat. *IEEE Transactions on Power Systems* , *19* (2), 905-912.

Savageau, K. H. (2004). *Impact of electricity market rules on system reliability via a hidden failure model.* Ithaca: Cornell University.

SCE&G. (2010). *South Carolina Electric & Gas Company*. Retrieved February 4, 2010, from Service Area Map: http://www.sceg.com/en/commercial-and-industrial/service-area-map/

Scully, M. (2008). Needed: 200 New Aircraft a Year. *Air Force Magazine* , 54-57.

Shaw, J. (2009, May). NERC CIP & Smart Grid: How do they fit together? *Utility Automation & Engineering* , pp. 17-22.

Sherif, Y. S. (1991). On Risk and Risk Analysis. *Reliability Engineering and System Safety* , *31*, 155-178.

Shih, C. Y., Scown, C. D., Soibelman, L., Matthews, H. S., Garrett Jr., J. H., Dodrill, K., et al. (2009, September). Data Management for Geospatial Vulnerability Assessment of Interdependencies in U.S. Power Generation. *Journal o f Infrastructure Systems* , 179-189.

Slocum, T. (2008, October). *Public Citizen.* Retrieved July 7, 2009, from The Failure of Electricity Deregulation: History, Status and Needed Reforms: http://www.citizen.org/documents/USdereg.pdf

Tobler, W. R. (1970). A computer movie simulating urban growth in the Detroit region. *Economic Geography* (46), 234-240.

U.S. Department of Homeland Security. (2007). *Characteristics and common vulnerabilities, infrastructure category: electrical distribution systems.* Protective Security Coordination Division. Washington D.C.: Office of Infrastructure Protection.

U.S. Department of the Interior. (2009, September 17). *Map Layers*. Retrieved March 12, 2010, from National Atlas Home Page: http://www-atlas.usgs.gov/maplayers.html

Umstattd, R. (2009). Future energy efficiency improvements within the U.S. department of defense: incentives and barriers. *Energy Policy , 37*, 2870-2880.

Watts, D. (2003). Security & vulnerability in electric power systems. *NAPS 2003, 35th North American Power Symposium* (pp. 559-566). Rolla, MO: University of Missouri.

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14. ABSTRACT

The United States (U.S.) electric grid is considered one of the greatest inventions of the twentieth century, yet it become apparent over the past few decades that it is not without its own set of problems. The deregulation of the U.S. electric system in the late 1990s eliminated monopolies and resulted in the nation's generation, transmission, and distribution systems becoming separate entities owned and operated by multiple companies. This created a market economy in which many electric companies failed to plan for the future, did not invest in maintenance and upgrades, and began to push the aggregate system to its maximum capacity. A number of cascading power outages in the late 1990s, culminated by the complete blackout of the northeastern U.S. in 2003, have subsequently caused the federal government to question the reliability of the nation's deregulated electric grid and take action to remedy current issues.

Therefore, the objective of this study was to leverage the trend and spatial analysis capabilities embedded in typical geographic information system (GIS) platforms to examine power outage data from the Energy Information Administration (EIA). Utilizing the industry standard for GIS, ArcGIS, interpolation using the inverse distance weighted approach was used to calculate preliminary vulnerability levels at military installations based on EIA's power outage database from 2000 to 2009. The results of the study offer insight that will help key stakeholders better understand the state of the nation's electric grid and identify areas of concern. This allows stakeholders to be in a better position to address associated vulnerabilities by making appropriate plans for either system upgrades or mitigation efforts.

15. SUBJECT TERMS
Electric Power Outages, Inverse Distance Weighted (IDW) Analysis, Geographic Information System (GIS), Impact of power outage on Air Force Installations

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