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Christopher Shannon Ryals

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GEOGRAPHIC INFORMATION SYSTEM (GIS) SIMULATION OF EMERGENCY POWER PRODUCTION FROM DISASTER DEBRIS IN A COMBINED HEAT AND POWER (CHP) SYSTEM

By

Christopher Shannon Ryals

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GEOGRAPHIC INFORMATION SYSTEM (GIS) SIMULATION OF EMERGENCY POWER PRODUCTION FROM DISASTER DEBRIS IN A COMBINED HEAT AND POWER (CHP) SYSTEM

By

Christopher Shannon Ryals

Approved:

Jeremiah Davis Assistant Professor, Agricultural and Biological Engineering (Major Professor)	Scott Samson Professor, Extension Service (Director of Research Thesis)
David Evans Professor of Forestry (Committee Member)	
Jeremiah Davis Assistant Professor, Agricultural and Biological Engineering (Graduate Coordinator)	George Hopper Interim Dean of the College of Agriculture

Name: Christopher Shannon Ryals

Date of Degree: April 29, 2011

Institution: Mississippi State University

Major Field: Engineering Technology (Agricultural and Biological Engineering)

Major Professor: Dr. Jeremiah Davis

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Candidate for Degree of Master of Science

The objective of this study is to determine a predicted energy capacity of disaster debris for the production of emergency power using a combined heat and power (CHP) unit. A prediction simulation using geographic information systems (GIS) will use data from past storms to calculate an estimated amount of debris along with an estimated energy potential of said debris.

Rather than the expense and burden of transporting woody debris such as downed trees and wood framing materials offsite, they can be processed (sorting and chipping) to provide an onsite energy source to provide power to emergency management facilities such as shelters in schools and hospitals. A CHP unit can simultaneously produce heat, cooling effects and electrical power using various biomass sources.

This study surveys the quantity and composition of debris produced for a given classification of disaster and location. A comparison of power efficiency estimates for various disasters is conducted.

Keywords: Hurricane debris, combined heat and power unit, geographic information systems, Debris Emergency Power Production Simulation (DEPPS)

DEDICATION

I would like to dedicate this research project to my wife Laura. You have been with me from the very start of this project. Thank you for your understanding when I spent long sleepless nights on this project. Your love and support through the headaches of the programming of the simulation was the only thing that kept me going. “I am so proud of you” was the phrase that pushed me through the end of this part of our lives. From here, into our unknown future, you are my stronghold. I love you so very much.

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I want to thank my committee for all of their input and time they spent with me to make sure that I understood the concepts of my research project.

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To my parents, you taught me to reach for the stars even when I cannot fathom how far away they are. Pop, I have reached out only because of your discipline and encouragement throughout my youth. You have driven me to become something you are proud of. Mom, you taught me how to accomplish great things just by breaking them down into smaller pieces. I love you both so very much.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOML: Atlantic Oceanographic and Meteorological Laboratory

BRAVO: Biomass Resource Assessment Version One

CDL: Crop Data Layer

CHP: Combined Heat and Power

C-MAN: Coastal-Marine Network

DEPPS: Debris Emergency Power Production Simulation

DSS: Decision Support System

FIA: Forest Inventory and Analysis

FRIS: Forest Resource Information System

FS: Forest Service

HRD: Hurricane Research Division

IDW: Inverse Distance Weighting

MIFI: Mississippi Institute for Forest Inventory

NASS: National Agricultural Statistics Service

NCDC: National Climatic Data Center

NHC: National Hurricane Center

NLCD: National Land Cover Dataset

NOAA: National Oceanographic and Atmospheric Administration

SRS: Southern Research Station

TIFF: Tagged Image File Format

TM: Thematic Mapper (Landsat 5 satellite)

TVA: Tennessee Valley Authority

USDA: United States Department of Agriculture

USGS: United States Geological Survey

CHAPTER 1

INTRODUCTION

Atlantic hurricane seasons have been quite active in the first decade of the 21st century. Storms from the 2004 and 2005 hurricane seasons were some of the most devastating in recorded history (Fitzpatrick, 2006). In late August 2005, Hurricane Katrina struck the Florida, Louisiana, Mississippi and Alabama coasts with an intensity that had not been experienced in the Gulf of Mexico since Hurricane Camille in 1969. Hurricane Katrina was considered to be the most costly and one of the top five deadliest Atlantic hurricanes in history (NOAA, 2007). Heavy damage occurred to both man-made structures and forest ecosystems in southern Louisiana and Mississippi.

The US Forest Service's early estimate of the forest damage from Hurricane Katrina stated that 4.2 billion cubic feet of timber were damaged in Louisiana, Mississippi, and Alabama. One third of this damage was centered in eight southern counties of Mississippi (McCollum, 2005). Damage throughout the region was so devastating that electricity was not fully restored to the coastal counties of Mississippi for several weeks (Glenn Hughes, personal communication, June 1, 2010). Recovery crews utilized diesel and gasoline-powered generators to power the recovery effort from the storm.

Often the fuel of choice to power emergency generators in disaster situations is gasoline or diesel. This is due to the availability and high fuel energy density. Diesel, gasoline and natural gas all have a large amount of energy compared to their mass, but these fuels have the potential for limited availability and increase in price. However, because of the probable level of destruction in the region, transportation of fossil fuels can become both costly and dangerous. During the post-Katrina recovery, many emergency recovery crews were at the mercy of the next fuel truck to continue to coordinate the recovery effort.

Scientists and labs around the world are devoting intensive research to exploring alternative forms of fuel for all aspects of energy demand. Biomass is increasingly becoming a viable alternative fuel for many energy-demand applications. Ethanol created from agricultural crop biomass has been blended into gasoline for several years to reduce the consumption of fossil fuels. Recent research has also gone into the study of using woody biomass in a combined heat and power (CHP) unit. The CHP unit uses thermal energy to produce electricity, and the waste heat from the heat exchanger can be used to heat air and water. The woody biomass could be waste wood from many timber harvesting/maintenance activities. Research has shown that trash or waste wood, which is often burned or disposed in landfills, can be processed into usable fuel (Dornburg and Faaij, 2001).

A wood-fueled CHP unit would have benefitted the recovery effort of the region in two specific ways. First, the requirement for fossil fuels would be lessened. If the generators were replaced with CHP units, the wood debris from the storm event would provide available fuel for electricity. Second, the woody debris from the damaged forests hampered recovery crews from restoring electricity and transportation of services to the region. If this debris were chipped on site and utilized in a CHP unit, two goals would be accomplished with the same action. Emergency power would be available to a shelter facility, and the debris obstructing the roadways would be cleared. In the event of another devastating hurricane, it is only prudent to make efforts toward faster and more efficient recovery (Glenn Hughes, personal communication, June 2009).

The goal of this research was to provide a real-world simulation for the utilization of disaster debris in a CHP for emergency power. The simulation was designed to predict the amount of debris produced by a hurricane event. After the predicted amount was calculated the simulation dealt with the collection, transportation and utilization of the disaster debris. The simulation was also designed to incorporate parameters from user inputs and from researched literature. The objectives of this study were to:

1. Develop a spatial simulation to predict the concentration of debris from a hurricane event according to current data and literature parameters.
2. Develop a network transportation model using current road network data to simulate transportation of the debris from the field to the CHP unit location.
3. Develop and test a supply-and-demand algorithm to assume the output of a CHP unit being fueled by hurricane disaster debris.

The Debris Emergency Power Production Simulation (DEPPS) was designed to meet the objectives of this study using current geospatial data from the Mississippi Gulf Coast pertaining to past storm events. The simulation was also designed to incorporate user inputs to manipulate variables depending upon the application of the simulation. This design allows DEPPS to test different situations of storm intensity, processing of debris, and problems associated with the impacts of a hurricane event to coastal counties. DEPPS was created as a framework for future development of simulations and real-world applications in multiple fields of research.

CHAPTER 2

LITERATURE REVIEW

2.1 Past Hurricane Events

The Atlantic hurricane season spans from June 1 to November 30 as defined by the Atlantic Oceanographic and Meteorological Laboratory (AOML) (Boose and Foster, 1994). Hurricanes, also known as tropical cyclones, have been historically known to cause damage to structures with their landfall. The majority of damage to coastal regions is due to both storm surge and high wind speed as the hurricane heads inland. However, once the hurricane moves inland, wind becomes the most destructive factor. According to an estimate by United States Department of Agriculture (USDA) Forest Service (FS) in September 2005, nearly ninety percent of Mississippi coastal forests were damaged by Hurricane Katrina. This damage was observed up to sixty miles inland. USDA FS Inventories estimated the forest destruction to be approximately 4.2 billion cubic feet of timber. This placed Hurricane Katrina as one of the most destructive Atlantic hurricanes in recorded history (McCollum, 2005).

According to the National Oceanographic Atmospheric Administration (NOAA), Hurricane Katrina is the most costly hurricane on record with at least 81 billion dollars of property damage throughout Florida, Louisiana, Mississippi and Alabama (NOAA, 2007). Locations along the Gulf coast were without utilities for several weeks because the infrastructure to accommodate the needs of the region was obliterated. The recovery of the region was hindered by several different factors, including the presence of debris blocking roadways.

2.2 Hurricane Wind Effects on Timber

Atlantic hurricanes are often categorized by sustained wind speed and storm surge using the Saffir-Simpson Hurricane Scale (Blake, 2007). This scale is shown below in Table 2.1 with wind speed in both miles per hour (mph) and meters per second (m/s).

Table 2.1

Saffir-Simpson Hurricane Scale Definition

Wind Speed (mph)	**Wind Speed (m/s)**	**Saffir-Simpson Hurricane Scale**
0 - 38	0 - 16.99	Tropical Depression
39 - 46	17 - 20.56	Tropical Storm
47 - 73	20.57 - 32.63	
74 - 95	32.64 - 42.47	Category 1 Hurricane
96 - 110	42.48 - 49.17	Category 2 Hurricane
111 - 130	49.18 - 58.12	Category 3 Hurricane
131 - 155	58.13 - 69.29	Category 4 Hurricane
>156	>69.30	Category 5 Hurricane

Powell et al. (1998) with the Hurricane Research Division (HRD) of the National Hurricane Center (NHC) developed and evaluated the HRD real-time wind analysis system, which has compiled various sources of hurricane wind data into a common framework for several years. The HRD system uses data from Air Force and NOAA aircraft, ships, buoys, Coastal-Marine Automated Network (C-MAN) platforms, and surface airways. Three quality control parameters were placed on the data: (1) the data can be used for both marine and land-cover types, (2) the data were conformed to a ten meter height above the surface of the Earth and (3) the wind data was captured using an averaging period of one minute maximum sustained wind speed. Accurate collection of these data required several hours of observations. The primary analysis of the data provided a contour plot designed to show the location and strength of the hurricane force and the maximum wind speeds. The researcher noted that future development of this system could allow power utility companies to estimate the damage to their power grid over the affected hurricane area.

The official report of Hurricane Katrina by the NHC concluded that on August 29, 2005 at 1110 UTC the hurricane made landfall near Buras, Louisiana with an estimated maximum wind speed of 110 knots (127 mph), classifying the storm as a powerful Category 3 hurricane. The storm moved over southeastern Louisiana and weakened to a Category 2 hurricane as it passed over south-central Mississippi.

Oswalt and Oswalt (2008) with the USDA FS Southern Research Station – Forest Inventory and Analysis (SRS-FIA) conducted research on the effects of Hurricane Katrina on the forests of the state of Mississippi. Oswalt and Oswalt performed spatial analysis of the debris using data from a study conducted by USDA FS SRS-FIA. Following Katrina, the USDA FS SRS-FIA began sampling forest resource plots across the state to ascertain the actual damage from Hurricane Katrina. A method called “condition mapping” was used by Oswalt and Oswalt (2008) to generate a random sample of the forest plot data. The damage was then assessed on the basis of wind damage from Hurricane Katrina, and each plot was given a binary value of 0 or 1 (0 = no wind, 1 = wind). The effects of varying wind speed were not considered. Binary coding was used to identify bole and branch damage based on a true-or-false statement, designed to show a simple ‘damage or no damage’ assessment. This assessment underwent an inverse distance weighting (IDW) interpolation to create a surface showing regions that were “damaged” versus “undamaged.” Zones were created that showed the intensity of the damage based on the interpolated surface. Statistics were conducted on the amount of damage the storm presented within each zone. The initial reports from the study stated that a larger percentage of softwoods received damage than the hardwoods.

Stanturf et al. (2007) explained that wind is the most damaging factor of a hurricane on coastal forests. Research showed that the most common form of damage to coastal forests from hurricane winds is due to abrasion between trees. Leaves, twigs and branches experience damage under most conditions. Increased damage occurred when the distance between trees increased.

Dr. David L. Evans, professor in the Department of Forestry at Mississippi State University, explained that the canopy supports individual trees from the effects of direct wind shear. Thinning throughout the age of the stand can result in trees losing their canopy support and cause trees to become more susceptible to breakage. Thinning increases the distance between the trees allowing for this higher probability of stem breakage (personal communication, August 4, 2010).

Boose and Foster (1994) stated that the effect of wind on forests is complex and not fully understood. Hypotheses from different researchers suggested that much forest damage occurs because of wind gusts instead of sustained wind speed. However, it was noted that sustained wind speeds for extended periods of time could result in fatigue failure. A model by Boose and Foster (1994) used sustained wind speeds and peak gusts to quantify damage from the storm event. However, in the event of a weather station failure, peak gusts would be extremely difficult to assess.

James et al. (2006) conducted research on the effects of wind on Australian tree species. Five species were studied to determine the wind-shear effect created by high winds. It was noted that the overall effect of wind shear is greatly influenced by tree shape and structure. Mechanical models of tree statics are traditionally used to predict wind shear; however, because of the varying growth of trees over a large area, it is extremely difficult to model each individual tree within a forest for its structural capability. Therefore, a simplification of the model methods is required to allow the model to have utility. James et al. (2006) chose several trees within their species list to model each tree's resistance to wind shear force.

Myers and Lear (1998) compiled a damage estimate from a National Climatic Data Center (NCDC) research publication conducted by Neumann et al. in 1993. Correlation of Saffir-Simpson storm category and visually observed damage were compiled in a NCDC table. Damage was quantified on effects of hurricane force winds for both man-made structures and forest canopy losses.

Generalized wind shear assessments on trees were compiled by Cullen (2002) in a technical note to the Journal of Arboriculture. Cullen's (2002) assessment analyzed the NCDC tables to infer a predicted wind shear effect based on wind speed. The values for wind speed were given using the Saffir-Simpson Hurricane Scale factor as a reference. These generalizations did not take into account species, age, dimensions, terrain or stand condition. However, many of these factors are historically difficult to predict in modeling because of the variety of conditions that a forest can contain. Cullen (2002) concluded with stating that all indices of wind effects on trees were for understanding biomechanics of wind and tree exposure.

The USDA National Agricultural Statistics Service (NASS) produces an annual Crop Data Layer (CDL) for the continental United States. This CDL contains data that relates to updates in agricultural practices across the United States. The non-agricultural domain (forest, wetlands, urban, and water covers) is proportionally sampled from the United States Geological Survey (USGS) National Land-cover Dataset (NLCD). The ground truth proportions of this data are maintained by sampling the CDL at the same rate as the NLCD (USDA, 2009).

2.3 Processing and Transportation of Woody Biomass

Möller and Nielsen (2007) studied the increasing need for transported wood chips in Denmark. Wood chips have been used in increasing numbers to heat homes and power electricity plants throughout the country. The high demand and low supply of forested areas have led to an increase in wood chip transportation. Use of shortest-distance fuel optimization paths and maximizing the payload of the chip transporter were noted as means to increase the efficiency of the chip transportation. A geographic information system (GIS) was used to create the model for the transportation analysis. A cost-weighted distance analysis was conducted to produce a spatial reference to wood chips and their transportation costs. It was noted by Möller and Nielsen (2007) that because of the inherent complexity of forest systems, a modeling of the exact location of forest biomass potential could not be accomplished. Therefore, forest location was determined by using a land-cover raster that was interpreted from 1995 Landsat 5 Thematic Mapper (TM) imagery. The resampled resolution of the dataset was 100 meters by majority, which neglected all smaller cells in the analysis. The land-cover raster was then reclassified to contain only forest cells. The transportation model was based on a road network with the average truck speed as travel time. The researchers concluded that some of the errors with the model were the lack of topological data of the region, tolls or tariffs for the use of certain routes, driver-preferred routes and a sufficiently high-resolution forest resource map (Möller and Nielsen, 2007).

Noon and Daly (1996) developed a computer-based decision support system (DSS) for estimation of the transportation cost of wood chips to Tennessee Valley Authority (TVA) coal-fired power plants. The model was called Biomass Resource Assessment Version One (BRAVO). BRAVO considered biomass from mill residues, logging residues and short-rotation woody crops. Potential locations for logging residues were determined based on the Forest Resource Information System (FRIS) from the USDA. BRAVO was developed using the ARC/INFO platform. The results from the BRAVO project demonstrated that the model was capable of producing an accurate cost estimation of transporting wood chips to the TVA power plants. The generated values were based on simulated transportation conditions with existing plant locations. Significant regional differences in the generated values were attributed to the varying supply of biomass and availability of roads for transportation.

Graham et al. (1997) used the BRAVO model and hypothetical power plant locations in the state of Tennessee. Twenty-one plants were placed across the state and were split into three regions: Appalachian Highlands, Interior Plains, and the Gulf-Atlantic Plain. Each of these regions has very different biomass and road network characteristics. Graham et al. (1997) used the dataset developed by Noon and Daly (1996). The model used hypothetical biomass resources to determine the most efficient plant location based on transportation costs. They determined the Interior Plains of the state contained the best road network and biomass availability. The researchers noted that an initial dilemma concerning transportation would be the participation of biomass farmers to produce a supply to meet the power plant demand as well as the available transportation network.

2.4 Combined Heat and Power Unit Operation

Ragland et al. (1991) conducted a systematic compilation of 21 different properties of wood fuel for energy production. The initial modeling of thermal and chemical characteristics of wood fuel required an accurate density of the fuel. The researchers used a density table of different wood products from the Forest Products Laboratory. Pine whole-tree chips have a density of 181 kilograms per cubic meter according to the Forest Products Laboratory table (1987). Pine whole-tree chips were chosen for the project analysis because the majority of estimated available wood fuel was of the *Pinus* genus.

Demirbras (2004) discussed the history and combustion characteristics of biomass. Waste wood has potential to be a biomass fuel simply because of its varying sources. Wood scraps, sawdust and thinning residues all can be processed for fuel usage. Two classifications of biomass in combustion models are macroscopic and microscopic.

Macroscopic biomass focuses on the larger properties of the biomass including moisture content, particle size, heating value and bulk density. These properties are greatly influenced by particle size, surface area and species of the biomass. Moisture content of varying biomass species has been shown to change the amount of heat energy captured by the energy unit. The author also noted that in comparison to fossil fuels, biomass has a lower heating value coupled with a lower carbon emission. This lower heating value suggested to the author that cofiring, which is a form of combusting biomass and coal together, is currently the most efficient way to use biomass in conventional combustion systems.

Dempster (2009) performed a study for technical and economic system assessments of three methods of biomass fuel utilization: fast pyrolysis, gasification, and pelleting systems. Current combustion systems require that the biomass be processed for utilization. Dempster assessed the processing as chipping, drying and grinding. The next step outlined was the primary conversion of the processed biomass through a thermochemical combustion process. The intermediate product of this process is heat which is then converted to electricity. The author noted that for this process, the biomass must first be dried to less than 10% moisture content to improve the overall efficiency of the system.

Dornburg and Faaij (2001) conducted a study on the efficiency and economics of using a heat and power generation unit fueled by woody biomass. The efficiency of the unit was tested with an optimal utilization of resources to produce the maximum energy output at the minimal cost. This study focused on several different combustion systems ranging from 0.1 to 300 MW of thermal energy output. ‘Clean’ and ‘Waste’ wood were considered in the study as viable sources of biomass for fuel. The efficiencies of the power unit were determined to be related to the fossil fuel savings by using the system. The costs for the power unit included capital for initial investment, maintenance of the unit and the operation of the unit. Operation and maintenance costs would include technicians and staff to maintain unit performance. Transport of the material was also considered to be a determining factor in the efficiency of the power unit. The available biomass supply was simulated to be a constant over the area in the study. Transport of the material was simulated in a circle outward from the biomass processing facility. The study did not include calculations based on road networks, terrain or distance.

Biedermann et al. (2004) developed a small-scale combined heat and power (CHP) unit for biomass fuel exclusively in Denmark. The CHP unit was rated to produce a nominal output of 35 kilowatts of electric (kW_{el}) and 220 kilowatts of thermal (kW_{th}) power. The researchers determined that efficient operation of a biomass-fueled CHP unit would depend on the availability and nearby location of fuel. With a steady input of wood chips, this unit could provide electric power to small villages or individual buildings. Wood-fuel chips were tested with varying moisture contents ranging from 10 to 55 percent wet basis to determine the effects of moisture in the fuel on energy production. The CHP unit ran successfully with the varying moisture contents without a noticeable energy loss. Test runs of the unit produced 31 kW_{el} of power while consuming 96 kilograms per hour of wood chips. The overall efficiency of the unit was calculated to be 90 percent during the test runs.

Mago et al (2009) studied the use of a CHP unit in a modeled office building. The modeled building had an area of 465.4 square meters with maximum electricity demand five days a week. Modeled energy requirements were determined to be 3,749 W for electric equipment and 5,017 W for lighting every hour. The modeled CHP unit used a heat-recovery system along with natural gas to produce an overall efficiency of 80 percent.

CHAPTER 3

MATERIALS AND METHODS

3.1 Overview

In order to consider the many varying conditions of this study, a simulation using GIS was created to account for potentially changing parameters. The Debris Emergency Power Production Simulation (DEPPS) created for this study simulates use of disaster debris in a wood-fueled CHP unit. The process of DEPPS can be broken down into three smaller processes. These are: (1) the determination of available debris created from a hurricane event, (2) retrieval and transportation of the debris and (3) utilization of the debris as fuel in a CHP unit. The following sections will detail the definitions and methods of simulating these three processes. All data used in the construction of the simulation have been reviewed for integrity and accuracy. The data were compiled from sources that provided extensive metadata about the collection and organization of the data.

3.2 Study Area Selection

Ten counties from southern Mississippi were selected for the study area for the DEPPS analysis: Hancock, Harrison, Jackson, George, Stone, Pearl River, Lamar, Perry, Forrest and Greene Counties. The USDA defined the area contained within these ten counties as the area most wind-affected by Hurricane Katrina. The USDA Forest Service estimated that up to sixty miles inland from the Mississippi Gulf Coast, nearly ninety percent of all forests were damaged (McCollum, 2005). Since this region of the Gulf Coast is prone to hurricane activity, the DEPPS will focus on these ten counties for this study.

The base map for the DEPPS was based on data extracted from the United States Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) system database. A TIGER shapefile of the county boundaries was downloaded to serve as the DEPPS focus area. The original datum of the TIGER files was the North American Datum of 1983 (NAD 83).

3.3 Simulation Data Justification and Collection

The DEPPS project will be created based on data with extensive metadata and well-documented methodology of data collection. The justification and collection of the various types of data are important to maintain proper data use and documentation. Therefore, the following sections define both the justification and collection of data used in the DEPPS project.

3.3.1 Hurricane Wind Data

Historically, scientists have tried to predict the outcome of the weather on Earth. However, even in recent years with the development of Doppler radar and aircraft capable of flying into the eye of a hurricane, it has not been possible to harness or predict with certain accuracy the outcome of the weather. Therefore, assumptions were made with justification in the prediction of the effects of wind on forests. The following are both the justification and collection of hurricane wind data used in the simulation.

The nature of hurricane activity and development is followed by several different organizations. The National Oceanographic and Atmospheric Administration (NOAA) houses different hurricane data collection agencies depending on the location of the storm. The Atlantic Oceanographic and Meteorological Laboratory (AOML) is in charge of monitoring the conditions of the Atlantic Ocean for signs of hurricane development.

In 1993, the Hurricane Research Division (HRD) of the National Hurricane Center (NHC), under the guidance of the AOML, began developing a real-time wind analysis model that would ascertain the properties of a hurricane from many different sources of hurricane data. Public and private data were used together to provide the most available data from the hurricane event. The model took data from previous storms and developed a common framework to conform the data into a usable format. The model was initially tested from the data of Hurricane Andrew in 1992. Hurricane Fran in 1996 was modeled with the real-time system as it made landfall in Georgia and South Carolina. Data from the results of the model were used to help the recovery of the area after the storm (Powell et al., 1998).

The AOML-HRD website contains a compilation of wind data from recorded past hurricane events. The data are first categorized by the hurricane season. After selecting a hurricane season, the data can be retrieved by hurricane name and region. The data for each hurricane can be downloaded in two formats. The first dataset type is the maximum sustained winds for the duration of the storm. Wind speed and location are the two factors in this dataset. The second dataset type is the wind field of the storm at specific points in time. The "snapshot" dataset gives specific details about the hurricane at three-hour intervals.

For the execution of this simulation, the maximum sustained wind dataset was retrieved for Hurricane Katrina. Data from Hurricane Katrina were downloaded for the hurricane wind attributes within the simulation. Hurricane Katrina made landfall in Louisiana as a large Category 3 hurricane on August 29, 2005. This storm was considered to be the most destructive hurricane to strike the United States in recorded history. Katrina was chosen for the simulation because of its destructive properties along with the wealth of data that has been obtained from the storm to date.

The dataset's original extent covered southeastern Louisiana to southwestern Alabama then north to central Mississippi. Katrina's wind dataset contained three different units of wind speed. The attribute "MAXSFC" provides the wind data in meters per second (m/s), "MAXSFC_KTS" provides the data in knots (kn) and "MAXSFC_MPH" provides the data in miles per hour (mph). "MAXSFC" was used for the wind simulation through the DEPPS to match the units of the other variables in the simulation.

3.3.2 Land-Cover Data

Land-cover or land-use data are instrumental in many modeling projects. The data can be utilized to see changes in agricultural crops over seasons or a period of years along with many other applications. The United States Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) Crop Data Layer (CDL) was used in the DEPPS project to define areas of forest cover and to exclude certain cover types. The CDL data defines regions of the United States that are utilized for agricultural purposes. Enumerators, on behalf of the USDA-NASS Agricultural Survey along with imagery, collect these data from Resourcesat-1's Advanced Wide Field Sensor (AWiFS) and Landsat 5/7. Data obtained from Resourcesat-1, an Indian remote sensing satellite, have a five-day repeat coverage, 24-hour orbital repeat, four spectral bands and 56-meter resolution. Landsat 5/7 data were used to fill gaps or supplement the AWiFS dataset. No data available to the public contain any farmer or landowner data.

The United States Geological Survey (USGS) maintains the non-agricultural land-covers, which are contained in the National Land-cover Dataset (NLCD). The NLCD contains land-cover types including urban, forest, water, wetlands and many others that are not related to agriculture. The data maintained by the USGS are defined in the CDL dataset as NLCD. NASS samples the CDL at the same rate as the NLCD to maintain proper proportions in the ground truth methods.

The 2009 Delta States dataset was downloaded directly from the NASS CDL webpage. The Delta States dataset contained individual raster datasets from Alabama, Arkansas, Kentucky, Louisiana, Missouri, Mississippi, and Tennessee. The original format for the raster files was Tagged Image File Format (TIFF). All of the datasets had a 56-meter resolution inherited from the AWiFS imagery.

3.3.3 Forest Value Data

The NASS CDL dataset contained the needed geographic data of forest cover, however, there were no data relating to the forest inventory of the region. In order for DEPPS to produce a debris volume for the simulation product, a volume estimate of southern Mississippi forests was required. Determining the volume of forest stands has conventionally been a difficult and labor-intensive practice. Estimations of forest attributes including volume have been conducted by the USDA in the past. The USDA estimations have been conducted every six to fifteen years with little to no spatial correlation with existing stands of timber. These estimations are statistically based on values obtained from timber harvesting and salvage operations in each county.

The Mississippi Institute for Forest Inventory (MIFI) was created in 2002 to inventory the forests of the state. Inventories were designed to be conducted in five regions of the state. Each year, one region is inventoried to ensure that each region's inventory is no older than five years. The MIFI data for the DEPPS study area were collected in September 2005 through April 2006 (Emily B. Schultz, personal communication, November 21, 2010). Therefore, all of the values for volume from the MIFI dataset would represent a post-Hurricane Katrina estimate.

The MIFI dataset was obtained from Dr. Thomas G. Matney and Dr. Emily B. Schultz with the Department of Forestry at Mississippi State University. Dr. Matney was responsible for the inventory volume analysis from raw data obtained by MIFI. The original data was stored in a Microsoft Access database as tabular data by year. Location information was stored as geographic coordinates (latitude and longitude) and all volume data was stored in cubic feet.

3.3.4 Road Network Data

The United States Census Bureau produces the TIGER shapefile datasets detailing all public and political spatial information annually. The base map for DEPPS was taken from the TIGER shapefile database system. TIGER Line shapefiles include roads, railroads, rivers and other geographic areas. Many global positioning system (GPS) navigation devices use TIGER files as a road network. The TIGER road network includes data relating to the type, name, county, along with many other attributes. The metadata contained within the shapefile gives all of the details about the attributes of the road network.

The 2009 TIGER Line shapefiles were downloaded for each of the ten counties included in the study area. This dataset was used as the basis for the transportation simulation portion of DEPPS.

3.4 Simulation Data Preprocessing

Data collected for DEPPS had to undergo preprocessing due to the varying sources, units and coordinate systems of the data. All of the data were projected to the USA Contiguous Equidistant Conic projection. This was done to ensure the integrity of the transportation network, yielding a more accurate representation of distance. The distance unit for the projection was meters to ensure SI units were used throughout the simulation.

All data were stored in a geodatabase to ensure compatible location and processing capability of the data for the simulation. Feature datasets, within the geodatabase, were created to catalog the multiple dataset types (wind speed, road network, study area base map, etc.). Feature datasets maintained ease of data access for the simulation processes. A secondary geodatabase was created to perform as a workspace for all simulated data. The secondary geodatabase was designed to be purged by iteration of the simulation to maintain current simulation outputs.

The downloaded TIGER Line shapefiles were originally county-level datasets. The TIGER County Boundary files were merged into a single polygon feature class representing the entire ten-study area. The TIGER road network was also merged to facilitate development of the transportation network for the debris collection and transportation simulation of DEPPS.

DEPPS was designed using the geographic information system software ArcGIS 9.3.1 from Environmental Systems Research Institute (ESRI). Python and Visual Basic programming languages were used throughout the designing process to program a streamlined processing system into one graphical user interface (GUI) for DEPPS.

3.5 Simulation Layout

The DEPPS project was broken into two parts because of the computing power demanded by the simulation. DEPPS Part 1 simulated the effects of wind on forest cover and created an available "supply" of debris as an output. Steps were taken to minimize the amount of random access memory (RAM) required by the simulation. DEPPS Part 2 took the output from Part 1 as an input supply to the transportation simulation. Part 2 simulated retrieval and loading, and transportation to the CHP unit along with unloading of the chipped debris. The final step of Part 2 outputs the status of the simulated CHP unit.

A complete flow chart of DEPPS Part 1 and 2 is available in Appendix B. Graphical figures are used to illustrate data processing in throughout the description of the simulation design where necessary.

The problems presented with the development of DEPPS were complex and many of the parameters of the simulation could not be fully explored or explained because of the time constraints of the research. Therefore, assumptions about the interactions of the different datasets were made to complete development of DEPPS. These assumptions are detailed in the description of the process of the simulation development.

3.5.1 DEPPS: Part 1 of 2

The goal of DEPPS Part 1 was to produce a point feature class with debris supply attributes to be utilized as an input for Part 2. The following are problems that were solved to allow the simulation to output the goal.

The initial task for this analysis was to locate the area covered by forest and to subset this region for the debris analysis. An equivalent-value query was conducted on the 56-meter resolution NASS CDL dataset to subset the forest-value land-cover and exclude all other land-cover values. As a result, forest covers retained their values while all other covers were assigned a value of “0”. The CDL forest covers selected were “NLCD: Evergreen Forest”, “NLCD: Mixed Forest”, and “NLCD: Deciduous Forest” which are represented by the values 142, 143 and 141 respectively.

Although the study area contained other types of forest cover, the chosen cover types avoided anomalies arising from debris retrieval from wetlands and regions that did not contain a suitable road network. CDL cover types such as “Herbaceous Wetland

Forest" were excluded from the simulation to ensure preservation of ecological systems during debris retrieval. The deciduous forest cover shown in Figure 3.1 contained few cells because the wetland cover types were excluded. Figure 3.1 is a graphical representation of the forest subset operation of DEPPS Part 1.

The inputs for this portion of DEPPS are not available from the GUI for Part 1 because of their importance in the simulation. DEPPS simulates the debris from forest cover; since this section of Part 1 quantifies and subsets the forest cover layers, there was no need to allow the user to modify the inputs. The final output, "ForestCov," contains the forest cover subset of the NASS CDL dataset for utilization in DEPPS.

The second task for DEPPS Part 1 was to quantify hurricane wind speed over the study area. This was accomplished by using the HRD Real-Time Wind Speed analysis data from Hurricane Katrina. The original HRD Wind dataset extended beyond the study area and included 33,489 calculated points of wind-speed data. Processing this large number of points took over an hour of processing by the simulation. A better processing method was decided upon that was a more effective use of computer RAM and reduced the computing time of this process to a few minutes.

The HRD wind-processing portion of Part 1 was accomplished by first dissolving the study area county boundaries into one polygon boundary. A new boundary, using a 31 mile buffer, was created to eliminate biased results or truncated data during the interpolation of the HRD Wind points. The HRD Wind points were subset to points contained within the buffer of the dissolved boundary. This reduced the number of points included in the interpolation to 2,523 points.

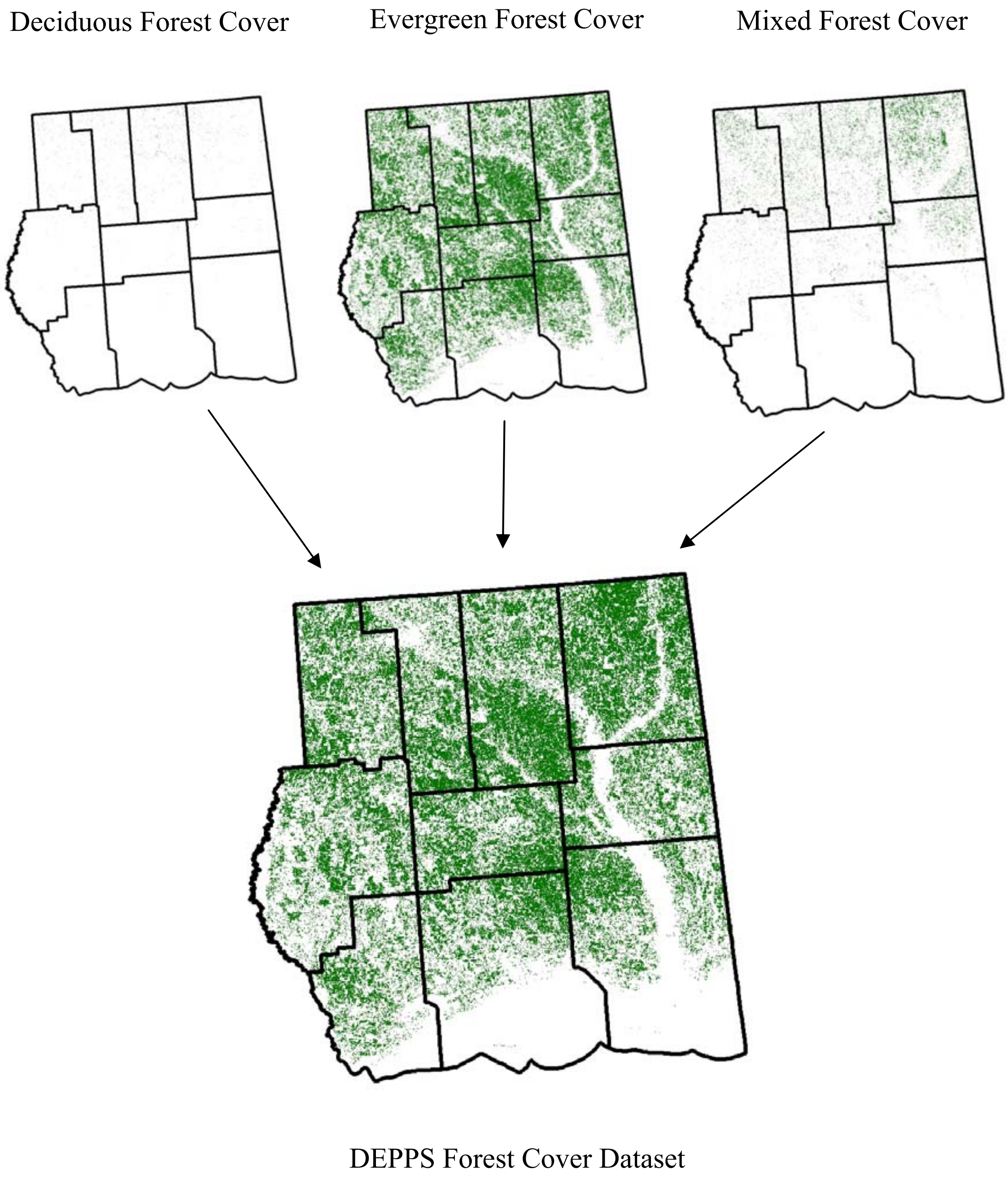


Figure 3.1

DEPPS Part 1: Forest Cover Extraction from NASS CDL Dataset

The HRD Wind point subset dataset was interpolated by using the Spline method. According to Scott A. Samson, private communication, 2010; Hartkamp, et al., 1999; and ESRI, 2007 the spline interpolation method is used in situations where there may be natural and gently varying surfaces such as rainfall and elevation. Therefore, the maximum sustained HRD Wind Speed data fit these parameters for use in a spline interpolation.

The z-value used in the interpolation was the “MAXSFC” value, which contains recorded one-minute maximum sustained hurricane winds in meters per second (m/s). The output cell size of 56 meters was selected for the interpolation to match the NASS CDL forest cover dataset.

The tension spline method was selected due to the variability of the regularized method. The regularized spline method allows a relaxed curve of values to be created that may produce unrealistic outliers over the interpolated surface. The tension method however, stiffens the predicted curve of values to match the actual data being interpolated (ESRI, 2007).

The interpolation weight value represents the amount of stiffness associated with the tension method. The interpolated surface becomes coarser as the weight value increases. The value of 0.1 was used because of the resolution of the interpolation output.

The last variable in the spline method was the Number of Points variable. This variable defines the number of points surrounding one point to be included in the interpolation. A value of 12 was used to ensure a smooth interpolation by relating each interpolated point to 12 surrounding points.

The result of this operation within DEPPS Part 1 was a 56-meter resolution raster of the HRD maximum wind speed from Hurricane Katrina. This raster provided the location of damaging wind speeds over the study area. Within this portion of DEPPS Part 1, the user can select another study area, storm event, and a different wind-speed unit based on the application of DEPPS. These parameters were designed to create new simulation iterations with different attributes in an easy and time- efficient manner.

The next step of Part 1 was the combination of the NASS CDL forest cover and the HRD Interpolated Wind data. This combination was crucial to DEPPS operation because of the need to understand the maximum sustained wind speed over the forest covered regions within the study area. A raster value combination method was used to combine the wind speed of the HRD subset and the forest values of the NASS CDL subset. The result of the raster value combination was a raster dataset that contained both wind and forest cover values. All other values that did not have wind or forest value were represented with a value of “0”. Figure 3.2 shows the graphical representation of this operation.

The next step of DEPPS Part 1 was to create a damage coefficient attribute in the newly combined raster. The damage coefficient field would provide the combined raster “damage” attribute to the forest cover regions based on the wind speed experienced from the storm event. The task presented with this section of Part 1 is the relationship between hurricane wind speed and forest damage.

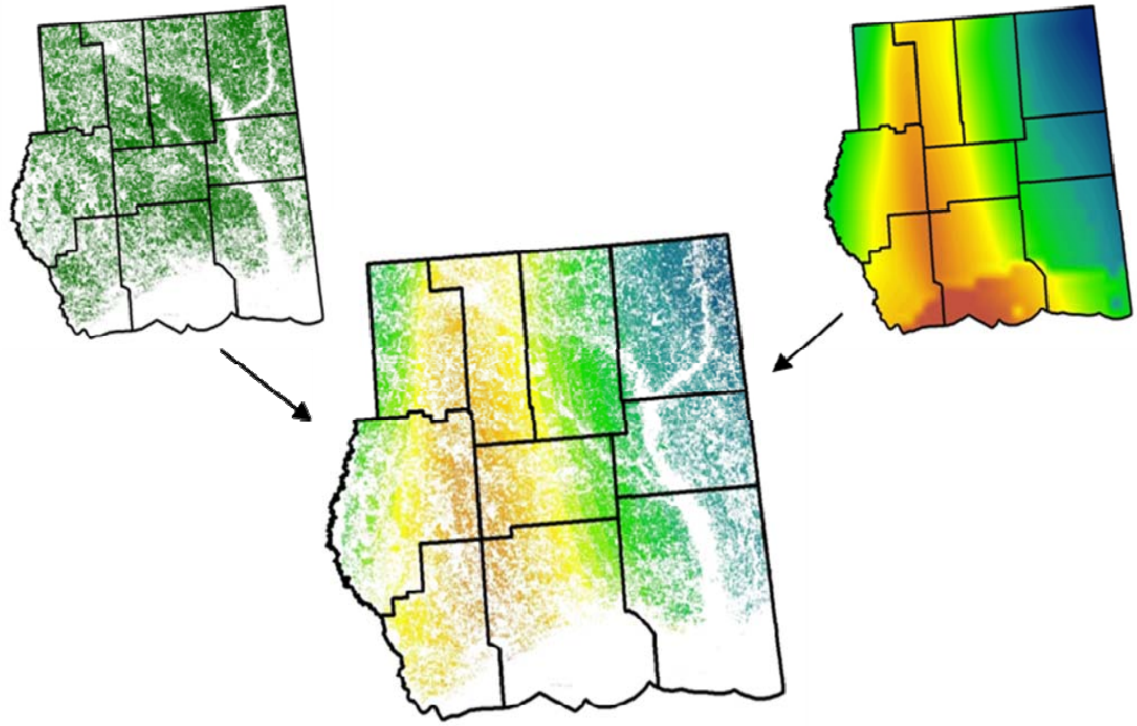


Figure 3.2

Forest Cover and Maximum Wind Speed Raster Combination

Historically, it has been proven that the relationship between wind speed and forest damage has several factors, many of which are difficult to measure. First, the actual hurricane wind speed is difficult to measure accurately. The HRD wind data are derived from many different observations that have been restricted to a common framework. This framework allows the observations to be interpreted as one observation (Powell et al., 1998). While this method allows for large areas to have a good representation of wind effects, smaller areas are less likely to be interpreted correctly as compared to the actual values from the ground. Other factors that can influence wind speed are land-use, land-cover, topography and elevation. It has also been noted that microbursts and tornados can damage a small-forested area without affecting the whole forest (David L. Evans, private communication, 2010).

The conclusion of the literature review suggests that assumptions be made about the variability of wind characteristics in a hurricane event. The use of the HRD Wind data assumes no land effects on wind speed and no damage effect due to microbursts and tornados. Forest damage by wind was assumed to be strictly related to the 1-minute maximum wind speed data from the HRD.

Myers and van Lear (1998) conducted a review of current technology to monitor hurricane and fire interactions within coastal forests in the southern United States. They used a table created by the National Climatic Data Center (NCDC) containing information about the effects of a hurricane on natural and man-made objects. The 1993 NCDC table described damage according to a range of wind speeds organized in the Saffir-Simpson scale ranging from Category 1 to 5. Wind speed was described in miles per hour (mph) and did not include wind speeds of less than 74 mph.

Cullen (2002) published a technical note in the Journal of Arboriculture using an updated version of the NCDC table. Cullen's table described the effects on trees from 0 to 318 mph in detail using the Fujita Tornado, Beaufort, and Saffir-Simpson wind scales. Cullen specifically described the effects of wind on trees at sub-category speeds.

Another factor in forest damage by wind is the density of the forest cover. Wind effects on forest stands have shown that the trees on the edge of forest stands are more susceptible to wind damage while the trees within the canopy are supported by one another. Thinning of forest stands can result in increased distance between trees and cause unsupported trees to break under high wind conditions (David L. Evans, private communication, 2010). The increased distance also causes the trees to sway in an abrasive manner, which breaks leaves, twigs and small branches (Stanturf et al., 2007).

With all of these factors that are conventionally difficult to quantify, assumptions were made to allow DEPPS to simulate wind effects on forest damage. The MIFI data obtained from the Department of Forestry at Mississippi State University were chosen as the best available data pertaining to the volume of timber products for the study area. The tables used by Myers and van Lear (1998) along with the information gathered by Cullen (2002) were used to simulate the effects of hurricane force winds over a forested area.

The interpretation of the NCDC tables was first quantified by breaking down wind speed according to the Saffir-Simpson scale. The difference between the effects of wind on branches and stem of a tree were noted by several sources during the research of this project (Stanturf et al., (2007); David L. Evans, private communication, (2010);

Boose and Foster, (1994)). Table 3.1 below was derived from the NCDC tables of observed damage by hurricane wind.

Table 3.1

Interpreted Wind Damage to Trees based on NCDC Table

Wind Speed (m/s)	**Category**	**Branch Affected**	**Stem Affected**	**Description**
0.00	NA	0%	0%	None
17.43	TS	25%	0%	Twigs Break
24.59	TS	50%	0%	Limbs Broken, Foliage Removed
33.08	1	50%	25%	Primary Damage to Foliage
42.92	2	75%	50%	Considerable Damage to Foliage, some Trees Blown Down
49.62	3	100%	75%	Foliage Torn, Large Trees Blown Down
58.56	4	100%	100%	Most Trees Blown Down
69.74	5	100%	100%	Most Trees Blown Down

The branch and stem damage interpretations were plotted and a linear trendline was selected to determine the slope of the fit line of the branch and stem damage. The linear trendline was based on interpreted information gained from the NCDC table. This trendline was chosen to facilitate the execution of DEPPS. It was noted by David L. Evans, personal communication, 2010 that the relationship between wind and trees would not have a linear trendline. Figure 3.3 shows the scatter plot of the wind speed effects on branch and stem damage.

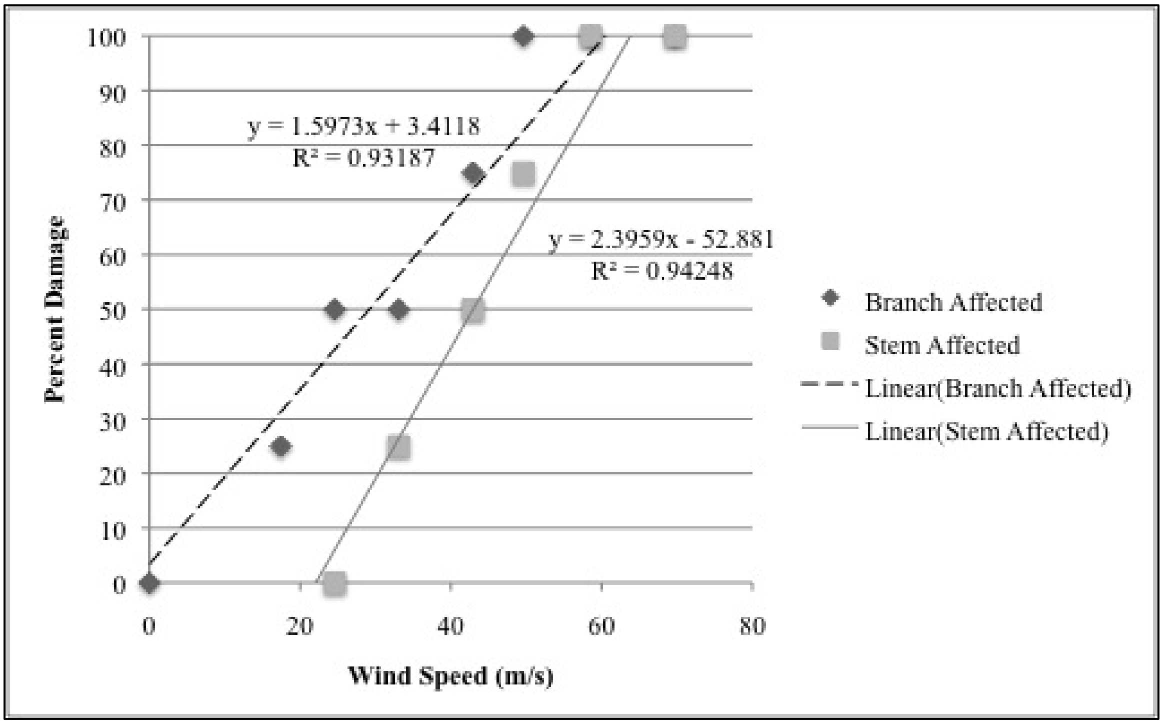


Figure 3.3

Wind Effects on Tree Branches and Stem

In order for DEPPS to predict the damage of a given hurricane event, the slope of both lines was used to help calculate the damage coefficient attribute field. Since the branches and stem were affected differently, two damage coefficients were created. “Damage_Coef_Branch” and “Damage_Coef_Stem” were created using the corresponding slope to give a percentage of damage based on the part of the tree. These values would give a damage coefficient for branch and stem volumes from the MIFI data.

Since there was a noticeable difference in the reviewed effects of wind on stem and branches, DEPPS created two separate wind analysis rasters. These rasters were based on the branch and stem damage coefficients.

The development of the wind damage prediction portion of DEPPS was designed to allow the user to modify the simulated intensity of wind effects on both Stem and Branch damage volumes. The damage coefficient was defined as:

$$BranchDamCoef = ((1.5973 \times WS_{m/s}) + 3.4118)$$
$$StemDamCoef = ((2.3959 \times WS_{m/s}) - 52.881)$$

where:

$WS_{m/s}$ = Wind speed in meters per second.

The next task of DEPPS was to quantify the volume of debris predicted from a hurricane event. The MIFI data contained many different formats of volumetric information of forest stands. The “cfobstem” and “cfobbranch” were the calculated volume in cubic feet outside the bark of both stems and branches for each plot. These attributes were used to quantify the volume of timber for the DEPPS debris supply calculator.

The MIFI plot was characterized as three concentric circles covering a total area of 0.20 acres (Parker et al., 2005). The concentric circles were used to locate timber based on a merchantable or submerchantable stem quality. The data contained within each plot is volume of timber within the plot area. Therefore, the simulation assumed that both merchantable and submerchantable timber is damaged at the same wind speed. This assumption allowed the simulation to use the timber volume regardless of salvage value. Because the spacing of merchantable timber is often maintained by thinning, the assumption is not true (Stanturf, 2007). Simulating differing wind effects, on managed and unmanaged timber stands, was beyond the project objectives.

The original format of the MIFI data was a table containing the geographic location and the volume analysis of the data. The simulation required the table to be converted to a point feature class containing all of the volume analysis data for utilization in DEPPS. Points outside of the study area were removed and the remaining points were processed to create an estimated volume over the study area.

DEPPS Part 1 took the MIFI point input data and first created two new fields: "Stem_Vol_m3_m2" and "Branch_Vol_m3_m2". These fields were calculated based on the stem and branch volume for each plot. The original volume was represented as cubic feet. The volume was then converted to cubic meters to match the units of the study. The MIFI branch and stem volume was calculated from the trees within the plot area. According to the MIFI report (Parker et al., 2005), the area for each plot remained a constant 0.2 acres. The volume within the plot area was converted to cubic meter per square meter. The final conversion of the volume data converted the area to 3,136 square meters. This conversion allowed DEPPS to prepare the data to calculate volume per pixel area. The formula below represents the conversion for the branch volume.

$$VolArea = ((([BranVol]/0.2) \times (0.0283/4046.8564) \times 3136$$

where:

[BranVol] = Branch volume in cubic feet per plot

The "VolArea" final output is the volume per 56-meter pixel of the interpolated MIFI data. The Stem volume was calculated with the same parameters and tools. A detailed flow chart of this process can be found in Appendix B.

The new fields “Stem_Vol_m3_m2” and “Branch_Vol_m3_m2” were then used as the “z-values” for an interpolation of the forest volumes. Three interpolation methods were tested to determine the best method for DEPPS: Inverse Distance Weighting (IDW), Natural Neighbor and Spline. The spline method failed to create an interpolated surface due to variability in the MIFI plot data. The IDW and Natural Neighbor methods executed successfully.

A cross-validation method was used to determine the best interpolation method between IDW and Natural Neighbor. The entire MIFI dataset for the study area was interpolated by IDW and Natural Neighbor methods. Fifteen percent of the forest volume points were randomly removed from the MIFI dataset. The remaining 85 percent were interpolated using the same parameters as the first interpolations. Sample points were created to gather values from the interpolations. These sample points were used to calculate the RMSE of the two interpolation methods.

The IDW method of interpolation produced an RMSE of 10.96 percent, while the Natural Neighbor method produced a RMSE of 14.95 percent. The lower RMSE confirmed the use of the IDW interpolation on the MIFI dataset. The IDW interpolation created a 56-meter resolution raster over the study area to show volume per pixel. The IDW was processed with 12 points as the variable search radius and a power of two.

The MIFI IDW process interpolated the volume data over land-covers that did not contain forests. This process could skew the interpolation results over the forested areas by over-or under-estimating the existing timber volume. Because of the use of the IDW interpolation method, the interpolated values could not be confined to the forested areas.

The following task of DEPPS combined the Stem and Branch damage coefficient with the IDW of Stem and Branch volume. The combination of these two datasets was accomplished by using a raster value combination method. The combination prepared DEPPS to create a new field to represent the predicted volume damaged due to hurricane force winds. Figure 3.10 shows the flow chart of the combination of the two raster datasets.

At this point, DEPPS added a new field called “Stem_Dama_By_Vol” and “Branch_Dama_By_Vol” to each of the respective combined Stem and Branch Damage by Volume datasets. The new field contains the mathematical combination of the fields containing predicted percent damage by wind speed multiplied by the estimated volume of stem or branch within the forest land-cover. The new field values gave a predicted volume of debris available at each 56 square meter pixel for utilization in the combined heat and power (CHP) unit. The Stem dataset was processed in the same fashion.

The transportation simulation of DEPPS Part 2 requires the input debris “supply” to be represented as a point feature class. The simulation views each point as a supply that has a certain value demanded by another process. The supply value is volume of debris available for fuel usage. Therefore, the raster containing branch debris by volume was converted to a point feature class. The point feature class would contain the debris volume at the center of the 56 square meter footprint of the raster.

The DEPPS process thus far has created a point feature class for available Stem and Branch debris by volume for utilization in the CHP unit. However, this feature class covers the entire study area, and retrieval and transportation of each supply point to the CHP unit location would be impossible. The Stem and Branch datasets contain over five million points each within the study area. The real transportation of these supply points or sites would be very difficult in many locations because of the unavailability of roads to transport material. Therefore, the points were subset into a point dataset that was at a defined as a 200 foot "retrieval distance" from the centerline of the road network.

A buffer of the road network was created by DEPPS according to the retrieval distance given by the user. The buffer method created an offset from the road network for each road segment. These segments were then dissolved to create one polygon feature class covering the entire road network of the study area. The dissolved polygon of the road buffers allowed DEPPS to subset the debris points within the retrieval distance more efficiently.

The output of this process in DEPPS is debris supply retrieval distance for the simulated debris retrieval crews. It is assumed that crews will retrieve debris only from the specified offset of the road network. This ensures the integrity of the simulation of transportation and retrieval of the available debris supply.

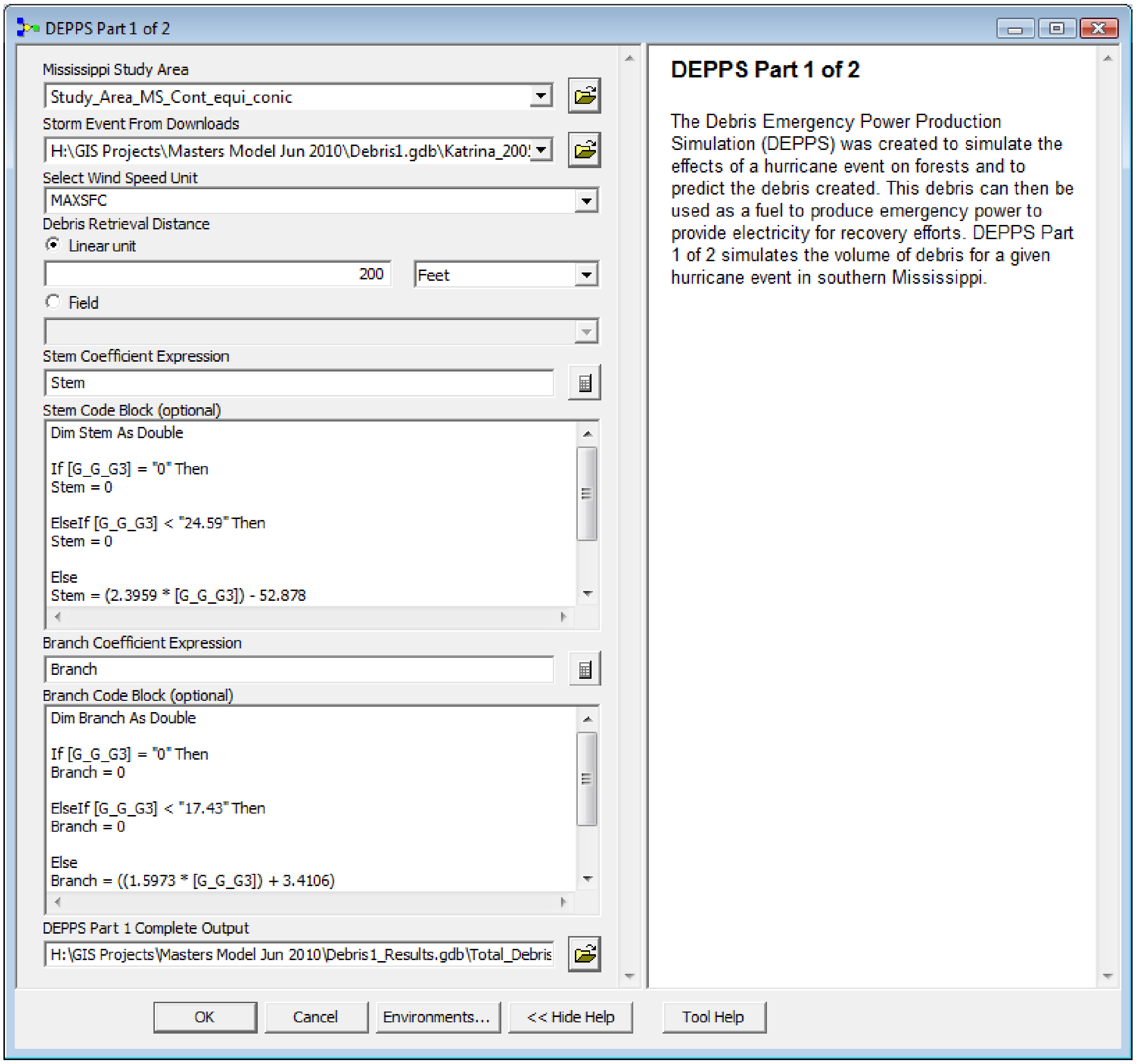
The next process involved the subset of the overall point feature class by extraction within the buffer to create the retrieval point feature class. The points retained their debris volume attributes for the CHP utilization. The default retrieval distance for DEPPS was 200 feet. The English foot unit was used in this instance because of the probable familiarity of the foot unit by the future user. DEPPS converts this distance to meters to ensure integrity of the units within the simulation. The same process was executed on the Stem debris volume point feature class.

The subset point feature classes for both Stem and Branch were examined to find whether some of the data points contained a volume of "0". The points which had a value of “0” were found to be outside of the forest classification executed at the beginning of DEPPS Part 1. Therefore, a query of the points was conducted to remove the points containing no forest debris. Figure 3.15 shows the process flow chart of the removal of all points that had a value of “0” or less for Stem and Branch debris.

The next step in DEPPS Part 1 combined the attributes of both Stem and Branch Debris Supply into one point feature class. This feature class would be the “supply” used in the transportation simulation of DEPPS Part 2. A spatial intersect was conducted to combine the attributes of both point feature classes into one feature class based on the spatial attributes of each point. Figure 3.16 gives the graphical representation of the total supply point feature class.

A new field was added to the Total Debris Supply point feature class to add the two debris supply attributes together. This new supply field would contain the total volume of debris damaged by the storm. The field was calculated by adding the Stem and Branch debris supplies. This process flow chart is shown in Figure 3.17.

The file location of the DEPPS Part 1 Complete Output was designed as a user parameter to allow the user to change the name or location of the file for each run of the simulation. Figure 3.18 is the DEPPS Part 1 GUI. The GUI is complete with documentation relating to the input of parameters by the user. Each parameter has a detailed description of the type of data needed to run the simulation. DEPPS Part 1 of 2 was placed in an ArcToolbox for easy sharing and activation of the simulation. The DEPPS toolbox was placed in the original data geodatabase to maintain data organization for the simulation. The results geodatabase was the location of all results data created after the successful execution of DEPPS. The detail to data management allows DEPPS to be placed on a flash drive or compact disc for easy sharing of the program.



Mississippi Study Area: Study_Area_MS_Cont_equi_conic

Storm Event From Downloads: H:\GIS Projects\Masters Model Jun 2010\Debris1.gdb\Katrina_200

Select Wind Speed Unit: MAXSFC

Debris Retrieval Distance

● Linear unit

200 Feet

○ Field

Stem Coefficient Expression: Stem

Stem Code Block (optional)

```
Dim Stem As Double

If [G_G_G3] = "0" Then
Stem = 0

ElseIf [G_G_G3] < "24.59" Then
Stem = 0

Else
Stem = (2.3959 * [G_G_G3]) - 52.878
```

Branch Coefficient Expression: Branch

Branch Code Block (optional)

```
Dim Branch As Double

If [G_G_G3] = "0" Then
Branch = 0

ElseIf [G_G_G3] < "17.43" Then
Branch = 0

Else
Branch = ((1.5973 * [G_G_G3]) + 3.4106)
```

DEPPS Part 1 Complete Output: H:\GIS Projects\Masters Model Jun 2010\Debris1_Results.gdb\Total_Debris

DEPPS Part 1 of 2

The Debris Emergency Power Production Simulation (DEPPS) was created to simulate the effects of a hurricane event on forests and to predict the debris created. This debris can then be used as a fuel to produce emergency power to provide electricity for recovery efforts. DEPPS Part 1 of 2 simulates the volume of debris for a given hurricane event in southern Mississippi.

Figure 3.4

Illustration of graphical interface developed in Python imported to ArcGIS Toolbox

3.5.2 DEPPS: Part 2 of 2

DEPPS Part 2 of 2 was designed to simulate retrieval, processing and transportation of hurricane debris for utilization as fuel for a CHP unit. The process of Part 2 requires an input supply (debris volume) and a demand (Optimal CHP fuel feed rate) along with a road network to design an efficient method of fulfilling the demand with the available supply and within existing time constraints. These parameters were simulated using a network analysis GIS model. In order to produce a realistic simulation, debris retrieval and transportation were limited to operation from 7:00 AM to 7:00 PM each day.

DEPPS Part 2 used the point feature class created by the execution of Part 1 as the available supply of usable debris. The point feature class contained the simulated volume of woody debris from the hurricane event in cubic meters. The simulated debris was defined as woody or "green" debris from damaged tree matter. It has been stated that because of the inherent complexity of forests a model capable of creating an efficient transportation of debris or forest residue is extremely difficult (Möller and Nielsen, 2007).

An effective staging of the debris would be vital to defining the location of the debris retrieval. The process of debris staging would involve a crew using timber salvage and harvesting equipment to precede the debris chipping crew. The salvage crew would stage the woody debris by stacking it into large piles. The stacked debris would allow the debris chipping crews to chip debris from these piles to save time and fuel. The assumed time to retrieve and stage the residues from observations was set at 240 seconds per cubic meter. This time was a service time at each supply location based on the volume of debris available.

After the debris is staged, the retrieval crew would move to the stages to begin processing the debris. A Model 2400 Bandit chipper/harvester was used in the simulation to process the debris. The processing time was based on the operating input flow rate specification of the chipper. The maximum constant feed to the chipper was listed as 120 feet of timber per minute with a maximum tree diameter of 24 inches.

Since DEPPS Part 1 calculated a debris volume, the feed rate of the chipper must be based on volume not linear distance. DEPPS assumed that the diameter of each tree would not exceed 24 inches and each stem would not exceed 50 feet. This assumption set the chipping time of two calculated trees to one minute or 100 feet of stem per minute. The chipping flow rate was assumed to be nearly eight cubic meters per minute.

Chipping time was determined to be 12 seconds per cubic meter for simulation purposes. This was also included in the service time for each supply location dependent on the available debris volume. The service time for each supply location assumed a machine pre-and-post-chipping time to account for moving and setting up the chipper/harvester.

The retrieval and delivery of the chipped debris was based on a supply and demand process. The CHP unit modeled for DEPPS is a wood-fueled unit being tested in Denmark. The unit requires 96 kilograms of chips per hour to produce a 31 kWh electricity output (Biedermann et al, 2004).

The capacity of each chip truck was determined using the maximum tractor-trailer payload for the State of Mississippi. According to the Federal Highway Administration, the total weight of the tractor-trailer must not exceed 80,000 pounds (U.S.C., 2007). The truck and trailer weight was assumed to equal 28,500 pounds. The remaining weight was converted to cubic meters using the density of whole tree pine chips. The maximum volumetric capacity of the tractor-trailer was calculated to be 129.06 cubic meters. The volumetric capacity was simulated at 80 percent of the maximum. The final volumetric capacity of the chip truck was set as 103 cubic meters for the simulation.

Transportation of the chipped debris was simulated using the 2009 TIGER road network of the study area. The U. S. Census Bureau labeled each road with a feature classification code based on the type of road. The roads were divided into three classifications: Primary, Secondary, and Local, Rural or City Roads. A speed limit attribute was calculated based on the road type. Table 3.2 shows the attribute breakdown for the road network analysis.

Table 3.2

Road Network Travel Time Analysis

MTFCC Code	**Description**	**Speed Value (mph)**	**Speed Value (m/s)**
S1100	Primary Roads	55	0.04
S1200	Secondary Roads	45	0.05
S1400	Rural or City Streets	35	0.06

The speed value was combined with the length of each road segment to create a travel time attribute for the road network. The travel time attribute was used to determine the amount of time required for a chip retrieval truck to transport the chipped debris to the CHP fuel depot location. Once the retrieval truck reached the CHP fuel depot, a service time of 1800 seconds was included to account for unloading of chips. A fuel delivery truck then travels from the fuel depot to each CHP location; unloading chipped fuel until the delivery truck supply is depleted. Figure 3.5 graphically demonstrates the role of the retrieval trucks.

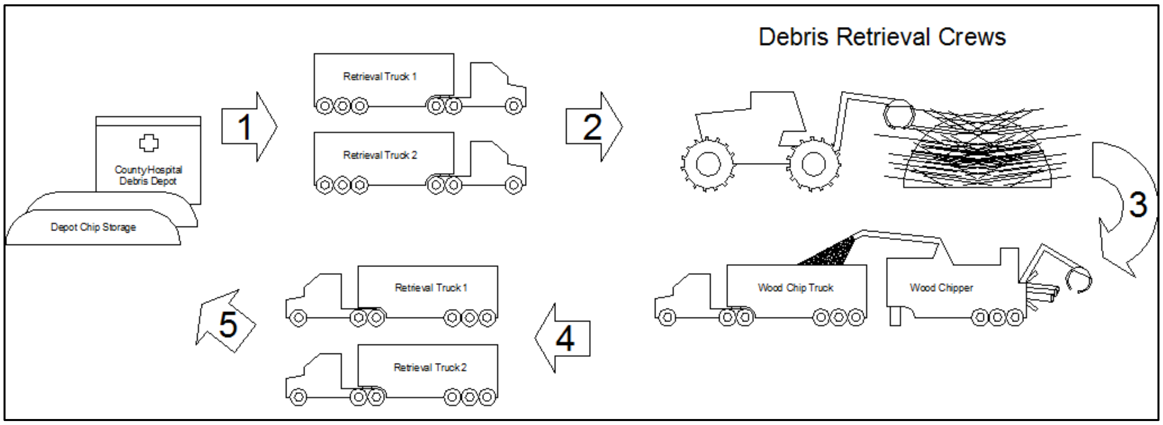


Figure 3.5

DEPPS Retrieval Truck Routing

DEPPS created different locations throughout the study area at which certain events began and ended. Depots were wood chip storage locations from which debris retrieval trucks would leave at 7:00 AM and return at 7:00 PM. Depots had a service time of 3,600 seconds for morning and evening maintenance. Orders were designated as high schools and hospitals in the study area, which were suitable for a CHP unit location. These locations were selected because of their potential for becoming shelters post-hurricane. The Orders locations also contained the debris supply points from DEPPS Part

1. The time attributes for separate location events in the network analysis model are defined in Table 3.3.

Table 3.3

Network Location Events and Service Times

Location	**Event Description**	**Time (Min)**	**Time (s)**
Depot	Morning Preparation	30	1800
Debris Supply Points	Retrieval	4 / m3	240 /m3
	Chipper Startup	15	900
	Chipping Time		12 / m3
	Loading Time		12 / m3
	Chipper Finishup	15	900
Road Network	Transportation Time	Based on Speed Limit	
CHP Locations	Unloading Time / Preparation	30	1800
Depots	Evening Preparation	30	1800

The total service times were calculated from values in Table 3.3. These service times were used to produce a real-world simulation of debris retrieval. The formulae for each service time are given in Table 3.4.

Table 3.4

Total Service Times for Network Location Events

Depot Service
Serv = 1800 + 1800
Supply Point service
Serv=(240 + 24)*[m3] +1800
Demand Service
Serv = 1800

Since the data from MIFI were based on a volume estimate, the CHP unit fuel requirement was converted to cubic meters. The majority of wood chips collected by

DEPPS were whole-tree pine chips. Therefore, the density of whole-tree pine chips obtained from the Forest Products Laboratory of 181 kilograms per cubic meter was used for the conversion (Ragland et al., 1991). The fuel requirements for each CHP unit over a 24-hour period totaled 12.73 cubic meters of debris. This number was rounded to 13 cubic meters to simplify simulation requirements.

The CHP demand was set as an attribute of each CHP unit location. The simulation placed CHP units at major-county medical facilities and high school gymnasiums. These locations were gathered from the Geographic Name Information System (GNIS), which contains a database of public places across the United States. The location selection ensured that the emergency power produced from the CHP unit would be used to facilitate the recovery of the community. The retrieval trucks would leave the hospital depot locations each day to retrieve debris. After 12 hours of service, the trucks would return to the depot location and unload the retrieved debris.

The output from DEPPS Part 1 produced 207,147 supply points containing assumed available debris from the hurricane event. However, the network model would successively execute only with fewer than 2,000 supply points. Therefore, six hospital locations were selected for the network simulation. Two locations were selected in the coastal counties, two in the central counties, and two in the northern counties of the study area. The six locations are represented graphically in Figure 3.20.

A buffer was created for each hospital location to subset available debris supply within 5,000 meters of the CHP unit. The supply points inside each buffer numbered less than 2,000, which allowed the network simulation to execute successfully. A CHP fuel depot was added to the simulation to store the retrieved debris to be utilized in the CHP unit.

The depots were placed near each hospital location to act as chipped debris storage at each hospital location. The Agricultural and Biological Engineering department at Mississippi State University is currently conducting research on portable grain storage units for their effectiveness in storing wood chips. The chip storage units do not require any existing structures to operate, which makes them ideal for this application. The grain storage unit requires an open, flat area to place, fill and unload the storage units. For simulation purposes, the location of the hospital parking lot was the site for that hospital's fuel depot.

Each CHP fuel depot was allocated three chip trucks. The trucks were set to operate from 7:00 AM to 7:00 PM. Two of the trucks were designated to only retrieve debris. The third truck was designated to deliver the fuel from each depot to each CHP unit location. The debris retrieved in the 12-hour period would be the determining factor on the effectiveness of using CHP units to power shelter/recovery facilities.

Due to the complexity of DEPPS Part 2, a GUI was not developed. The successful operation of the simulation rests in the understanding of the process by the user, the availability of valid data and the limits of the GIS software. The simulation can only be executed on one hospital location per iteration because of the limits of the GIS software used in this research project.

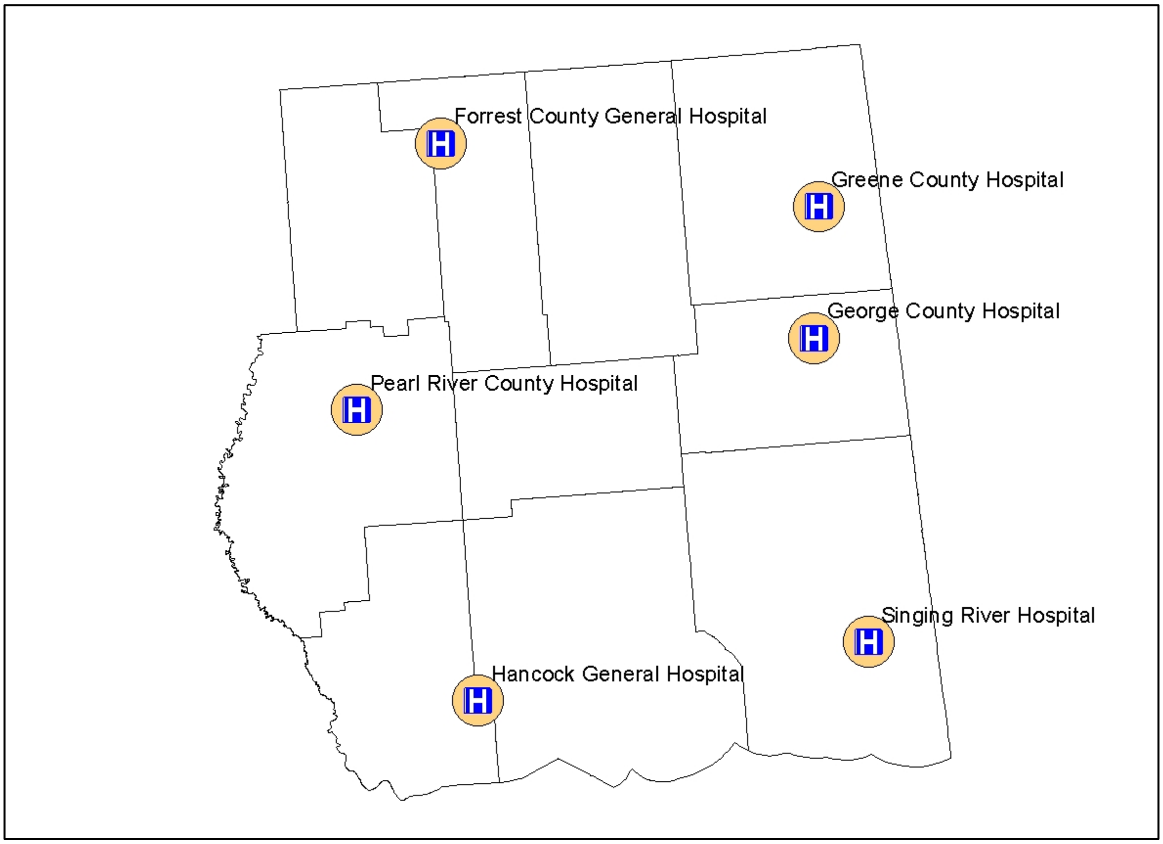


Figure 3.6

DEPPS Wood Chip Fuel Depot Locations in the Study Area

3.6 Summary of DEPPS Assumptions

DEPPS was designed to be a simulation that could be improved upon in the future. Many assumptions were made for data that did not exist or was difficult to retrieve. The list below defines the assumptions made in the development of DEPPS that could be studied further.

- Maximum hurricane wind speed is the only directly related force to forest destruction.
- Terrain has no affect on maximum hurricane wind speed.
- Areas defined as forest by the NASS CDL contain trees in the entire pixel area.
- The MIFI data volume interpolation represents actual forest volumes.
- All road networks for the simulation are in usable condition post-hurricane.
- Wind speed damage to trees is a linear relationship.
- Debris will be staged and retrieved from the center of each damaged pixel.
- Retrieval crews can legally remove debris from a 200 foot offset of the road centerline.
- Retrieval crews will only retrieve debris during the defined hours of operation each day.
- Chipped debris will output the same energy during combustion regardless of moisture content.
- Defined service times will allow sufficient time for all events.
- Acceleration and deceleration of simulated trucks does not occur.
- Structures will remain for CHP units to power.

With advancements in the many fields that DEPPS uses to operate, these assumptions can be defined to more accurately describe the process of using disaster debris as fuel in a CHP unit.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DEPPS Part 1 of 2 Results

The DEPPS Part 1 simulation produced a point feature class that contained volumetric debris supply from a hurricane event within the study area. This feature class was confined to a buffer of the road network for ease of staging the debris for retrieval and chipping. Figure 4.1 illustrates the supply points in and around Wiggins, Mississippi.

The first iteration of the model was conducted using the defined variables in Section 3.6 of this manuscript. The simulation was calculated to be a conservative estimate of both the available debris and ground conditions post-hurricane. As more information is gathered about the interaction between wind and trees, these values could be modified to produce a more realistic result in further studies.

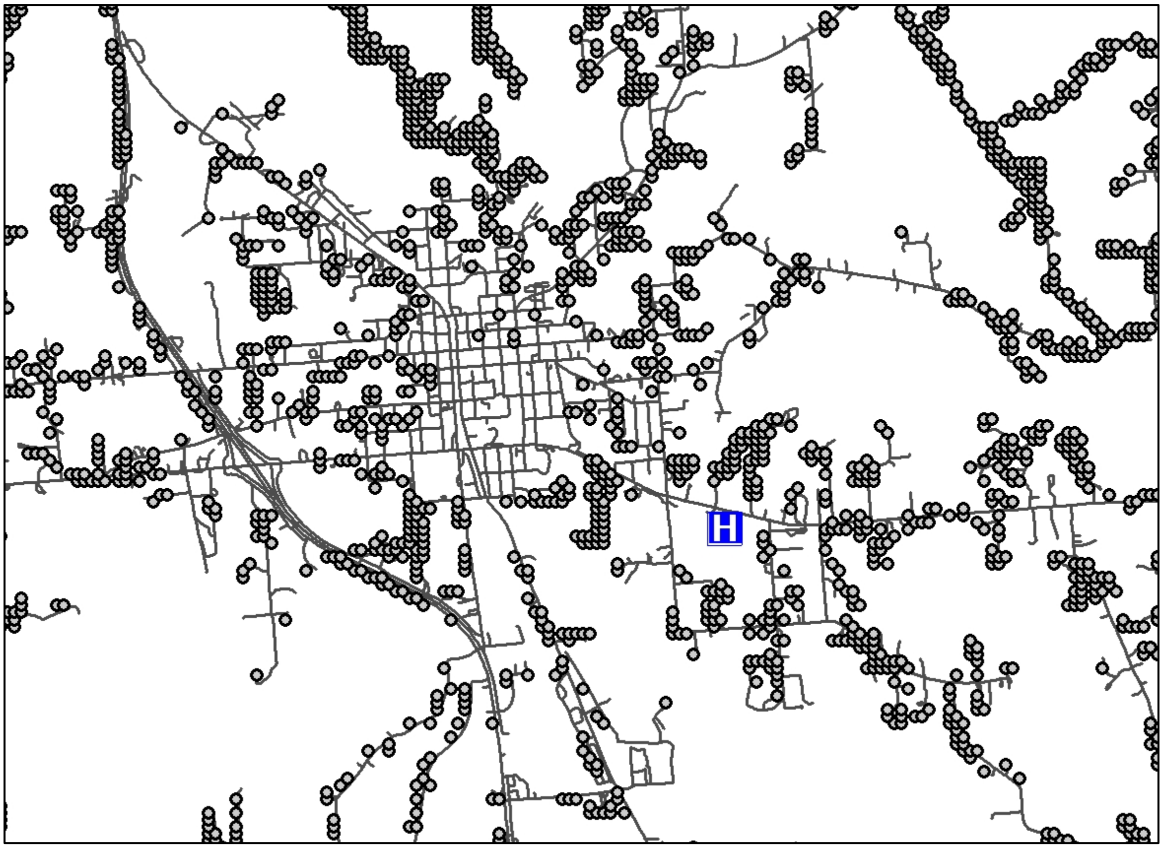


Figure 4.1

Assumed Debris Supply Points in and around Wiggins, Mississippi

4.1.1 Damage Prediction Results

Using damage values from the MIFI dataset, the effectiveness of the damage prediction of DEPPS Part 1 was tested. The damage coefficient was calculated from NCDC hurricane damage tables and available wind speed data from Hurricane Katrina. Figure 4.2 shows the forest damage regions over the study area. The orange area represents severe forest damage (Stem Damage > 43%, Branch Damage > 68%) and the yellow represents moderate foliage damage (Stem Damage: 42% to 20%, Branch Damage: 67% to 52%).

The points represented in Figure 4.2 are MIFI plots that had observable wind damage after Hurricane Katrina. Fifty-eight percent of the MIFI points with wind damage were within the severe forest damage area. The majority of MIFI points with wind damage confirms observable damage to plots and therefore confirms the presence of forest damaging winds within the study area.

4.1.2 Volume Estimation Results

The debris volume was calculated from an interpolation of the MIFI dataset. The interpolation produced a forest volume over non-forested areas, which could cause an over or underestimation of forest volume. The method of interpolation was selected based on the best root mean square error (RMSE) between IDW and Natural Neighbor interpolations of the MIFI volume.

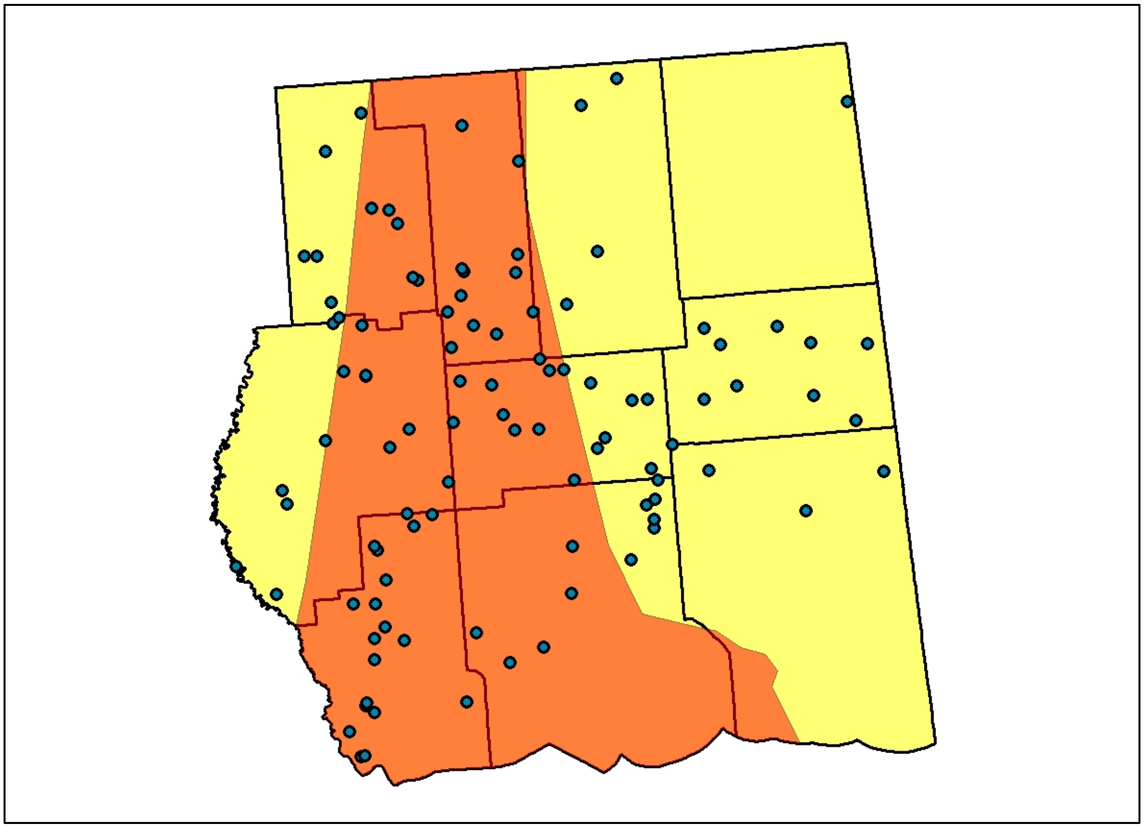


Figure 4.2

DEPPS Predicted vs. MIFI Observed Forest Damage Post-Katrina

A process of cross-validation was used to test the effectiveness of the interpolation methods. The entire MIFI dataset for the study area was interpolated by IDW and Natural Neighbor methods. Fifteen percent of the forest volume points were randomly removed from the MIFI dataset. The remaining 85 percent were interpolated using the same parameters as the first interpolations. Sample points were created to gather values from the interpolations. These sample points were used to calculate the RMSE of the two interpolation methods.

The IDW method of interpolation produced an RMSE of 10.96 percent, while the Natural Neighbor method produced a RMSE of 14.95 percent. The lower RMSE confirmed the use of the IDW interpolation on the MIFI dataset.

4.1.3 Debris Supply Point Results

DEPPS Part 1 positioned the gray supply points, seen in Figure 4.1, for retrieval by the network analysis of DEPPS Part 2. The simulation created 207,147 supply points over the study area. The mean volume for the supply points was 13.08 cubic meters over the 3,136 square meter areas for each pixel.

4.2 DEPPS Part 2 of 2 Results

DEPPS Part 2 simulated the retrieval, transportation and utilization of the debris supply points from DEPPS Part 1. A spatial network model within ArcGIS 9.3.1 software was used to execute the simulation. The results for each CHP fuel depot in DEPPS Part 2 are shown in Table 4.1. These results are based on a 12-hour retrieval period.

Table 4.1

DEPPS Part 2 Debris Retrieval Results from Hurricane Katrina Simulation

Depot Location (Hospitals)	**# of CHP Units**	**CHP Demand**	**Retrieval (m3/12hr)**
Forrest County	6	78	169.12045
Greene County	3	39	2.57327
George County	2	26	130.45646
Hancock General	5	65	270.67128
Pearl River County	4	52	109.86533
Singing River	7	91	146.38436

The DEPPS Part 2 network simulation was able to fulfill the fuel demand at five of the six CHP depots. The Greene County Hospital simulation required 39 cubic meters of debris to operate three CHP units in the 5,000 meter buffer area. Retrieval from the available debris was only 2.57 cubic meters. This result suggests that CHP recovery units would not be feasible at this location. The low debris retrieval at the Greene County Hospital location is directly related to 30 meter per second maximum wind speed at the location. The wind speed would only damage tree branches resulting in lower debris volume.

The simulation chose to remove debris from major highways first throughout all six locations. It was inferred that since the speed limit allowed a shorter travel time, the simulation selected these road segments first. This outcome allowed major highways to be cleared first, and then recovery crews could move into an area with greater ease and speed.

Truck routes designated for delivery also retrieved debris along the route to the CHP locations. Since the amount of debris being transported never exceeded the demand (i.e. Demand < 103 cubic meters), this operation by the simulation was allowed. The amount of debris, in cubic meters, retrieved by each truck at each location is shown in Table 4.2.

Table 4.2

Cubic Meters of Debris Retrieved by Truck and Depot

	Truck 1	**Truck 2**	**Delivery Truck**	**Debris Retrieved**
Forrest	63.35	60.29	45.48	169.12
George	32.59	62.58	35.29	130.46
Greene	0.91	0.81	0.84	2.56
Hancock	90.59	90.90	89.18	270.67
Pearl River	41.90	36.46	31.51	109.87
Singing River	61.94	66.86	17.59	146.39

Regional differences in the amount of available debris were visible from the simulated debris retrieval. The depots located along the coast received more wind damage than locations further north. The regional difference is the inferred explanation for the lack of available debris at the Green County Hospital depot. This depot is located in the most northeastern county of the study area. Hurricane Katrina moved over the southern and eastern portions of the study area with more intensity and thereby more damage.

Table 4.3 shows the average volume and number of supply points per 5,000 meter buffer location. The regions are described in Table 4.3 to demonstrate the spatial differences in damage.

4.3 Summary of Results

The execution of both DEPPS Part 1 and Part 2 produced conservative estimates of the damaged green debris from a Katrina sized hurricane in the future. The volume data obtained from MIFI was collected post-Katrina. Therefore, DEPPS could not be compared or statistically proven by comparison to Katrina damage estimates.

Table 4.3

Regional Supply Point Attributes

Depot Location	# of Supply Points	Average Volume (m3)	Region
Hancock General Hospital	314	36.72	Coastal
Singing River Hospital	159	24.18	
Pearl River County Hospital	1029	9.36	Central
George County Hospital	1493	18.20	
Forrest County Hospital	862	18.78	Northern
Greene County Hospital	1129	6.51	

The damage assessment of DEPPS was based on a linear correlation of wind speed and tree damage. While these parameters allowed the simulation to execute without major problems, it has been cited from sources (Boose and Foster, 2004, D. L. Evans, personal communication, August 4, 2010) that the relationship between wind speed and tree damage are far from linear. It is understood that the outcomes of DEPPS are those of a simulation and the assumptions made in the development of DEPPS should be further studied and modified over the use of the simulation.

CHAPTER 5

CONCLUSIONS

The Debris Emergency Power Production Simulation Part 1 of 2 predicted the volume of green debris created from a given hurricane event. The simulation used data from Hurricane Katrina to predict the amount of debris. The relationship between the maximum wind speed of Katrina and forest cover of the study area was studied and simulated with DEPPS Part 1. While DEPPS Part 1 contains several assumptions about the interaction between hurricanes and tree damage, the results from the simulation offer evidence that DEPPS is a foundational simulation in the relationship between wind speed and forest damage.

DEPPS Part 2 of 2 produced a time efficient routing simulation to retrieve, transport and utilize disaster debris from the roadways as fuel in a CHP unit. The parameters for DEPPS Part 2 were designed to follow real-world scenarios in the event of a hurricane disaster situation. Speed limits, operation time windows, transportation capacities and CHP unit demand are all properties of DEPPS Part 2 that were based on real-world expectations of a debris recovery crew.

As a counterpart to DEPPS Part 1, DEPPS Part 2 fulfilled the designated goal of the research project. The supply of debris predicted by Part 1 was retrieved, transported and utilized by Part 2 to satisfy the demand from the CHP unit. The retrieved supply was sufficient for five of six CHP fuel depots, which implies the effectiveness of using debris-fueled CHP units as a means of emergency power for recovery efforts. The Greene County Hospital depot's unsuccessful CHP fuel quantity also showed the ability for DEPPS to predict the effective locations for CHP units in the event of a hurricane disaster.

Overall, DEPPS completed all of the goals for which it was created. The simulation could be developed for more efficient operation and results in future work. However, DEPPS was developed originally as a foundational simulation. It is the intention of the researcher for DEPPS and the simulation's parameters to be studied further to provide better information about the use of debris as a source of emergency power in future hurricane disasters.

CHAPTER 6

FUTURE WORK

The development of DEPPS required some assumptions to be made about critical components to the simulation's execution. These assumptions were made with the best available information regarding the multiple fields of study covered by the simulation. It is the opinion of the researcher that scholars of these individual fields may have made different conclusions to the assumptions made by this research project. However, without future work to refine the properties of DEPPS, these assumptions could not be used to better define the relationships between the fields studied. It is the duty of future research to refine the elements that are used to execute DEPPS.

Portions of DEPPS that the researcher believes to be important research projects to the future development and refinement of the simulation are:

1. The relationship between wind speed and forest damage was based on information from an NCDC table used by some sources (Cullen, 2002 and James et al, 2006) and the studied impacts from Hurricane Katrina (Oswalt and Oswalt, 2008). This information was formatted to produce a linear correlation of wind speed effects on the stem and branches of trees. Research into the interaction between wind and trees would improve this portion of

DEPPS by providing a more defined relationship of these parameters for the simulation.

2. The MIFI forest volume data used in the simulation (E. B. Schultz, personal communication, November 21, 2010) were collected in the study area from late 2005 throughout 2006 after Hurricane Katrina. Because the focus of the MIFI project is to provide a statewide forest inventory, the state of Mississippi has been divided into five districts. Therefore, the MIFI plot data used in DEPPS has not been reassessed and is at least four years old. For the execution of DEPPS, the MIFI data was used as the best available estimate of forest inventory for the study area. A more detailed forest inventory for the study area could significantly increase the accuracy of the debris volumes predicted.
3. Research into the energy content of multiple species within the study area could be used to give an overall fuel quantity available for use from the disaster event. The moisture content and degradation of the debris, along with multiple wood chemistry factors, could change the energy output of the debris fuel in the CHP unit.
4. The CHP unit modeled in the simulation was part of a pilot project in Denmark (Biedermann et al, 2004). The results from the research suggested a highly efficient CHP unit capable of producing enough power to facilitate disaster recovery. However, a CHP unit would need to be developed specifically to meet the needs of a disaster situation. Development of such a unit would contribute to refining the CHP unit properties of DEPPS.

5. The rise in fossil fuel costs would determine whether to implement DEPPS along with a wood-fueled CHP unit for emergency power or to utilize conventional diesel or gasoline generators. A fuel economics study could be conducted to determine the feasibility of using the CHP unit over conventional generators. Information pertaining to each aspect of both power production methods could be used as an input to DEPPS to determine the overall cost of the operations. The most cost efficient method could be determined based on the scale and scope of the disaster event (i.e. a Category 1 hurricane may not be able to sustain a CHP unit, while a Category 3 could sustain five CHP units.).

Future research of these and other parameters in DEPPS will assure refinement in the operation of the simulation and the integrity of the results. It is the desire of the researcher for these topics to be studied and researched to develop DEPPS into a more realistic simulation of the use of disaster debris to fuel the recovery of a devastated region.

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APPENDIX A

DEPPS PART 1 OF 2 PYTHON SCRIPTING CODE

```
# ---------------------------------------------------------------------------
# DEPPS Part 1.py
# Created on: Tue Jan 11 2011 02:34:25 PM
#   (generated by ArcGIS/ModelBuilder)
# Usage: DEPPS Part 1 <Mississippi_Study_Area> <Storm_Event_From_Downloads>
<Select_Wind_Speed_Unit> <Debris_Retrieval_Distance> <Final_DEPPS_Part_1_Output>
# Description:
# The Debris Emergency Power Production Simulation (DEPPS) was created to simulate the effects of a
hurricane event on forests and to predict the debris created.
# This debris can then be used as a fuel to produce emergency power to provide electricity for recovery
efforts. DEPPS Part 1 of 2 simulates the volume of debris
# for a given hurricane event in southern Mississippi.
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx")

# Script arguments...
Mississippi_Study_Area = sys.argv[1]
if Mississippi_Study_Area == '#':
 Mississippi_Study_Area = "Study_Area_MS_Cont_equi_conic" # provide a default value if unspecified

Storm_Event_From_Downloads = sys.argv[2]
if Storm_Event_From_Downloads == '#':
 Storm_Event_From_Downloads = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1.gdb\\Katrina_2005Max" # provide a default value if unspecified

Select_Wind_Speed_Unit = sys.argv[3]
if Select_Wind_Speed_Unit == '#':
 Select_Wind_Speed_Unit = "MAXSFC" # provide a default value if unspecified

Debris_Retrieval_Distance = sys.argv[4]
if Debris_Retrieval_Distance == '#':
 Debris_Retrieval_Distance = "200 Feet" # provide a default value if unspecified

Final_DEPPS_Part_1_Output = sys.argv[5]
if Final_DEPPS_Part_1_Output == '#':
 Final_DEPPS_Part_1_Output = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Total_Debris_Supply" # provide a default value if unspecified

# Local variables...
SADissolve = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\SADissolve"
SADissolveBuff = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\SADissolveBuff"
```

```
Katrina_2005Max_Clip = "C:\\GIS Pojects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Katrina_2005Max_Clip"
Kat56Max = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Kat56Max"
Correct_Forest_Cover_and_Wind_Cover = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefBranch"
NASS_HRD_Add_Field_Branch = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefBranch"
Decid = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Decid"
MS_NASS_SA09__2_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MS_NASS_SA09"
Deciduous_Value__141_ = "141"
Everg = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Everg"
MS_NASS_SA09 = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MS_NASS_SA09"
Evergreen_Value__142_ = "142"
Mixed = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Mixed"
MS_NASS_SA09__4_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MS_NASS_SA09"
Mixed_Value__143_ = "143"
MixEvg = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\MixEvg"
ForestCov = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\ForestCov"
Damage_Coef_Branch_Calculated = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefBranch"
SA_Roads_Proj_Buff = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\SA_Roads_Proj_Buff"
Study_Area_Roads_Project = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\TIGERFiles\\Study_Area_Roads_Project"
RoadBuff_Dissolve = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\RoadBuff_Dissolve"
Branch_Supply_Retrieval_at_200_Feet = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Branch_Supply200"
NASS_HRD_Add_Field_Stem = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefStem"
Damage_Coef_Stem_Calculated_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefStem"
MIFI_VOL_ONLY_GR0__2_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
IDW_Branch_Vol56m = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\IDW_Branch_Vol56m"
MIFI_VOL_ONLY_GR0 = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
With_Branch_Volcuft = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
With_BranchVol_m3_m2 = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
With_Stem_Volcuft = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
With_Stem_Volcuft_Calc = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1.gdb\\MIFI_Inputs\\MIFI_VOL_ONLY_GR0"
IDW_Stem_Vol56m = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\IDW_Stem_Vol56m"
Correct_Forest_Cover_and_Wind_Cover__2_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefStem"
Stem_Dama_Vol = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Damaged_Stem_Vol2"
Damaged_Stem_Vol2__2_ = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Damaged_Stem_Vol2"
```

```
Branch_Debris_Volume = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Damaged_Branch_Vol2"
With_Branch_Damage_by_Vol_Field = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Damaged_Branch_Vol2"
Branch_Supply_Feature_Class = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Branch_Supply"
Stem_Supply = "C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\Stem_Supply"
Stem_Supply_Retrieval_at_200_Feet = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Stem_Supply200"
Stem_Debris_Supply_for_Retrieval_Output = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Stem_Supply200_Select"
Branch_Debris_Supply_for_Retrieval_Output = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Branch_Supply200_Select"
Total_Debris_Supply = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Total_Debris_Supply"
Total_Debris_Supply__2_ = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Total_Debris_Supply"
DEPPS_Part_1_Final_Output = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Total_Debris_Supply"
Damaged_Stem_Vol2 = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Damaged_Stem_Vol2"
Damaged_Branch_Vol2 = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Damaged_Branch_Vol2"
Total_Debris_Supply__3_ = "C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Total_Debris_Supply"

# Process: Add Field: StemVol_m3_m2...
gp.AddField_management(MIFI_VOL_ONLY_GR0, "StemVol_m3_m2", "DOUBLE", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field: StemVol_m3_m2...
gp.CalculateField_management(With_Stem_Volcuft, "StemVol_m3_m2", "VolArea", "VB", "Dim
VolArea as Double\\n\\nVolArea = ((( [cfobstem] / 0.2) * (0.0283168 / 4046.85642)) * 3136) *
1000\\n\\n")

# Process: IDW of 'cfobstem' ...
gp.Idw_sa(With_Stem_Volcuft_Calc, "StemVol_m3_m2", IDW_Stem_Vol56m, "56", "2", "VARIABLE
12", "")

# Process: All Values Equal to "143"...
gp.EqualTo_sa(MS_NASS_SA09__4_, Mixed_Value__143_, Mixed)

# Process: All Values Equal to "142"...
gp.EqualTo_sa(MS_NASS_SA09, Evergreen_Value__142_, Everg)

# Process: Mixed Plus Evergreen...
gp.Plus_sa(Mixed, Everg, MixEvg)

# Process: All Values Equal to "141"...
gp.EqualTo_sa(MS_NASS_SA09__2_, Deciduous_Value__141_, Decid)

# Process: Deciduous Plus Mixed Evergreen...
gp.Plus_sa(MixEvg, Decid, ForestCov)

# Process: Dissolve County Boundaries...
```

```
gp.Dissolve_management(Mississippi_Study_Area, SADissolve, "", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Buffer Dissolved Boundary 50000m...
gp.Buffer_analysis(SADissolve, SADissolveBuff, "50000 Meters", "FULL", "ROUND", "NONE", "")

# Process: Clip HRD Wind Points to Buffer...
gp.Clip_analysis(Storm_Event_From_Downloads, SADissolveBuff, Katrina_2005Max_Clip, "")

# Process: HRD Wind Speed Interpolation...
gp.Spline_sa(Katrina_2005Max_Clip, Select_Wind_Speed_Unit, Kat56Max, "56", "TENSION", "0.1",
"12")

# Process: Combinatorial And: NASS and HRD (2)...
gp.CombinatorialAnd_sa(ForestCov, Kat56Max, Correct_Forest_Cover_and_Wind_Cover__2_)

# Process: Add Field: Damage_Coef_Stem...
gp.AddField_management(Correct_Forest_Cover_and_Wind_Cover__2_, "Damage_Coef_Stem",
"DOUBLE", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field Using Stem Coef...
gp.CalculateField_management(NASS_HRD_Add_Field_Stem, "Damage_Coef_Stem", "Stem", "VB",
"Dim Stem As Double

If [G_G_G3] = \"0\" Then
Stem = 0

ElseIf [G_G_G3] < \"24.59\" Then
Stem = 0

Else
Stem = (2.3959 * [G_G_G3]) - 52.878

End If

")

# Process: Single Output Map Algebra...
gp.SingleOutputMapAlgebra_sa("combine (IDW_Stem_Vol56m ,C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\DamageCoefStem.Damage_Coef_Stem)", Damaged_Stem_Vol2, "'C:\\GIS
Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\IDW_Stem_Vol56m';'C:\\GIS Projects\\Masters
Model Jun 2010\\Debris1_Results.gdb\\DamageCoefStem'")

# Process: Add Field: Stem_Dama_By_Vol...
gp.AddField_management(Damaged_Stem_Vol2, "Stem_Dam_By_Vol", "DOUBLE", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field...
gp.CalculateField_management(Stem_Dama_Vol, "Stem_Dam_By_Vol", "DamVol", "VB", "Dim
DamVol as Double

DamVol = ( [RASTER2]/100) * [G_G_G3]")

# Process: Raster to Point (3)...
gp.RasterToPoint_conversion(Damaged_Stem_Vol2__2_, Stem_Supply, "Stem_Dam_By_Vol")
```

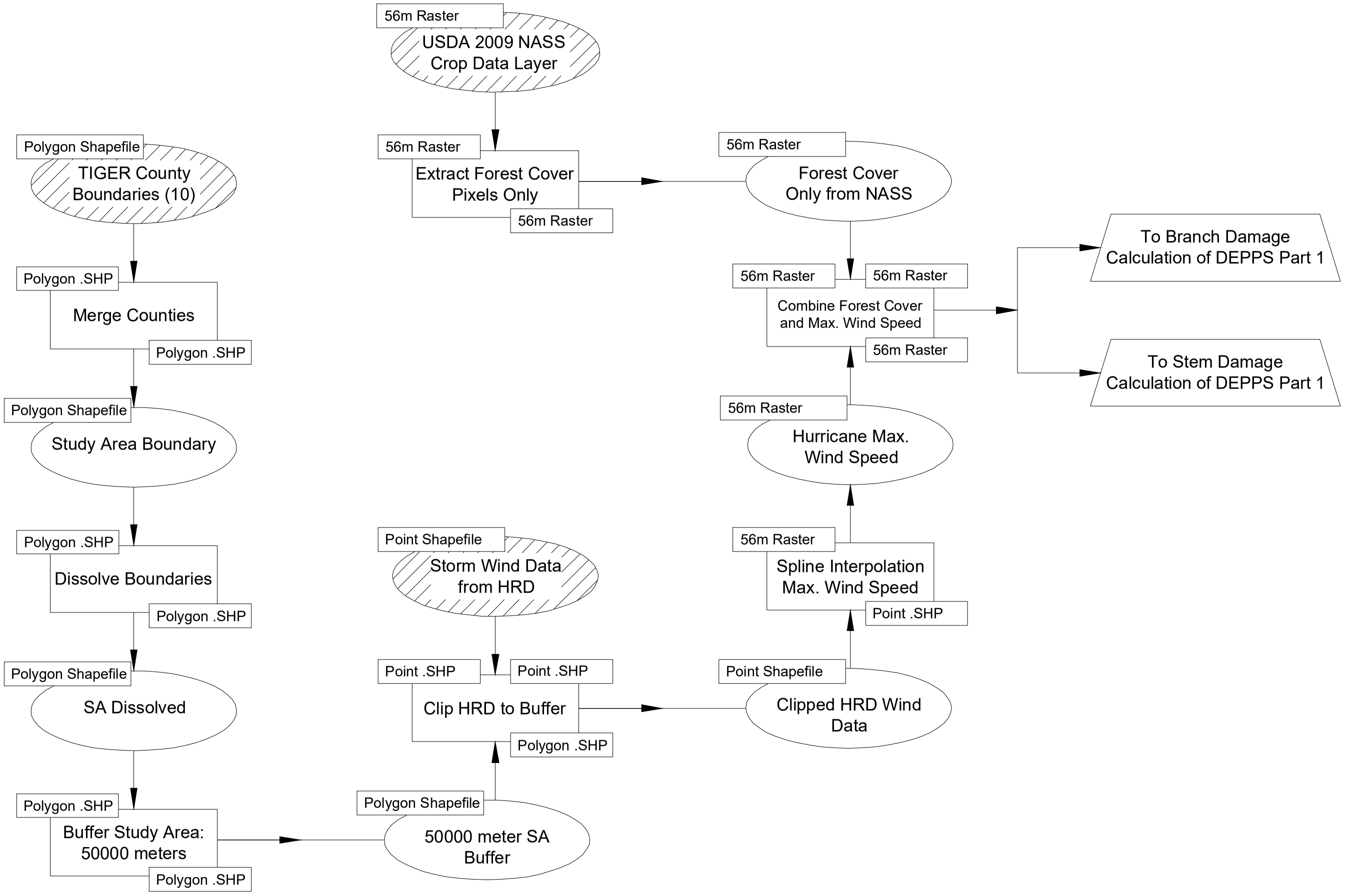
```
# Process: Road Buffer...
gp.Buffer_analysis(Study_Area_Roads_Project, SA_Roads_Proj_Buff, Debris_Retrieval_Distance,
"FULL", "ROUND", "NONE", "")

# Process: Road Buffer Dissolve...
gp.Dissolve_management(SA_Roads_Proj_Buff, RoadBuff_Dissolve, "", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Stem Supply 200 feet...
gp.Clip_analysis(Stem_Supply, RoadBuff_Dissolve, Stem_Supply_Retrieval_at_200_Feet, "")

# Process: Removal of "0" Stem Debris Values...
gp.Select_analysis(Stem_Supply_Retrieval_at_200_Feet, Stem_Debris_Supply_for_Retrieval_Output,
"\"GRID_CODE\" > 0")

# Process: Combinatorial And: NASS and HRD...
gp.CombinatorialAnd_sa(ForestCov, Kat56Max, Correct_Forest_Cover_and_Wind_Cover)

# Process: Add Field: Damage_Coef_Branch...
gp.AddField_management(Correct_Forest_Cover_and_Wind_Cover, "Damage_Coef_Branch",
"DOUBLE", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field Using Branch Coef...
gp.CalculateField_management(NASS_HRD_Add_Field_Branch, "Damage_Coef_Branch", "Branch",
"VB", "Dim Branch As Long

If [G_G_G3] = \"0\" Then
Branch = 0

ElseIf [G_G_G3] < \"17.43\" Then
Branch = 0

Else
Branch = ((1.5973 * [G_G_G3]) + 3.4106)

End If

")

# Process: Add Field: BranchVol_m3_m2...
gp.AddField_management(MIFI_VOL_ONLY_GR0__2_, "BranchVol_m3_m2", "DOUBLE", "", "", "",
"", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field: BranchVol_m3_m2...
gp.CalculateField_management(With_Branch_Volcuft, "BranchVol_m3_m2", "VolArea", "VB", "Dim
VolArea as Double\\n\\nVolArea = ((([cfobbranch] / 0.2) * (0.0283168 / 4046.85642)) * 3136) *
1000\\n\\n")

# Process: IDW of 'BranchVol_m3_m2'...
gp.Idw_sa(With_BranchVol_m3_m2, "BranchVol_m3_m2", IDW_Branch_Vol56m, "56", "2",
"VARIABLE 12", "")

# Process: Single Output Map Algebra (2)...
```

```
gp.SingleOutputMapAlgebra_sa("combine (IDW_Branch_Vol56m, C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\DamageCoefBranch.Damage_Coef_Branch)", Damaged_Branch_Vol2,
"'C:\\GIS Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\DamageCoefBranch';'C:\\GIS
Projects\\Masters Model Jun 2010\\Debris1_Results.gdb\\IDW_Branch_Vol56m'")

# Process: Add Field: Branch_Dama_By_Vol...
gp.AddField_management(Damaged_Branch_Vol2, "Branch_Dama_By_Vol", "DOUBLE", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Branch Debris Volume...
gp.CalculateField_management(With_Branch_Damage_by_Vol_Field, "Branch_Dama_By_Vol",
"DamVol", "VB", "Dim DamVol as Double")

DamVol = ( [RASTER2]/100) * [G_G_G2]

# Process: Raster to Point Feature Class...
gp.RasterToPoint_conversion(Branch_Debris_Volume, Branch_Supply_Feature_Class, "VALUE")

# Process: Branch Supply 200 feet...
gp.Clip_analysis(Branch_Supply_Feature_Class, RoadBuff_Dissolve,
Branch_Supply_Retrieval_at_200_Feet, "")

# Process: Removal of "0" Branch Debris Values...
gp.Select_analysis(Branch_Supply_Retrieval_at_200_Feet, Branch_Debris_Supply_for_Retrieval_Output,
"\"GRID_CODE\" > 0")

# Process: Intersect...
gp.Intersect_analysis("'C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Stem_Supply200_Select' #;'C:\\GIS Projects\\Masters Model Jun
2010\\Debris1_Results.gdb\\Branch_Supply200_Select' #", Total_Debris_Supply, "ALL", "", "POINT")

# Process: Add Field: Total Available Debris...
gp.AddField_management(Total_Debris_Supply, "Tot_Debris_Supply_m3", "DOUBLE", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field: Total Debris...
gp.CalculateField_management(Total_Debris_Supply__2_, "Tot_Debris_Supply_m3", "([GRID_CODE] +
[GRID_CODE_1]) / 1000", "VB", "")

# Process: Add Field...
gp.AddField_management(DEPPS_Part_1_Final_Output, "ServTime", "DOUBLE", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field (2)...
gp.CalculateField_management(Total_Debris_Supply__3_, "ServTime", "Serv", "VB", "Dim Serv as
Double\\n\\nServ = (264 * [Tot_Debris_Supply_m3]) +1800")
```

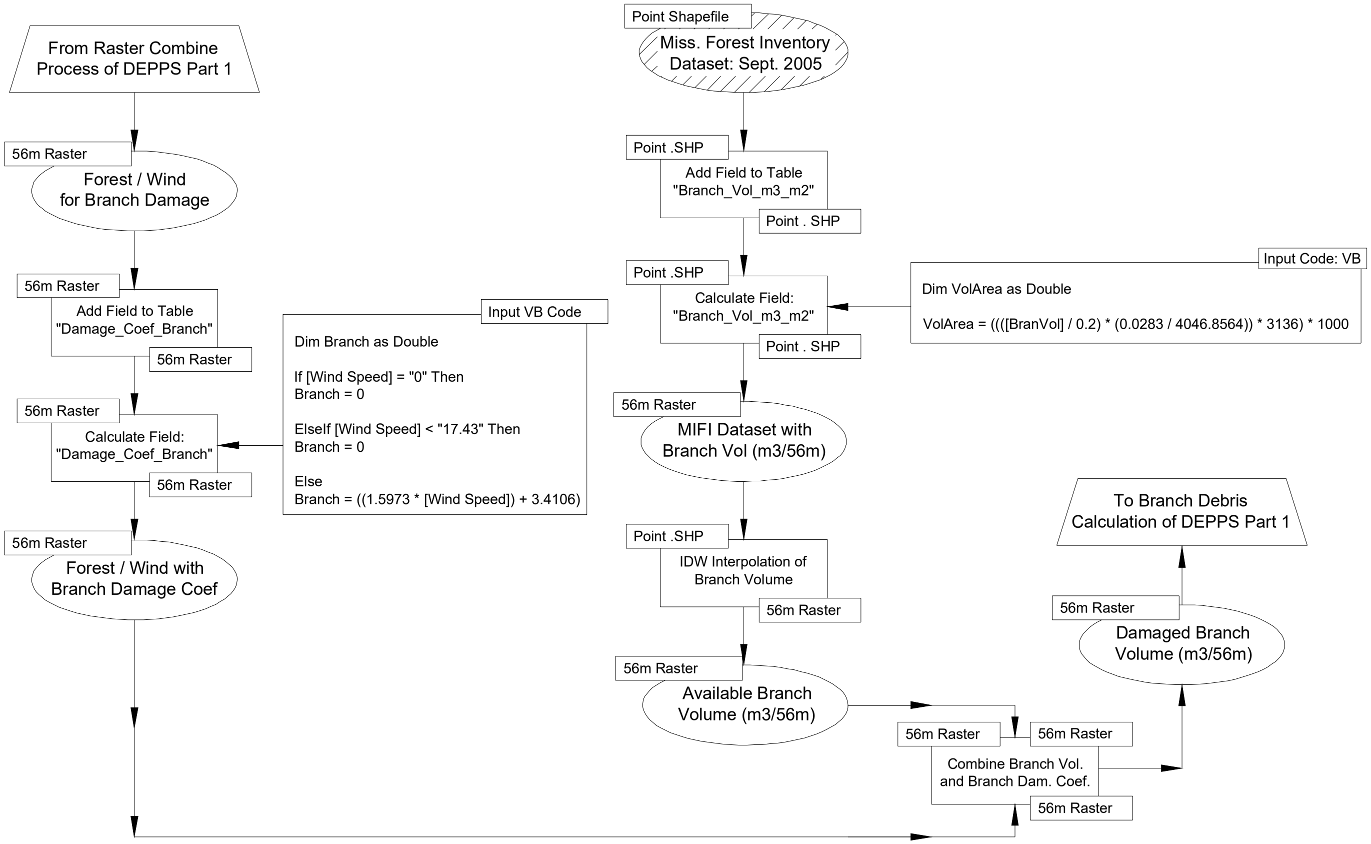
APPENDIX B

DEPPS PROGRAM / PROJECT FLOW CHART

DEPPS Part 1 of 2: Page 1



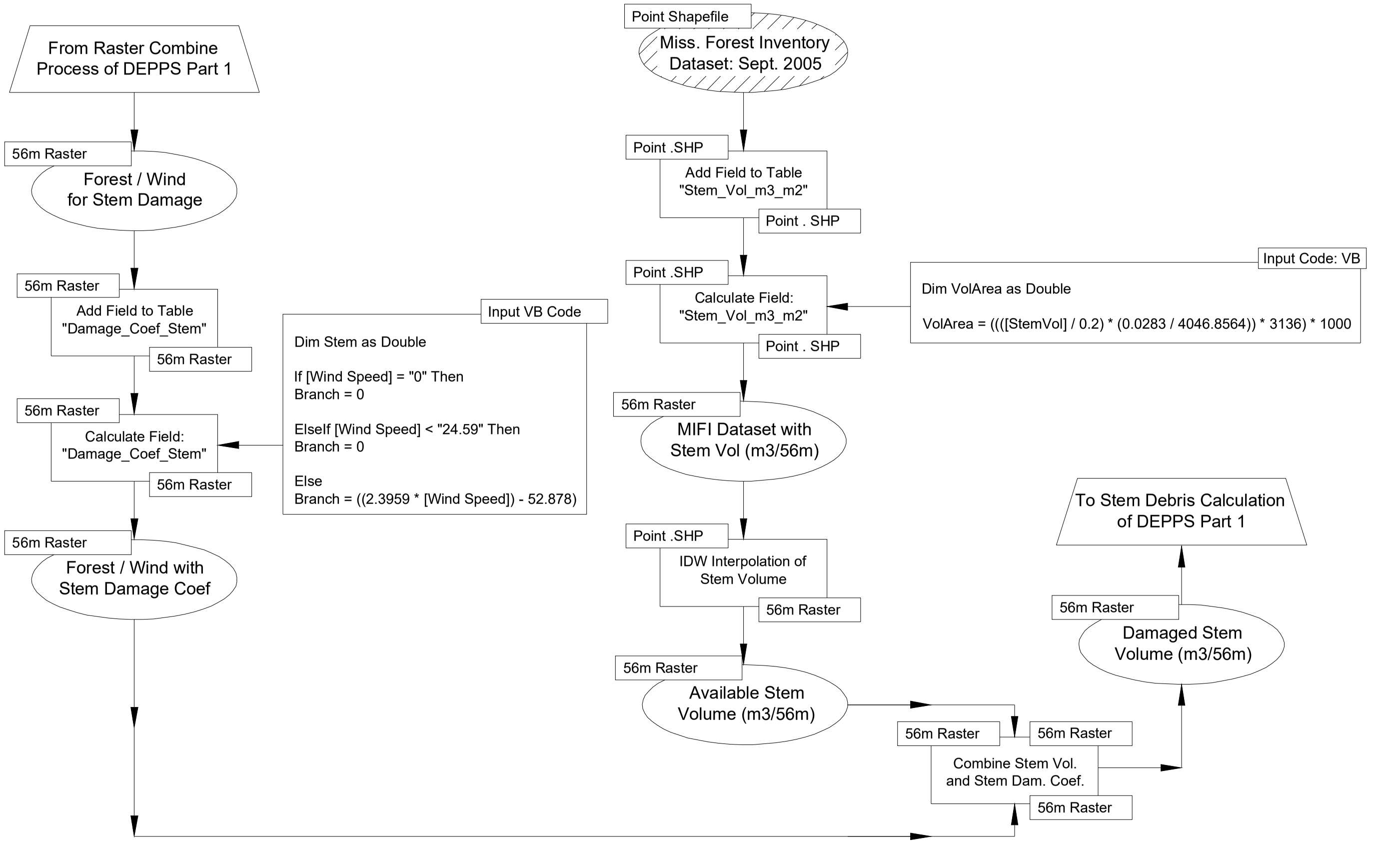
DEPPS Part 1 of 2: Page 2



```
Dim Branch as Double

If [Wind Speed] = "0" Then
Branch = 0

ElseIf [Wind Speed] < "17.43" Then
Branch = 0

Else
Branch = ((1.5973 * [Wind Speed]) + 3.4106)
```

```
Dim VolArea as Double

VolArea = ((([BranVol] / 0.2) * (0.0283 / 4046.8564)) * 3136) * 1000
```

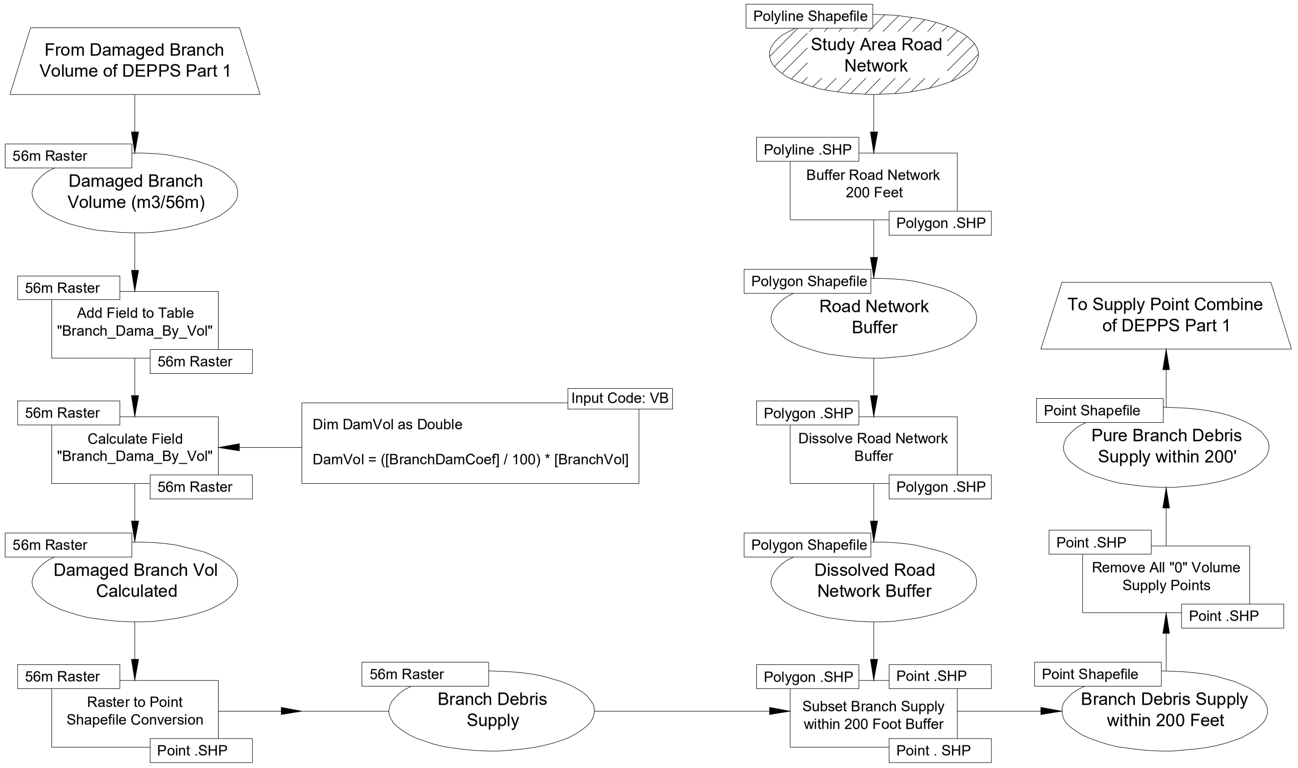
DEPPS Part 1 of 2: Page 3



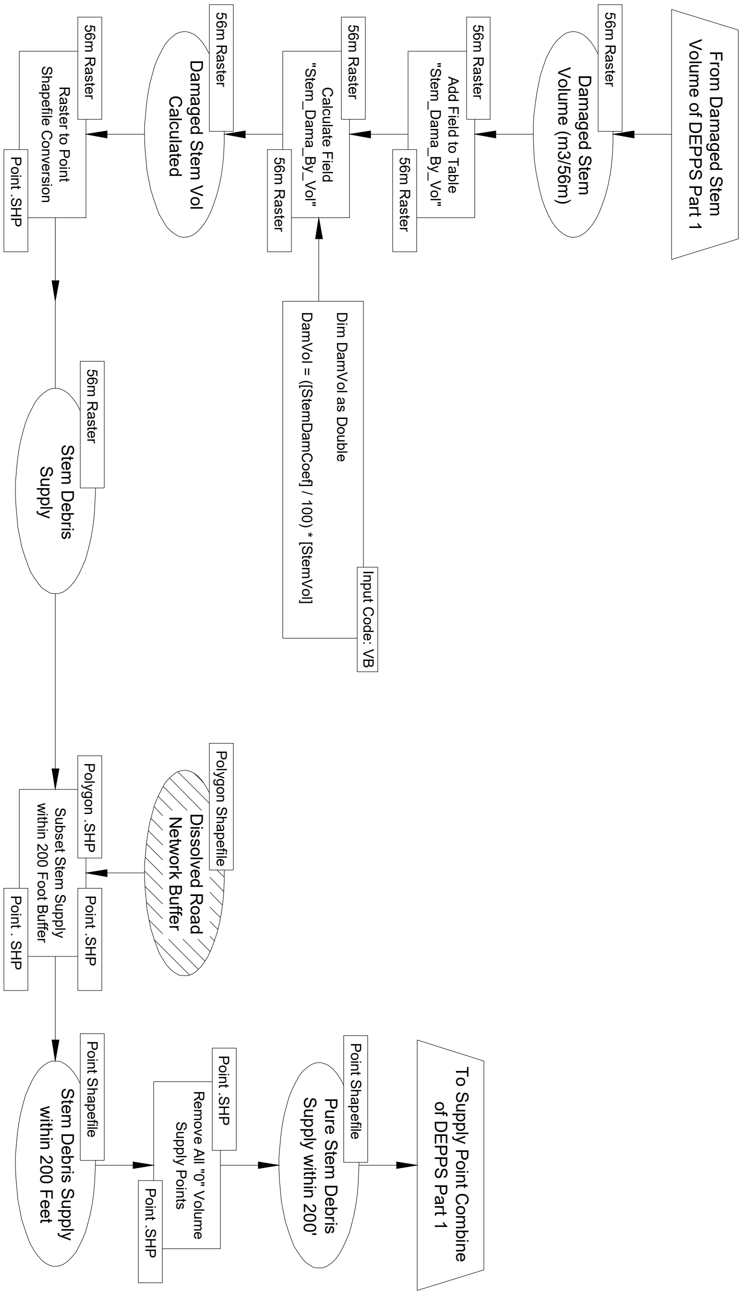
```
Dim Stem as Double

If [Wind Speed] = "0" Then
Branch = 0

ElseIf [Wind Speed] < "24.59" Then
Branch = 0

Else
Branch = ((2.3959 * [Wind Speed]) - 52.878)
```

```
Dim VolArea as Double

VolArea = ((([StemVol] / 0.2) * (0.0283 / 4046.8564)) * 3136) * 1000
```

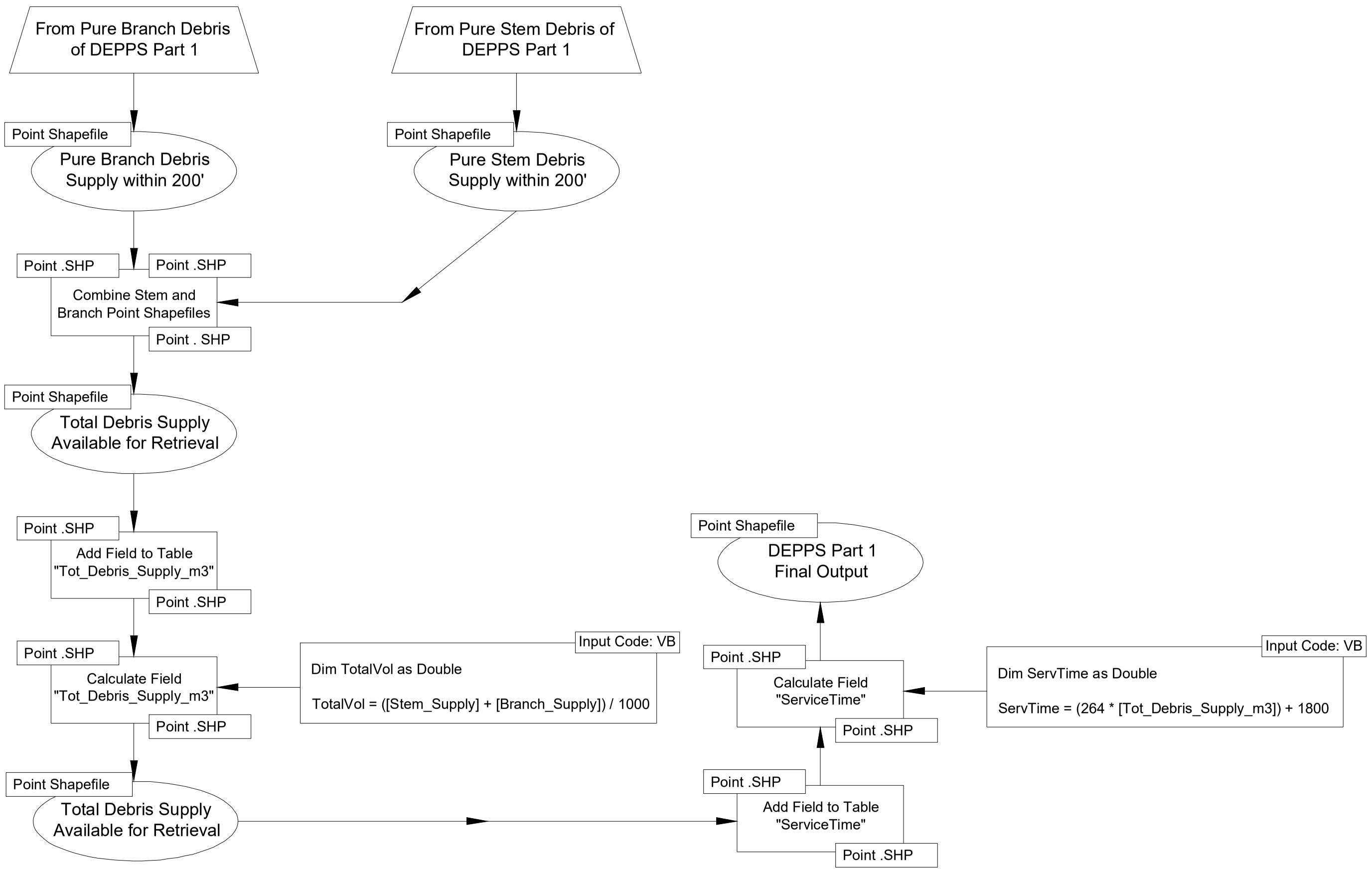
DEPPS Part 1 of 2: Page 4



```
Dim DamVol as Double

DamVol = ([BranchDamCoef] / 100) * [BranchVol]
```


DEPPS Part 1 of 2: Page 5

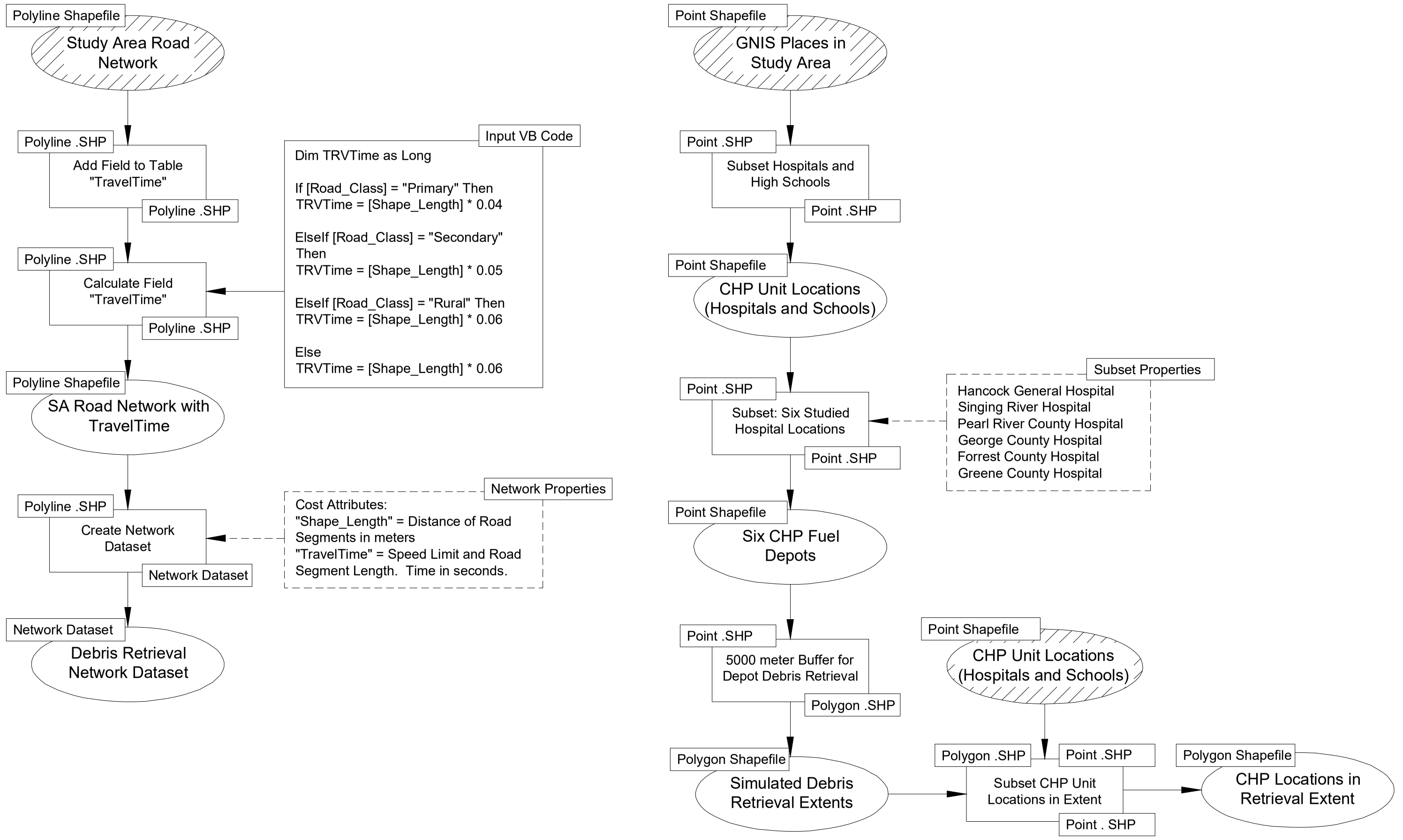
DEPPS Part 1 of 2: Page 6



```
Dim TotalVol as Double

TotalVol = ([Stem_Supply] + [Branch_Supply]) / 1000
```

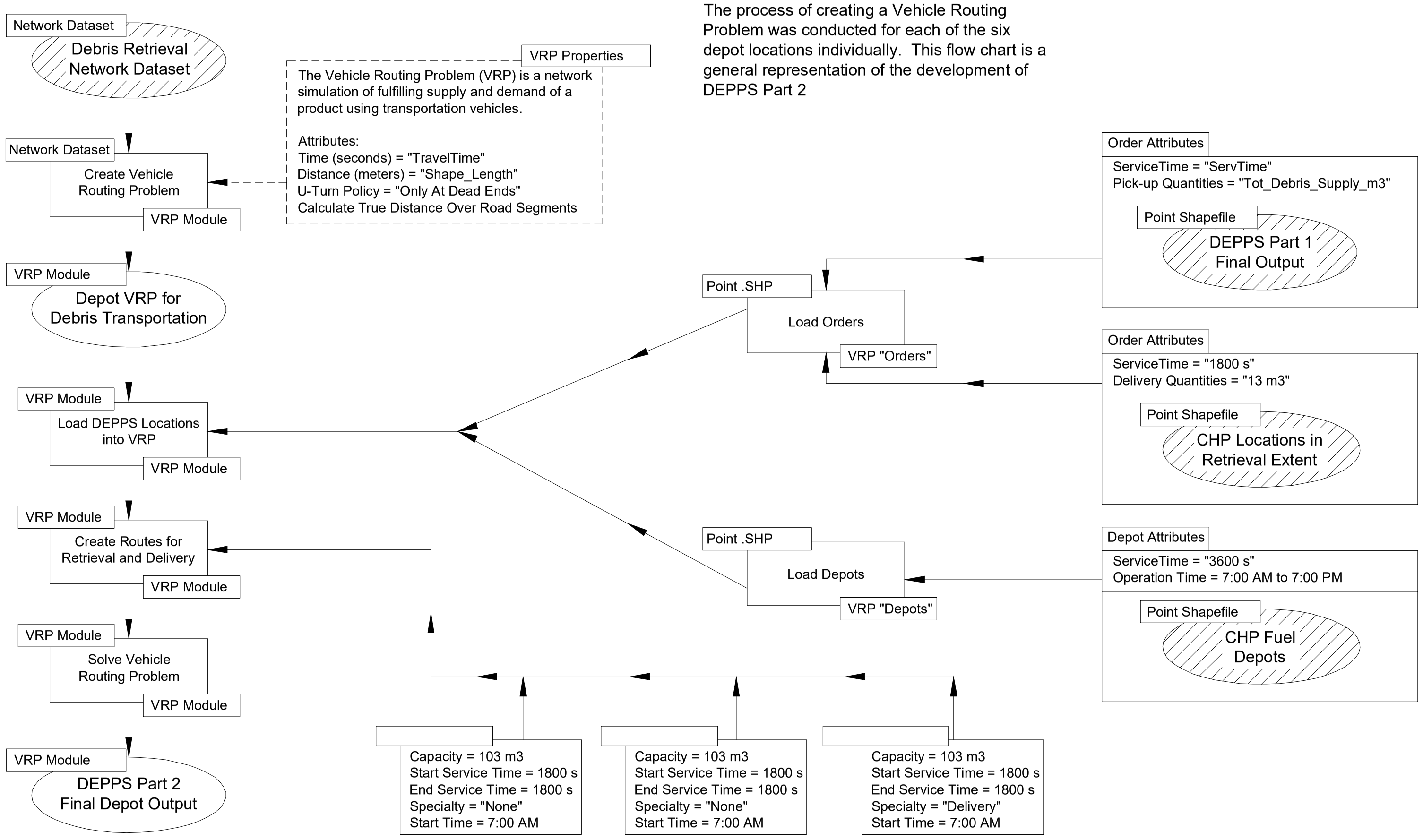
```
Dim ServTime as Double

ServTime = (264 * [Tot_Debris_Supply_m3]) + 1800
```

DEPPS Part 2 of 2: Page 1



```
Dim TRVTime as Long

If [Road_Class] = "Primary" Then
TRVTime = [Shape_Length] * 0.04

ElseIf [Road_Class] = "Secondary"
Then
TRVTime = [Shape_Length] * 0.05

ElseIf [Road_Class] = "Rural" Then
TRVTime = [Shape_Length] * 0.06

Else
TRVTime = [Shape_Length] * 0.06
```

DEPPS Part 2 of 2: Page 2



NOTE:
The process of creating a Vehicle Routing Problem was conducted for each of the six depot locations individually. This flow chart is a general representation of the development of DEPPS Part 2