A Geospatial Analysis of the Role of Urban Forestry in Outdoor Ambient Air Pollution Reduction in Dayton, Ohio

Nicholas P. Clemens

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A Geospatial Analysis of the Role of Urban Forestry in Outdoor Ambient Air Pollution Reduction in Dayton, Ohio.

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Wright State University
Acknowledgments

This project would not have been possible without the work of a handful of very committed people. Firstly, I’d like to thank my committee – Dr. Naila Khalil, Dr. William Spears, and Dr. Patrick Ryan. I’d like to thank Andrew Roth of the Regional Air Pollution Control Agency. Additionally, I’d like to thank all the faculty at Wright State University for providing all the support and knowledge through my time here. I’d like to give specific recognition to Dr. Cristina Redko and Christopher Eddy for all their patience and help during my Culminating Experience, and Practice Placement journeys.
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Abstract

Objective: Air pollution is associated with negative respiratory and cardiovascular health outcomes. According to the American Lung Association listing for 2011, the Dayton-Springfield-Greenville, OH area ranks 22 out of 277 US cities for year round particulate pollution. The tree canopy cover plays a significant role to reduce air pollution. The purpose of this analysis was to quantify the role of urban forestry in the Dayton, Ohio metropolitan area in reducing air pollution.

Methods: Using a peer-reviewed model designed by the US Forest Service, the imagery data was analyzed to create a descriptive analysis of the canopy cover in the Dayton, Ohio Study area. A secondary geospatial analysis was conducted by building a region map based on US Census poverty data, and layering the study area canopy data onto the image. Data used in the models was obtained from the Department of Agriculture Forest Service, and the Multi-Resolution Land Characteristics Database.

Results: Analysis of the Dayton, Ohio Study area shows that the canopy cover within this area is responsible for the removal of approximately 101.6 short tons of Nitrogen Dioxide (NO2), 242.9 short tons of Ozone (O3), 51.3 short tons of Sulfur Dioxide (SO2), 177.5 short tons of Particulate Matter (PM10), and sequester 22,278.6 short tons of Carbon annually. The secondary analysis displayed changes to the initial reduction estimates based on two separate scenarios, substantial growth and loss of canopy cover. In the case of expansion of canopy cover to 25% of the study area, an increase in reduction of roughly 50% in all pollutants was shown. The scenario displaying a 10% loss of canopy cover displayed a loss in pollution reduction across all measured pollutants. In all analyses, the most heavily removed pollutant was carbon, while the most valuable pollutant removed was Ozone, at approximately 46% of total removal value.

Conclusion: The canopy cover of the Dayton, Ohio study area plays a significant and constant role in helping to reduce air pollution. Urban Forestry should be a part of any comprehensive pollution reduction plan. More should be done to increase urban forestry efforts, to further inhibit pollution build up and disperse the benefits of canopy cover more widely.
Introduction

In recent years, the interest to design communities that promote health and wellbeing has gained significance. When designing an urban community, city planners look at myriad of characteristics, which are all important to the general health of the public within that community. A major component of any healthy community is a healthy environment, which includes soil, water, air, or vegetation. For over a century, studies have shown that the importance of air and air quality goes beyond simply sustaining life, but rather directly impacting the overall health of a community.

In urban communities pollutants are ubiquitous. Vegetation exists as a natural mechanism for cleaning the air. Trees and plants absorb chemicals in the air that are unpleasant or toxic to humans. The ability of plants and trees to actively and passively clean the air in our communities is imperative when designing and building healthy cities and communities. This analysis will quantify the pollution reduction effects due to the vegetation of Dayton, Ohio, on outdoor air.

Literature Review

In the last decade as interest in improving urban environments within our communities has increased, interest in the role of urban forestry has also increased (Bradley, 1995). In the United States, the concept of urban forestry has existed for over a hundred years (Konijnendijk, Ricard, Kenney, & Randrup, 2006). In Konijnendijk, Ricard, Kenney, and Randrup’s (2006) perspective study on urban forestry, he defines urban forestry as such: “managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society”. Over the course of the last decade, efforts have grown to document and quantify urban forests throughout the United States. As
with standard forests, urban forests tend to be measured by canopy cover. Canopy cover is defined as proportion of the forest floor covered by the vertical projection of the tree branches, stems, and leaves (Korhonen, Korhonen, Rautiainen, & Stenberg, 2006). Currently, the United States Forestry Service has made overall tree canopy data available (United States Forestry Service, 2010).

Table 1. Canopy Cover by City, Trees only

<table>
<thead>
<tr>
<th>City</th>
<th>% tree Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calgary, Canada</td>
<td>7.2</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>36.7</td>
</tr>
<tr>
<td>Toronto, Canada</td>
<td>20.5</td>
</tr>
<tr>
<td>New York, NY</td>
<td>20.9</td>
</tr>
<tr>
<td>Baltimore, MD</td>
<td>21</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>15.7</td>
</tr>
<tr>
<td>Washington, DC</td>
<td>28.6</td>
</tr>
<tr>
<td>Boston, MA</td>
<td>22.3</td>
</tr>
<tr>
<td>Woodbridge, NJ</td>
<td>29.5</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>26.4</td>
</tr>
<tr>
<td>Syracuse, NY</td>
<td>23.1</td>
</tr>
</tbody>
</table>

According to research conducted by the environmental policy group, American Forests (2010), the optimal canopy cover for US cities is between 35-40% of land surface. Benefits comprised in this assessment include health improvements, erosion protection, reduction of urban heat islands, decreased spending on heating/cooling, and other economic factors (American Forests, 2010).

While the direct benefits of urban canopy cover are often times hard to quantify, they are generally accepted as being beneficial to human health, both physical, mental, and aesthetics (Bradley, 1995). Additionally, as is commonly noted, green spaces and urban forestry may play a role in promoting physical activity (Dwyer, McPherson, Schroeder, & Rowntree, 1992) which
can contribute to positive health outcomes. In addition to improving individual health outcomes, urban forestry has been shown to improve the overall health and efficiency of an environment. An analysis of urban forestry strategies in New York City shows that urban greenery inhibits the development of what is known as the urban heat island (Slosberg, Rozenzweig, & Solecki, 2006). Studies on green scape programs, like those in Washington, D.C., have proven statistically significant savings in energy costs due to heating and cooling buildings (Hao, Corrie, Jiti, & Peter, 2010). Vegetative cover can prevent soil erosion and runoff; a study in Dayton, Ohio revealed that even modest improvements in urban canopy cover can impact the hydrology of an area (Sanders, 2002). Community trees have also been recommended as a means for increasing property values (Dwyer et al., 1992).

**Air Pollution and Health.**

Air pollution is made up of two general categories, as defined by the Environmental Protection Agency. The first of these categories is gases. This is the portion of pollution that is generally attributed to automobiles, energy generation, and manufacturing. Common gas pollution is made up of Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Oxide (NO2), Ozone (O3), as well as what is referred to as Volatile Organic Compounds (VOCs) (Environmental Protection Agency, 2011). A VOC is an organic compound with an extremely low boiling point. This allows for quick evaporation, and can be easily inhaled. The second category of air pollution is particulate matter. Particulate matter is any type of liquid or solid that is suspended in the ambient air. These types of pollutants include dusts, sand, pollen, and mist (Environmental Protection Agency, 2004). All of these compounds are considered hazardous to human health (Environmental Protection Agency, 2011).
In recent years the relationship between air quality and a number of health outcomes has been explored (Pope, 2000; Adar, Klein, Klein, & Szpiro, 2010; Kramer, Herder, & Sugiri, 2010). Air pollution affects individual health through three general pathways, systemic inflammation or stress, alterations in autonomic balance, or systemic circulations (Brook, 2008). Air pollution is capable of affecting multiple organs and bodily systems. Conditions associated with air pollution encompass a wide range of both acute and chronic maladies (Kampa, 2008). Exposure to air pollution has been correlated to respiratory infections, heart disease, lung cancer, bronchitis, asthma, and premature mortality (Kampa, 2008). Often the direct outcome of air pollution exposure is difficult to ascertain as humans tend to inhale mixtures of pollutants with variable concentrations. This variability leads to a wide range of possible health effects (Kampa, 2008). Research has shown that the systems most commonly affected by air pollutants are the respiratory and cardiovascular systems (Kampa, 2008).

The respiratory system can be affected by air pollution in both low and high concentration scenarios (Kampa, 2008). Sulfur Dioxide and Nitrogen Dioxide have been linked to nose/throat irritation, bronchioconstriction, and dyspnea (Kampa, 2008). Nitrogen Dioxide increases the likelihood of respiratory infections (Chauhan, Krishna, Frew, & Holgate, 1998) and has been shown to produce ‘Emphysema-like’ lesions in mice (Kampa, 2008). Both Nitrogen Dioxide and Sulfur Dioxide are capable of exacerbating respiratory infections or chronic lung and heart disease in humans, especially in at-risk populations (Kampa, 2008).

The cardiovascular system is equally susceptible. Inhaled Carbon Monoxide bonds to the hemoglobin in blood, not allowing blood cells to carry oxygen (Kampa, 2008). A reduction of oxygen in the blood can affect any organ within the body, but those organs that consume a great deal of oxygen, like the brain and heart, are at highest risk (Badman & Jaffé, 1996). At low level
concentrations, carbon monoxide can induce confusion, impaired vision and reflexes, and disrupt concentration (Kampa, 2008). At high level concentrations carbon monoxide can cause serious organ damage, and death (Folinsbee, 1993). Particulate matter is capable of being inhaled deep into the lungs, and can illicit inflammatory responses within the body (Kampa, 2008). In some studies, the inflammatory response associated with particulate matter has caused changes in blood clotting, as well as increased the risks for angina and myocardial infarction (Kampa, 2008). Because of the range of negative possible health outcomes, reductions in these pollutants are widely endorsed to improve community health (Brook, 2008; Kelly, 2003).

**Air Pollution Reduction**

Urban forests actively or passively remove pollutants from outdoor air. Urban forestry canopy has been found to be the most effective vegetation type in capturing airborne particulate matter (Manning & Feder, 1980). This is mostly due to the large combined surface area of tree canopy. This vegetative cover plays a key role in the reduction of free floating particulate matter. Trees physically intercept airborne particles. From here they are either absorbed into the tree (as is the case with nitrogen, carbon, and sulfur dioxides), or in most cases, stored on the surface until being dropped to the ground due to rainfall (Nowak, 2000). In some cases, trees are only a temporary barrier to suspended particles, but urban forests have been capable of capturing 15 kilograms per day per kilometer of particulate matter (Nowak, 2000).

When using trees as a shield for capturing particulate matter, proper placement is imperative. Often times, the areas that would most benefit from particulate capture are devoid of vegetation (Delcarte, 1979). Relatively small strategically-placed tree lines have been shown to trap astounding amount of airborne matter (Spitsyna, 1991; Delcarte, 1979). To maximize the ability of urban forests to inhibit particulate matter pollution, trees must ideally be used in areas
close to viable generation points for pollutants. These include planting trees along roadsides or around industrial complexes. In open areas, tree lines can operate in a similar manner, creating a wall or blockade against airborne particles (Beckett, Freer-Smith, & Taylor, 1998). In past analysis of the capturing effects of trees in urban areas, the trees of Chicago were found to improve city air quality by up to 2.1% (McPherson et al., 1994); the trees of Philadelphia improved city air quality by up to 1% (Nowak, 1997) - and in both cases, at a remarkably low calculated opportunity cost (Beckett et al., 1998).

**Heat Reduction**

The concept of an urban heat island was first described in the early 1800’s (Howard, 1818). Howard’s observations about the difference in temperature between urban and rural areas helped pave the way for understanding the nature of urban heat retention today. In general, built environments in cities are capable of retaining significant amounts of heat (metals, asphalt, etc.). The ability of these materials to absorb and store heat during the day makes the ambient temperature in the locality hotter than the outlying areas (American Meteorology Society, 2009). While the problems associated with higher temperatures are worthy of discussion and planning, the effect these higher temperatures have on air pollution is of particular importance to urban forestry. High ambient temperatures are needed for the formation of many volatile organic compounds, as well as Ozone (O3) (Environmental Protection Agency, 2011). Analysis by Nowak (1997) has suggested that roughly 12% of pollution in city areas is attributed to urban heat islands.

Considering the role of heat in increasing urban pollution, heat reduction should be considered a goal of any urban forestry intervention. The simplest method for reducing the effects of the urban heat island is to decrease the amount of solar energy that reaches constructed
surfaces (Akbari, 2002). As vegetation is applied throughout a city, the amount of pavement and asphalt for capable of retaining solar energy diminishes. Studies have demonstrated that tree planting, especially along streets, offers the best cooling potential of all generally accepted methods of heat mitigation (Slosberg et al., 2006). Estimates of the impact of tree planting programs to reduce the urban heat island effect have been attributed with changes in temperature up to 6 degrees Fahrenheit (Taha, 1996).

**Carbon Sequestration**

Carbon Sequestration is “the extraction of atmospheric carbon dioxide in terrestrial ecosystems” (Jana, 2008). Carbon Dioxide is a pollutant capable of aiding in global warming. Carbon Dioxide is most commonly generated during the burning of fossil fuels. As trees are capable of absorbing CO2, urban forestry is a major sink for CO2 in cities (Liu & Xiaoma, 2011). It should also be noted that, carbon monoxide, another toxic gas, rapidly oxidizes into carbon dioxide in air (Nowak, 2000). In Akbari’s (2002) analysis of urban forestry, it was suggested that one well-placed urban tree can effectively remove the same amount of CO2 from the ambient air as three to five forest trees. This is due to the absorption rate of the tree, combined with the cooling effect of tree canopy, and the reduction in cooling costs of the surrounding area (Akbari, 2002).

It should be noted, that the direct health effects of CO2 on human population is considered minimal in most situations. It is possible for high concentrations of CO2 to cause respiratory problems, but occasions when the concentration in ambient air is sufficient to cause alarm, are rare. However the problem of global warming presents incredible health concerns for the human population across the board.
Threats to Urban Forestry

According the Ohio Department of Agriculture, the insect Emerald Ash Borer, has been found in all counties of Ohio (Ohio Department of Agriculture, 2010). This insect invades and kills ash trees. Currently, Ohio is home to roughly 4 billion ash trees (Mason, 2010). The ash tree population of Ohio accounts for approximately 10% of all trees. This would be a significant loss of canopy cover in Ohio urban forests, and by default, cause a decrease in air pollution reduction.

The Los Angeles Study

In 1996 an air quality model was tested for Los Angeles, California in an effort to demonstrate the impact of urban tree density to mitigate air pollutants. This study used a version of the Colorado State University Mesoscale Model (CSUMM) to investigate the role of urban canopy in decreasing particulate matter movement, and reducing the urban heat island effect, within the city area (Taha, 1996). The CSUMM model allows the user to make changes in vegetation cover with meteorology variables such as air movements, rain, and temperature, to approximate air pollution. A separate model called the Urban Airshed Model (UAM) was used to estimate the changes in ozone creation due to environmental changes due to canopy cover (i.e. temperature changes). Taha’s complete model is a set of equations based on these two models. For the initial estimates of vegetation cover, biomass volume data was taken from prior evaluations of the Los Angeles area.

In the Los Angeles study, Taha generated two simulations. The first was an increased in the Los Angeles urban tree coverage by 10 million trees. This increase accounted for a one percent increase in the average vegetation cover in the city (Taha, 1996). For comparison, Taha also constructed a model that increased the tree coverage by a 20 million trees (accounting for a
base increase of two percent tree population). According to Taha’s (1996) model, ten million additional trees allowed for a decrease in temperatures of up to 3.6 degrees Fahrenheit, while the twenty million additional trees allowed for a decrease of up to 6.3 degrees Fahrenheit.

When modeling changes in particulate matter and ozone creation, Taha (1997) suggested that the 1% increase in average vegetation cover would account for a decrease in 1% particulate matter, and roughly 0.6% of ozone. With a two percent vegetation increase, the particulate matter and ozone were reduced by 2.9%, and 1.6% respectively (Taha, 1997). Lastly, when analyzing the effect of the growth in tree population on the urban heat island, Taha described the effect in the amount of Carbon Dioxide saved due to a reduction in cooling costs. Taha (1997) offered that if serious efforts in planting trees were undertaken by a sizeable city, like Los Angeles, carbon dioxide emissions due to cooling costs could be reduced by 25%.

Taha’s results suggest that the most significant change in the environment due to the increase in vegetation is that shift in temperature. Furthermore, the UAM showed that planting trees would change ground temperatures to the point that it would help to inhibit photochemical reactions, or the development of ozone (Taha, 1997). The changes in vegetation produced a net increase in overall air quality, but it should be noted that the results are only necessarily beneficial on a broad scale, and at specific sites, it is possible that changes in vegetation could have a negative effect on air quality. However, an associated adverse effect could be an increase in natural organic compounds vegetation can release.

**Multi-Resolution Land Characteristics Consortium**

In 1995 several United States federal agencies formed a consortium with the sole purpose of making the costs of satellite imagery easier to shoulder. The Multi-Resolution Land Characteristics Consortium was designated ‘The MRLC’. This consortium is comprised of
agencies that frequently use or depend on regular imagery, for their normal operations. Current members include the Environmental Protection Agency, United States Forestry Service, United States Geological Survey, LANDFIRE, United States Department of Agriculture, NASA, United States Fish and Wildlife Service, National Oceanic and Atmospheric Administration, Bureau of Land Management, National Park Service, and the Office of Surface Mining Reclamation and Enforcement.

Since the inception of this consortium, Landsat imagery has been used to take wide spectrum images of the United States. In 1999, the newest program, Landsat 7 came online and allowed for the development of the National Land Cover Database (NLCD) in 2001. At its simplest, this database is an image of the surface of the entire United States. For the purposes of this consortium, they used high resolution image types specifically designed to allow for the capture of data pertaining to canopy cover, open land, and impervious structures (buildings, roads, etc.). While it is possible to acquire the entire image of the United States, individual subsets of the database can be obtained to deal with specific analysis projects. The database readily provides three different images for use in analysis, which are 1) general land cover, 2) developed impervious, 3) tree canopy.

The first image is of the general land cover. This satellite image displays to study area devoid of any specific filters. Essentially, this is how the satellite initially reads the image it has developed. While some of the colors in this image are intuitive (green for vegetation, blue for water, yellow/brown for agriculture), the shades of red represent physical structures (roads, buildings, etc.). This works as a foundation for comparison against the other available images.
The second image is labeled ‘developed impervious’. Unlike the first image, a filter is used to distinguish only the constructed physical structures within in the study area. With the filter in place, this image gives a much clearer view of physical structures throughout this area.
Most of the surfaces depicted are man-made and tend to be extremely dense, as is the case with cities – large stretches of land will have incredibly dense portions of ‘developed impervious’, due to the high volume of structures, and roads. From this image, Vue will be able to establish all the points within this study area where canopy cover cannot, or does not exist. This image, in coordination with the third image, will be referenced against the general land cover image to build the analysis.

The third image illustrates tree canopy. This image is a satellite filtered image, portraying only canopy cover within the study region. The standard surface is left an off-white shade, while all vegetation is displayed in the vibrant green. This image acts as a point of reference against the impervious image. It shows the spread and density of contemporary canopy cover.

![Figure 3. MRLC Canopy Cover Image for Study Area](image.png)
Using these three separate but comparable images within a modeling framework, certain characteristics about an environment, and more specifically the tree canopy, can be ascertained.

**Tools for Analyzing the Tree Canopy**

The United States Forestry Service has developed tools to monitor canopy cover and urban forestry throughout the United States. I-Tree is a suite of individual tools specifically designed to work with Geospatial and Remote Sensing data. The tool, I-Tree was initially released in 2006 with the goal of helping local communities and organizations better understand their ‘tangible ecosystem’. I-Tree has analysis capability ranging from water runoff to pollution control.

One of the I-Tree remote sensing tools is Vue. Designed as an initial overview analysis tool, Vue helps the user build a broad understanding of the nature of a community’s urban forest as well as the current benefits associated with the tree population. Vue is a tool designed to help gain a basic understanding of urban forestry. More complex analysis tools are available. In addition to current forestry data, Vue is capable of creating general models of urban forestry growth or reduction. Vue was designed so that it would seamlessly work with national data sources, like the Multi-resolution Land Characteristics Consortium. During the analysis of remote sensing data, Vue breaks up the images into specific land category types. These land category types are based on the amount and type of surface (vegetation, water, concrete, etc.) found in each pixel of the images. The relevant land types are such:

**Land Cover Types**

*Open Water* - All areas of open water, generally with less than 25% cover of vegetation or soil.
**Developed, Open Space** - Includes areas with a mixture of some structures, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

**Developed, Low Intensity** - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

**Developed, Medium Intensity** - Includes areas with a mixture of structures and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. These areas most commonly include single-family housing units.

**Developed, High Intensity** - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.

**Deciduous Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

**Evergreen Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
**Mixed Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

**Shrub/Scrub** - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

**Pasture/Hay** - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

**Cultivated Crops** (Agriculture) - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

(United States Department of Agriculture Forest Service, 2010)

**Pollution Report**

A typical pollution report will provide all pollution removal and value estimations for each broad land type category. Additionally, each of these broad groups can be separated into a series of smaller subset land types. This allows for specific pollution reduction estimations for targeted land type categories if needed by the user. The reports generated by this analysis include:

**Carbon Storage**: The carbon storage output report estimates the total carbon (and carbon dioxide equivalents) stores in the total urban forest. This is a cumulative value
based on the approximate age of the canopy, and the total amount of carbon absorbed by
the canopy till the point of conducting the analysis.

**Carbon Sequestration:** The carbon sequestration report estimates the annual
carbon (and carbon dioxide equivalents) sequestered each year by the urban forest.

**Carbon Monoxide CO pollution removal:** The CO pollution removal report
estimates the amount of carbon monoxide removed by the urban forest annually.

**Nitrogen oxides NO2 Pollution removal:** The NO2 pollution removal report
estimates the amount of Nitrogen Dioxide removed by the urban forest annually.

**Ozone O3 pollution removal:** The O3 pollution removal report estimates the
amount of Ozone (smog) removed by the urban forest annually.

**Sulfur oxides SO2 pollution removal:** The SO2 pollution removal report
estimates the amount of sulfur dioxide removed by the urban forest annually.

**PM10 pollution removal:** The PM10 pollution removal report estimates the
amount of small particulate matter removed by the urban forest annually.

Once an image is analyzed, Vue will generate air pollution removal estimates for each
pollution type. The average pollution removal values used to make these estimations are based
on the Urban Forestry Effects (UFORE) model (Nowak & Crane, 2000). Nowak and Crane’s
(2000) UFORE model is designed to extrapolate large scale changes in air pollutants based on
random sampling of tree populations throughout a study region. It should be noted that because
of the nature of this Vue analysis, the pollution removal values are uniform for the entire canopy
within the study area. In addition to the estimated amount of pollutant removed, Vue provides a
dollar value estimate associated with the reduction in each pollutant.
The value of carbon storage is derived from estimations of the marginal social costs of carbon dioxide (Fankhauser, 1994). The individual economic value of each pollutant removed was taken from the national average values used for the creation of energy policy (Murray, Marsh, & Bradford, 1994). These values are calculated from studying the overall macro-scale effects on pollutants on communities. To determine the costs of a pollutant to society, a series of externalities are considered, ranging from associated health costs, land depreciation, crop loss/damage, potential years of life lost, etc. In all instances, these values are estimates based on gauging the effect of the pollutants on all reasonable externalities. All estimates have been adjusted to better reflect current economic trends (United States Department of Agriculture Forestry Service, 2010).

**Methodology**

This analysis quantified the role of urban forestry in reducing air pollutants in the Dayton, Ohio metropolitan area. This was based on a geospatial analysis tool developed by the United States Forestry Department, called I-Tree Vue. To conduct this analysis, data was retrieved from the Multi-Resolution Land Characteristic Consortium. This output was used to develop estimations about the scale of canopy cover in this study area, and the capability of this canopy to removal air pollutants. In addition to an initial analysis of canopy cover, two separate scenarios were modeled. The first scenario assumed a significant growth in urban forestry – to 25% of the total study area land surface. The second, assumed a 10% decrease in canopy cover. The first model was used to mimic changes that might be associated with a large urban planting project. The second model was used to display the potential damage to be caused in this study area by the emerald ash borer.
The data from this region was most recently available from Spring of 2006. Using the database available through the MRLC, the images for land cover, canopy cover, and developed impervious targeting the area surrounding Dayton, Ohio was retrieved. The area captured in the initial images was beyond the scope of the analysis. To provide a more detailed assessment the images were enlarged to specific parameters using ArcMap prior to analysis. To be certain that all major neighborhoods of Dayton were included in the analysis, the boundaries associated with Dayton neighborhood councils were used as a template. These councils are called priority boards, and are formally linked to the government of the City of Dayton.

![Figure 4. Untrimmed Canopy Image, Study Area Highlighted](image)

Figure 4 is an unaltered canopy cover image from the MRLC database. The red outlines represent the boundaries of the Dayton, Ohio neighborhood councils. Using the clipping function in ArcMap, the original canopy cover image is trimmed to fit the boundary lines for Dayton based on the Priority Boards. Trimming the original images helps to target the area of analysis more accurately to Dayton, Ohio. As a tool, Vue requires a square image for
comparison purposes. Additionally, the neighborhood councils are used as a means to center the analysis, but do not present the entire population of the city metro area.

Figure 5. Trimmed Canopy Image, Study Area Highlighted

Figure 6. Trimmed Impervious Image, Study Area Highlighted
Figure 6 displays the developed impervious data for the same area. The trimmed image services the purpose of both narrowing the scope to a more accurate analysis, while still incorporating much of the population of Dayton, and the metro area. These three images were referenced against one another in Vue. During this comparison, Vue measures the amount of canopy cover, open land, water, and impervious surface in each pixel of the image. Each pixel translates to roughly 30 meters on the earth’s surface. Based on this analysis of each image pixel, Vue calculates the estimation of the total canopy cover within the study area.

After having calculated the total amount of canopy cover, Vue will multiple this value by data for the average rate of pollution removal by acre of canopy cover. As with this analysis, in the event specific study area sample data regarding tree age, type, pollution absorption, leaf characteristics, rainfall, and temperature cannot be provided for the study area – generalized national averages from the Forestry Service will be used to calculate pollution reduction. Once the total removed pollution is estimated for each pollution type (SO2, Carbon, NO2, Ozone, PM10), the estimation is multiplied by the Department of Energy economic values attributed by tonnage to each pollutant. Upon completion of these calculations, Vue generates the study area output with all relevant canopy, pollution reduction, and economic variables.

**Results**

The initial analysis in Vue was to characterize the benefits of the current urban forests of Dayton, Ohio. The specific area of study is the metropolitan area of Dayton, Ohio. This area encompasses dense city sections as well as rural agricultural lands. The entire surface area of the trimmed images is approximately 102,445 acres.
Figure 7 details the distribution of the total study area, by land type category. ‘Developed’ land accounts for the biggest portion of the total Dayton, Ohio study area at 77.1%. The next largest category of land type within the study area is ‘Agriculture’, at 13.4% of total surface area. Only 9% of the study area is categorized as ‘Forest’. Less than 1% of the study area is comprised of ‘Wetlands’ (0.5%) and ‘Miscellaneous’ (0.1%).

Table 2 displays the general assessment of canopy cover throughout the Dayton, Ohio study area. Canopy cover accounted for roughly 16.5%, or 16,648 acres of land surface. Impervious cover (a subset of ‘developed’ that is land devoid of canopy due to man-made
construction) accounted for a little over a quarter of land surface at 25,435 acres and approximately a third of total ‘developed’ land. When categorized, the canopy was nearly equally divided between developed land (8,023 acres) and forest land (7,165 acres). In addition to these two main general land types, land used for agriculture was also a significant portion of the study area. Agriculture accounted for 13,517 acres of the study area, and provided 1,268 acres of canopy cover. It should be noted that extremely small portions of the study area also fell into wetland (458 acres) and miscellaneous (63 acres) land types. Approximately 1787 acres of surface land was labeled water.

The data shows that the canopy cover is asymmetrically distributed throughout the study area. The ‘Developed’ land covers 77.1% of the total Dayton, Ohio study area, but only accounts for 48% of total canopy cover. ‘Forest’ land spans a significantly smaller portion of the total study area at 9%, yet accounts for 43% of total canopy cover.

### Carbon Storage

<table>
<thead>
<tr>
<th>Land Cover Type in Dayton, Oh Study Area</th>
<th>Tree Canopy (%)</th>
<th>Carbon Storage (tons)</th>
<th>Estimated Value ($USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed</td>
<td>10.3</td>
<td>325,690</td>
<td>6,736,514</td>
</tr>
<tr>
<td>Forest</td>
<td>79.2</td>
<td>290,853</td>
<td>6,015,958</td>
</tr>
<tr>
<td>Wetland</td>
<td>39.4</td>
<td>7,311</td>
<td>151,227</td>
</tr>
<tr>
<td>Agriculture</td>
<td>9.4</td>
<td>51,461</td>
<td>1,064,205</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>18.5</td>
<td>470</td>
<td>9,719</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>675,785</strong></td>
<td><strong>13,977,623</strong></td>
<td></td>
</tr>
</tbody>
</table>

The first metric generated by the Vue analysis was carbon storage (Table 3). Carbon storage refers to the total amount of carbon currently stored in the tree population of a given study area. The calculation is based on a general average values associated with tree growth and carbon uptake rate. The Dayton metro study area canopy cover was estimated to contain
675,785 tons of carbon. Using the policy values from the Department of Energy, estimated value of this carbon would be USD $13,977,623. Both ‘developed’ land, and ‘forest’ land were responsible for similar percentages of the total carbon stored, 48% and 43% respectively.

**Air Pollution Removal**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Removed (tons)</th>
<th>Estimated Value ($USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Sequestration</td>
<td>22,278</td>
<td>462,807</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>102</td>
<td>913,467</td>
</tr>
<tr>
<td>Ozone</td>
<td>243</td>
<td>2,182,586</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>51</td>
<td>112,820</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>178</td>
<td>1,065,193</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>4,736,873</strong></td>
<td></td>
</tr>
</tbody>
</table>

The analysis shows levels of air pollutant removal for all measurable pollutants (Table 4). For this study area, the estimated value for the total pollutants removed was approximately USD $4,736,873. Vue estimates that the urban forests sequester over 22,000 tons of carbon every year. When considering the value of pollutants removed, carbon accounts for approximately 10% of the total value. The canopy cover within the study area was estimated to be responsible for the removal of 102 tons of nitrogen dioxide, at 19% of total removed value. Through the cooling of local ambient air, the urban forests within the Dayton metro study area are estimated to remove or inhibit 243 tons of ozone at 46% of the total value of removed pollutants. Through the absorption of sulfur dioxide (SO2) through the leaf surface, the Dayton metro study area canopy cover was estimated to remove 51 tons of sulfur dioxide at 2% of the value of total removed pollutants. While tree leaves are not capable of chemically absorbing most types of particulate matter, Vue estimates the ability of large forestry clusters in the Dayton metro study
area were estimated to physically capture or inhibit 178 tons of particulate matter (PM10) accounting for 22% of the value of total pollutants removed. In analyzing the actual value of each pollutant reduction, the reduction in ozone accounts for the highest percentage of total pollution reduction value, roughly 46% of the total economic value of pollution reductions. This is despite removing far less tonnage of ozone than carbon dioxide.

**Future Modeling**

Two separate future models were run within the Vue construct. The first was an increase in the total canopy cover to 25% of the total study area. As one would expect, there are significant gains and losses in the respective models. Along with these models, Vue creates a general image of possible tree growth, only allowing canopy expansion in areas where it would be physically possible (not within a grid space labeled developed impervious).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Volume (tons)</th>
<th>Value (USD)</th>
<th>Volume (tons)</th>
<th>Value (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Sequestration</td>
<td>22,279</td>
<td>460,807</td>
<td>33,714</td>
<td>697,327</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>102</td>
<td>913,467</td>
<td>154</td>
<td>1,382,325</td>
</tr>
<tr>
<td>Ozone</td>
<td>243</td>
<td>2,182,586</td>
<td>368</td>
<td>3,302,849</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>51</td>
<td>112,820</td>
<td>78</td>
<td>170,727</td>
</tr>
<tr>
<td>Particulate Matter (10)</td>
<td>178</td>
<td>1,065,193</td>
<td>269</td>
<td>1,611,927</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>22,852</strong></td>
<td><strong>4,734,873</strong></td>
<td><strong>34,581</strong></td>
<td><strong>7,165,155</strong></td>
</tr>
</tbody>
</table>

Table 5 and Figure 7 show the increased pollution reduction associated with expanding the canopy cover to 25% of the total Dayton, Ohio study area. When increasing the total area of canopy cover, we see a dramatic increase in the amount of total pollutants removed from the air. This expansion of canopy cover equates to a total increase of 50% in pollution reduction. As the increased reductions are uniform across all pollutants, Carbon is the most heavily removed
pollutant (33,714 tons), while the plurality of benefit rests with the removal of ozone (46% of total economic benefit).

Table 6 displays the projection data for a 10% reduction in canopy based on the threat posed by the emerald ash borer. When studying the possible reduction in canopy due to the Emerald Ash Borer infestation, we measure the impact on pollutant reduction due to the 10% decrease of canopy cover. As would be assumed with a loss of canopy cover, we see decreases in overall reduction of pollution - a steady 10% decrease in the reduction of measure air pollutants. In both scenarios, the additional reductions are uniform across all pollutants. Carbon is the most heavily removed pollutant (33,714 tons), while the plurality of benefit rests with the removal of ozone (46% of total economic benefit).
Discussion

The current geospatial analysis highlights the importance of urban forestry in possible reductions in air pollutants in the Dayton, Ohio region. Canopy cover was found to play a role in the reduction of all measured pollutants. Annually, over 22,000 tons of carbon is sequestered by the study area canopy cover. The carbon sequestration is responsible for 10% of total pollutant removal value. The canopy cover is estimated to remove 102 and 51 tons (19% and 2% removal value) of Nitrogen Dioxide and Sulfur Dioxide, respectively. Most impressively, the canopy either inhibits or removes approximately 243 tons of Ozone annually or 46% of total removal value. Canopy cover within the Dayton, Ohio study area reduced the amount of airborne particulate matter by approximately 178 tons, equating to a removal value of 22%. We also observed the shifting capability of the urban forest to aid pollution reduction, as it related to growth or reduction in the canopy cover of the study area. The expansion of canopy cover to 25% of the total study area resulted in increased reduction of all pollutants by roughly 50%.
10% reduction in canopy cover designed to mimic the outcome of the Emerald Ash Borer infestation, accounted for a loss of 10% pollution reduction capability.

The total percentage canopy cover of the study area fell below the majority of cities already analyzed by the Forestry Service (United States Forestry Service, 2010). At 16.5% canopy cover, the Dayton, Ohio study area surpasses only Calgary (7.3) and Philadelphia (15.7). This may be due to the parameters used to define the study area. It is possible that the means for establishing a study area for any of the cities in question was not consistent with this analysis. Regardless of the way in which the Dayton, Ohio study area is referenced against other cities, it clearly falls short of the advised goal of 35 to 40% urban canopy cover proposed by American Forests (2010).

The analysis of canopy cover by land type illustrated the magnitude of developed surface within the study area. A remarkably small portion (10%) of the ‘developed’ land is canopied. Because of the poor canopy cover of the ‘developed’ land within the study area, when compared to ‘forest’ land, ‘developed’ land canopy accounts for only a slightly higher amount of pollution reduction (48 percent/43 percent), despite being over eight times larger. This means that in the most densely travelled and populated areas there is the smallest portion of canopy cover. However this also means that as only 10% of ‘developed’ land is canopied, and roughly 25% of ‘developed’ land is graded impervious, a sizeable portion (approximately 65%) of ‘developed’ land can potentially sustain canopy expansion. This is particularly noticeable in the projection output image for a canopy expansion to 25% of total study area. The image illustrates the sheer volume of space capable of being exploited for canopy expansion.

The analysis of the canopy cover mirrored reductions of air pollutants consistent with prior studies (Nowak, 2000; Taha, 1996). As was seen with both Nowak (2000), and Taha’s
studies, reduction spanned the entire cross section of pollutants targeted. In the case of the majority of the pollutants (NO$_2$, SO$_2$, Carbon, VOCs, and Particulate Matter), the leaf surface of the canopy is largely responsible for the pollution reductions. The pollutant reductions in the analysis are based on generalized tree pollution absorption numbers (Nowak, 2010), but help to create an image of the overall benefits of urban forestry. As the generation of ozone requires higher ambient temperatures (Environmental Protection Agency, 2011), reductions in ozone closely reflect the temperature reducing capacity of trees (Taha, 1997). In the initial analysis and the scenario models, the most heavily removed pollutant was carbon. This was consistent with prior findings in assessments by Taha (1997) and Nowak (2000).

As air pollution is correlated to a myriad of health conditions (Pope, 2000) these reductions in pollution would help reduce the likelihood of adverse health outcomes within the study area. The reductions in oxides (NO$_2$, SO$_2$), may help decrease incidence of respiratory infections (Chauhan et al., 1998), lung lesions (Kampa, 2008), and asthma (Kampa, 2008). In addition removal of particulate matter would diminish the risk of upper respiratory tract (Brook, 2008), and pulmonary conditions (Kampa, 2008).

Perhaps the most significant benefit from tree canopy is their role in reduction of ozone. Ozone is particularly important as its harmful effects on the body are closely related to the concentration of ozone inhaled (Holtzmann & Cunningham, 1979). Therefore, reductions of any level of ozone are significant. Lower levels of ambient ozone would protect upper respiratory tract and lungs (Folinsbee, 1993). The effects of ozone on the body are especially dangerous to at-risk populations like asthmatics, or those suffering from COPD, as it can exacerbate these conditions (Postma, 1998).
In both the initial analysis and the future scenarios, the greatest plurality of overall economic benefit due to pollution reduction stemmed from the removal of ozone. In the growth scenario, an increase in pollution reduction of approximately 50% was observed. In the 10% canopy loss scenario, a 10% reduction in pollutant removal was calculated. It should be noted however, that the projected gains/losses in ozone reduction during the scenario analysis are not congruent with results from Taha’s (1997) projections in the Los Angeles model. This is likely due the added complexity of Taha’s methodology and models. The addition of sampling local vegetation for pollution reduction values, as well as expanding the model with topographic, meteorological data, and air shed data would allow for a more accurate depiction of future pollution reductions/gains (Taha, 1997).

The demonstrated role of tree cover in removal of carbon from the ambient air is significant in two aspects. Firstly, carbon monoxide exposure is toxic to humans. However environmental concentrations of carbon monoxide are generally low and potentially harmful exposure levels are uncommon (Badman & Jaffé, 1996). Regardless of this fact, carbon monoxide will oxidize in open air to become carbon dioxide (Folinsbee, 1993). Carbon dioxide is a global warming gas (Environmental Protection Agency, 2010). Due to this fact the removal of carbon dioxide, like that estimated in the current analysis, will help in a long term and widespread effort to offset global warming (Environmental Protection Agency, 2010).

In addition to the actual tonnage of pollutants removed, this analysis also applies a monetary value to the pollution reductions. These values are derived from Fankhauser (1994) and Murray, Marsh, and Bradford’s (1994) studies on formulation of energy policy. Based on the monetary value of the pollutants removed, the most important benefits in the current analysis were for ozone removal. Murray and colleagues’ (1994) calculations point to ozone as being one
of the more ‘valuable’ gases to be removed from the ambient air. Our findings support this observation; and reinforce the benefits of urban forestry in passively reducing ozone. As the most heavily removed pollutant, Carbon is by far considered the ‘least valuable’ of any pollutant measured. While Carbon has been shown to be potentially harmful to humans (Badman & Jaffé, 1996), it fails to effect significant economic factors (United States Forestry Service, 2010). This is likely due to the extremely unlikely nature of medical conditions specifically related to Carbon Monoxide, or Carbon Dioxide inhalation (Badman & Jaffé, 1996).

In the projection models for increasing and decreasing tree canopy, significant findings in pollutant removal were noted. The first scenario projects an increase of the canopy cover to 25% of the total study area. This expansion of canopy cover translates to roughly 50% additional reduction in air pollution. This would be a significant improvement in overall air quality which could cut the risk of a number of associated human health risks (Kampa, 2008).

The second projection models the Emerald Ash Borer infestation that could potentially decrease the canopy cover across the study area by ten percent (Mason, 2010; Ohio Department of Agriculture, 2010). This would decrease the total air pollutant removal capacity in the study area by ten percent. To counter the threat of the emerald ash borer on tree population, concerted efforts to expand canopy cover would be needed (Mason, 2010).

Both of these scenario projections are stifled by incomplete data. Under optimal settings, the Vue model is designed to incorporate local agroforestry data to aid in calculations. This data is generally gained through the use of specific instrumentation and measurement of a number of factors in a study area. As this analysis was confined beyond the means to generate this data, the national average agroforestry data had to be used in place of locally specific information. This makes all projections based on uniform tree type/pollution reduction. Due to this, the projections
are at best guidelines for understanding possible positive and negative aspects of changes in canopy cover.

**Future Study**

As mentioned prior, the modeling tool used in this analysis is one of the preliminary programs used in the field. It is designed to help gain some knowledge of a community’s canopy and understand some of the general benefits it entails. Because of the entry-level nature of this tool, much of the analysis is based on state and national averages. A route for future study would be to expand the accuracy of this analysis by using more advanced tools to increase the effectiveness of the modeling in I-Tree. Specifically, I-Tree Eco and I-Tree Street would aid in this analysis. Both of these tools would require a substantial amount of time and capital to undergo, but would help better describe the types of vegetation in a given study area, and the capabilities of that vegetation to remove pollutants, store carbon, inhibit soil erosion, and reduce ambient temperatures.

A secondary avenue for study would be incorporating the canopy data and referencing it against recreation data from different neighborhoods within a study area. As there is evidence to suggest that people that live in areas with greater accessibility tend to be more physically active – it would be interesting to see if this is both true in a study area like Dayton, as well as if changes in recreational venues (like planting projections, new bike/walking paths, park construction) shift the data.

**Limitations**

The entry level nature of the modeling tool is the greatest limitation of the study. As mentioned prior, it requires the use of generalized data based on state and national averages. The more closely the study area resembles the state and national averages, the stronger the study.
However, the best possible way to run this analysis would be to use instruments to sample current study area vegetation and use these measurements as opposed to the generalized parameters. Furthermore, I-Tree Vue assumes that all trees are essentially the same in size/age. This is significant in modeling gains and reductions. Because all trees are the same, modeling any new growth assumes the new vegetation are full grown adult trees, providing roughly the same canopy per tree as every other tree. This is not the case in nature as different types of trees come in differing sizes and create variable canopies. Peer reviewed literature has also pointed to a potential for the I-Tree Vue tool to overestimate canopy cover by as much as 12% at times (this is more common in areas of little developed impervious structure). As well, the analysis data created by Vue is rounded. This reduces some levels of accuracy.

Further, the use of the Multi-Resolution Land Characteristics Consortium Database could also be considered a limitation. The images from the database are taken by a sophisticated satellite, are not flawless. The images themselves are susceptible to problems with weather, clouds, and shadows. In the images, one pixel reflects 30 meters of surface - this resolution may not be sufficient in all situations to allow for land type classification. However, there are strengths to this analysis. An innovative combination of GIS tools was used to address a public health issue. The economic value of tree canopy cover was calculated.

Conclusion

This geospatial analysis highlights the importance of urban forestry in possible reductions in air pollutants. Urban forestry acts as both an active and passive inhibitor of urban air pollution. Urban forestry should always be considered when planning future developments within any community. Forestry is should be a worthy component to any pollution mitigation strategy, and current urban forests and tree populations need to be actively protected. In the
event of the Ash Borer infestation action should be taken to protect current resources, and/or expand urban forestry efforts to counter any potential loss of canopy cover.
References


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169-176.


from: http://www.epa.gov/pm/health.html.


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Perspectives, 100*, 45-65.

Friedman, M. S. (2001). Impact of Changes in Transportation Behaviors During the 1996


Nowak, D., & Greenfield, E. (2010). Evaluating the National Land Cover Database Tree Canopy and Impervious Cover Estimates Across the Conterminous United States: A


Appendix A – List of Public Health Competencies Met

<table>
<thead>
<tr>
<th>Specific Competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain #1: Analytic Assessment Skill</strong></td>
</tr>
<tr>
<td>Defines a problem</td>
</tr>
<tr>
<td>Determines appropriate uses and limitations of both quantitative and qualitative data</td>
</tr>
<tr>
<td>Selects and defines variables relevant to defined public health problems</td>
</tr>
<tr>
<td>Identifies relevant and appropriate data and information sources</td>
</tr>
<tr>
<td>Evaluates the integrity and comparability of data and identifies gaps in data sources</td>
</tr>
<tr>
<td>Applies ethical principles to the collection, maintenance, use, and dissemination of data and information</td>
</tr>
<tr>
<td>Partners with communities to attach meaning to collected quantitative and qualitative data</td>
</tr>
<tr>
<td>Makes relevant inferences from quantitative and qualitative data</td>
</tr>
<tr>
<td>Obtains and interprets information regarding risks and benefits to the community</td>
</tr>
<tr>
<td>Applies data collection processes, information technology applications, and computer systems storage/retrieval strategies</td>
</tr>
<tr>
<td>Recognizes how the data illuminates ethical, political, scientific, economic, and overall public health issues</td>
</tr>
</tbody>
</table>

| **Domain #2: Policy Development/Program Planning Skills** |
| Collects, summarizes, and interprets information relevant to an issue |
| States policy options and writes clear and concise policy statements |
| Identifies, interprets, and implements public health laws, regulations, and policies related to specific programs |
| Articulates the health, fiscal, administrative, legal, social, and political implications of each policy option |
| Utilizes current techniques in decision analysis and health planning |
| Decides on the appropriate course of action |
| Develops a plan to implement policy, including goals, outcome and process objectives, and implementation steps |
| Translates policy into organizational plans, structures, and programs |
| Prepares and implements emergency response plans |
| Develops mechanisms to monitor and evaluate programs for their effectiveness and quality |

| **Domain #3: Communication Skills** |
| Communicates effectively both in writing and orally, or in other ways |
| Solicits input from individuals and organizations |
| Advocates for public health programs and resources |
| Leads and participates in groups to address specific issues |
| Uses the media, advanced technologies, and community networks to communicate information |
| Effectively presents accurate demographic, statistical, programmatic, and scientific information for professional and lay audiences |

| **Attitudes** |
| Listens to others in an unbiased manner, respects points of view of others, and promotes the expression of diverse opinions and perspectives |

| **Domain #4: Cultural Competency Skills** |
| Utilizes appropriate methods for interacting sensitively, effectively, and professionally with persons from diverse cultural, socioeconomic, educational, racial, ethnic and professional backgrounds, and persons of all ages and lifestyle preferences |
**Domain #4: Cultural Competency Skills**

**Attitudes**
- Understands the dynamic forces contributing to cultural diversity
- Understands the importance of a diverse public health workforce

**Domain #5: Community Dimensions of Practice Skills**

- Establishes and maintains linkages with key stakeholders
- Collaborates with community partners to promote the health of the population
- Identifies how public and private organizations operate within a community
- Accomplishes effective community engagements
- Identifies community assets and available resources
- Develops, implements, and evaluates a community public health assessment
- Describes the role of government in the delivery of community health services

**Domain #6: Basic Public Health Sciences Skills**

- Identifies the individual’s and organization’s responsibilities within the context of the Essential Public Health Services and core functions
- Defines, assesses, and understands the health status of populations, determinants of health and illness, factors contributing to health promotion and disease prevention, and factors influencing the use of health services
- Understands the historical development, structure, and interaction of public health and health care systems
- Identifies and applies basic research methods used in public health
- Applies the basic public health sciences including behavioral and social sciences, biostatistics, epidemiology, environmental public health, and prevention of chronic and infectious diseases and injuries
- Identifies and retrieves current relevant scientific evidence
- Identifies the limitations of research and the importance of observations and interrelationships

**Attitudes**
- Develops a lifelong commitment to rigorous critical thinking

**Domain #7: Financial Planning and Management Skills**

- Applies budget processes
- Develops strategies for determining budget priorities
- Monitors program performance
- Manages information systems for collection, retrieval, and use of data for decision-making
- Conducts cost-effectiveness, cost-benefit, and cost utility analyses

**Domain #8: Leadership and Systems Thinking Skills**

- Creates a culture of ethical standards within organizations and communities
- Helps create key values and shared vision and uses these principles to guide action
- Identifies internal and external issues that may impact delivery of essential public health services (i.e. strategic planning)
- Facilitates collaboration with internal and external groups to ensure participation of key stakeholders
- Promotes team and organizational learning
- Contributes to development, implementation, and monitoring of organizational performance standards
- Applies the theory of organizational structures to professional practice