The Effect of Environmental Variables on Local West Nile Virus Infection Rates
in Culex Mosquitoes Using an ‘Ecological Niche’ Model

A dissertation presented to
the faculty of
the College of Arts and Sciences of Ohio University

In partial fulfillment
of the requirements for the degree
Doctor of Philosophy

Francis Charles Hart
June 2010

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This dissertation titled

The Effect of Environmental Variables on Local West Nile Virus Infection Rates in

*Culex* Mosquitoes Using an ‘Ecological Niche’ Model

by

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ABSTRACT

HART, FRANCIS CHARLES, Ph.D., June 2010, Biological Sciences

The Effect of Environmental Variables on Local West Nile Virus Infection Rates in Culex Mosquitoes Using an ‘Ecological Niche’ Model (124 pp.)

Director of Dissertation: Mario J. Grijalva

West Nile Virus (WNV) has recently appeared in the United States in the New York City area in 1999. In 2002, a significant outbreak occurred in Ohio. Cuyahoga County recorded nearly half the deaths in the state. Consequently, important public health resources have been focused on the surveillance, study, and prevention of this vector-borne disease. Like many states, Ohio has suitable vector species, such as those in the genus Culex, capable of transmitting the infection and maintaining the mosquito-bird life cycle of West Nile Virus. Surveillance relative to arboviruses in mosquitoes involves dipping for larva and trapping adults to determine the frequency of WNV infection in order to target control measures to prevent disease. These activities are expensive and labor intensive.

This study demonstrates the utility of geographic information system (GIS) analysis as an adjunct in disease surveillance activities. It examines environmental factors using an ‘ecological niche’ model. Various risk maps were generated and map analyses conducted to establish endemic levels, direction of spread, risk areas, possible relationships with environmental factors, and implications for human disease in Cuyahoga County, Ohio. Over a five year period (2003-2007), environmental variables in half mile trap buffer areas were compared to MIR positivity using logistic regression
analysis. Soil type, slope, land use, catch basins, wetlands, and one and two month average precipitation and one month average temperature were not found to be significant contributors to WNV positivity at this scale. Two month average temperature was significant (p<0.0001). Old type catch basins that hold water seems to be associated with MIR positivity when mapped, and this may explain the lack of significance in the natural environmental factors studied. Catch basin type was not significant however in this study (p<0.182) in logistic regression models that used the first NCLD land use categorization; although continuing work is demonstrating the significance of catch basin type when land use is appropriately categorized. Differences between mosquito breeding in urban/suburban communities with extensive catch basin systems and in rural areas are discussed in reference to the findings of this study

Approved: _____________________________________________________________

Mario J. Grijalva
Associate Professor of Biomedical Sciences
ACKNOWLEDGMENTS

I would like to thank my advisor Dr. Mario Grijalva of the Department of Biomedical Sciences, Tropical Disease Institute, for his guidance and advice during this project; as well as my committee members, Dr. William Romoser, Department of Biomedical Sciences, Tropical Disease Institute, and Dr. Gillian Ice, Department of Social Medicine at Ohio University, and Dr. Jeffrey Ueland, Department of Geography, Bemidji State University, Minnesota. Their willingness to work with a non-traditional doctoral student over many years is very much appreciated.

I would also like to thank Dr. Alexander Sergeev from the School of Public Health Sciences & Professions at Ohio University for his statistical advice and our many conversations about this work and Darren Cohen of the Ohio University, Voinovich School of Leadership & Public Service for his help and insights during the GIS work on this project. I have also benefited from the friendly debate and counsel of my friends and colleagues at the Ohio University Dept. of Environmental Health & Safety over many years.

In addition, my collaborators at the Cuyahoga County Board of Health, Joe Lynch RS, and Chris Bauer RS, were invaluable and made this work possible. Their professionalism and willingness to cooperate on this study is much appreciated. I would like to thank the Ohio Mosquito Control Association (OMCA) for support of this work.
I would like to dedicate this work to my wife Chris, whose love and support have always been my strength and inspiration; and to my children Charles, Erin, and Alison and their families who continue to make my life and work a joy each day.
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CHAPTER 1: INTRODUCTION

Background

West Nile Virus (WNV), a mosquito-borne flavivirus, is a member of the Japanese encephalitis group. This group includes the St. Louis, Japanese, Kunjin, and Murray Valley encephalitis viruses (1). The first known case of WNV occurred in 1937 in Uganda. Since that time, cases have been reported from Africa, the Middle East, Europe, and Asia. In the 1950-60’s cases occurred in Egypt, Israel, France, and in South America in the 70’s. Cases have been reported in Romania, Morocco, Italy, Russia, and more recently North America in 1999 (2).

WNV is a febrile infection that is typically mild or asymptomatic; however neuroinvasive disease can occur in a small number of patients, especially the elderly. The case fatality rates in the United States (U.S.) are around 7% overall and a little higher among persons with neuroinvasive disease (1). The clinical presentation of WNV is reviewed in the literature (3, 4). Long term outcomes in WNV neuroinvasive disease patients is not fully known; however in one study, 37% of patients fully recovered within one year (5).

*Culex* species have been identified as important competent vectors in WNV transmission, and *C. pipiens*, *C. rustuans* and *C. salinarius* are particularly important in the northeastern U.S. (6, 7). Although *Culex* are the primary mosquito vectors, numerous genera and species are competent transmitters and have been found to be infected throughout the world. WNV has been found naturally in some 64 species of mosquitoes in the U.S. since 1999 (8). *Culex pipiens* was the most likely primary vector of WNV in
the New York outbreak in 1999 that introduced WNV to the United States (9). Birds are the primary reservoir for WNV. Although Culex species are less competent than some mosquito vectors of WNV, they are important because they maintain the disease in the bird population. Vector competence and the effects of temperature on vector competence are important issues in WNV transmission (7, 10, 11). Genome sequencing in exotic birds from the NYC zoo in 1999 indicated that the WNV strain as it initially appeared in the United States (U.S.) was closely related to the virus isolated from a goose in Israel in 1998 (12).

In the New York outbreak, overwintering adult mosquitoes and transovarial transmission were thought to be maintenance mechanisms that facilitate re-establishment of the disease cycle from year to year. Nasci, et al. (13) studied overwintering mechanisms in New York City (NYC) and found unexpectedly low transovarial transmission rates (0.04%) in adult mosquitoes overwintering in storm sewers and catch basins. Approximately 88% of the overwintering Culex mosquitoes were caught in structures built into hillsides or constructed of thick granite block or concrete (13). Temperature is an important factor in overwintering and in the development of the disease as weather warms in spring (14). Although Culex species appear to be the most important vectors of WNV in Ohio as well, many other species serve as bridge vectors in humans (15). Culex mosquitoes maintain the natural cycle of WNV in the bird populations; however, other species that are less discriminate biters can serve as bridge vectors, carrying the disease to other
mammals and humans. Although their role in the maintenance of the disease in nature is not known, ticks can be experimentally infected as well (2).

The natural cycle of WNV disease involves mosquitoes and birds; however other animals, including man, can be infected (Figure 1). Culex mosquitoes feed preferentially on birds, which serve as reservoirs in the maintenance of the mosquito-bird infection cycle. Many species of birds can be infected; however corvids, such as crows and blue jays, appear to have greater susceptibility and suffer more serious adverse effects from the disease, especially in the United States (12, 16). The possibility that cloacal shedding of WNV may be a transmission method in birds has also been reported. (17).

![West Nile Virus Transmission Cycle](image)

*Figure 1. West Nile Virus transmission cycle (Centers for Disease Control).*

Humans, horses, and other animals are ‘dead end’ hosts and are insignificant sources of additional mosquito infection under normal circumstances. The USDA is engaged in studies of WNV infection in horses, due to their veterinary and monetary importance in the U.S. (18).
Bird mortality and mosquito infection rates from mosquito trapping have been used as sentinels (early warning surveillance systems) to predict the potential for human disease by public health agencies throughout the U.S. and the world for many years.

Epidemiology of WNV in the USA

The first WNV detection in the U.S. occurred in September, 1999 in New York City. Sixty two human cases and 7 deaths were attributed to the ensuing outbreak. Shortly afterwards, the virus was detected in New Jersey and three surrounding states. In 2000 it was detected in 12 states (2). The outbreak differed in a number of ways from previous outbreaks in other parts of the world. In particular, there was an unexpectedly high level of bird mortality among corvids, like blue jays and crows (20).

It is clear that U.S. ecosystems provide a suitable ecological niche for the virus (2). The virus spread quickly throughout the U.S., with cases in 44 states by 2002 and 46 in 2003. The first case in Canada was reported in August of 2001 (2). The virus has since spread across the U.S. and into Mexico and the Caribbean, where it was detected in October, 2001 in the Caymen Islands (2).

Much remains to be learned about the epidemiology of WNV in the U.S. Many geographic and environmental factors require further study to determine their relationship to WNV transmission in the U.S. The CDC recommended that studies of ecological features, like climatic factors and the dynamics of vector and reservoir populations could help determine risk areas (21). Some of the hypothetically important environmental variables were evaluated in this study.
WNV in Ohio and Cuyahoga County

WNV was first documented in Ohio in 2001. In 2002 an epidemic occurred in Ohio and positive mosquitoes were reported in all 88 counties (22). The Ohio Department of Health (ODH) compiles all WNV data for the state (Table 1). In 2001, both birds and mosquitoes tested positive for WNV in Ohio. In 2002 Ohio had an outbreak, their first human case of West Nile Virus, and 441 human cases in all. Human cases dropped to 15 in Ohio by 2008 and two in 2009. The yearly progression of WNV in Ohio through the years from 2001 to the present can be reviewed on the Ohio Dept. of Health (ODH) website (23). In 2002, nearly half the WNV deaths in humans in the state of Ohio occurred in Cuyahoga County. A seroprevalence study of 1,209 people in 819 households was conducted in Cuyahoga County in 2002, and indicated that approximately 1.9% were infected with WNV. Children were 4.5 times more likely to become infected, but 110 time less likely to develop neuroinvasive disease (24).

Extensive surveillance activities at local health departments and the Ohio Department of Health (ODH) have been on-going since 2001. Surveillance methods are discussed in this paper and the Ohio and national systems can be reviewed in the literature and on the web as well (1, 23, 25, 26). It remains to be seen what long term endemic levels develop in mosquitoes in Ohio and Cuyahoga County, but WNV is likely here to stay. Since WNV and other mosquito-borne diseases are present in Ohio, mosquito surveillance and control will remain important preventive health measures. Accordingly, studies such as this one are important, as we try to develop new surveillance tools that might be effective in disease prevention.
**WNV Surveillance**

To date, speculation about the spread and distribution of WNV in the U.S. has centered on the habits and migratory patterns of birds (27, 28). Dead birds have been used as an early warning system for human cases of WNV. Although bird deaths have been the best indicator of disease in local areas, this is not without its problems. The home range and migratory variability in bird species has been a confounding factor in proposed models of transmission. Few health districts have the ability to adequately monitor bird deaths. Bird testing is sporadic and many health districts have varying policies on testing. In Ohio, many districts have stopped testing birds mid-season or all together for financial or policy reasons, making it difficult to compare regions from year to year. In addition, bird deaths are usually isolated events and large bird ‘die-offs’ are rare. Sentinel flocks have generally not proven valuable as a surveillance tool on a large scale. The CDC has summarized surveillance activities in the U.S. (1).

Mosquito trapping has traditionally been the surveillance method of choice by local health departments and has been used in this study as well. Positive mosquito pools can indicate virus activity in mosquito species that feed on birds and avian epizootics often occur without significant human disease (1). Turell, et al., describe several criteria required for a mosquito species to be incriminated as a vector of a certain disease, including (11):

1. Repeated isolation of virus from field-caught species.

2. Demonstration in the lab that field-caught species can be infected and transmit by bite.
3. The species feed in nature on the host that develops appropriate viremia during the season the disease occurs.

4. Other factors, such as abundance, feeding patterns, longevity, and environmental factors.

This study examines some of the environmental factors that may be important in Cuyahoga County, Ohio for WNV in Culex mosquitoes and birds. An active avian cycle along with the presence of competent Culex and other bridge vectors may support periodic outbreaks in human populations in this county and throughout Ohio.

Mosquito Collection

Mosquito data is collected by many local health departments in Ohio and many other states in the U.S. on a regular basis throughout the summer months, generally May-September. Mosquitoes are collected in CDC light traps with CO₂ baiting and in gravid traps which are selective for Culex species. Light traps may capture any species, including nuisance mosquitoes and non-Culex bridge vectors (15). Culex species are attracted to water with high organic content, such as water contaminated by sewage, decaying vegetation, and leaf debris. Gravid traps baited with water of high organic content attract ovipositing Culex females who are most likely to be infected with WNV. Water with a high organic content is prepared by mixing rabbit pellets or grass clippings and leaving it in the sun to ‘ripen’ until it is highly odorous. Traps are set at dusk and collected at dawn at each trap location (Figure 2).
Table 1

WNV Positive Samples in Ohio and Cuyahoga County, 2001-2009 (22)

<table>
<thead>
<tr>
<th>Year</th>
<th>Birds</th>
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<th>Horses</th>
<th>Humans</th>
<th>Total</th>
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<tr>
<td>2009</td>
<td>0 (0)</td>
<td>239 (3)</td>
<td>0 (0)</td>
<td>2 (1)</td>
<td>241 (4)</td>
</tr>
<tr>
<td>2008</td>
<td>14 (0)</td>
<td>381 (19)</td>
<td>0 (0)</td>
<td>15 (5)</td>
<td>410 (24)</td>
</tr>
<tr>
<td>2007</td>
<td>22 (0)</td>
<td>325 (20)</td>
<td>2 (0)</td>
<td>23 (6)</td>
<td>372 (26)</td>
</tr>
<tr>
<td>2006</td>
<td>133 (1)</td>
<td>909 (153)</td>
<td>12 (0)</td>
<td>48 (9)</td>
<td>1,092 (163)</td>
</tr>
<tr>
<td>2005</td>
<td>84 (6)</td>
<td>1,373 (194)</td>
<td>15 (0)</td>
<td>61 (32)</td>
<td>1,533 (232)</td>
</tr>
<tr>
<td>2004</td>
<td>107 (1)</td>
<td>874 (101)</td>
<td>9 (0)</td>
<td>12 (3)</td>
<td>1,002 (105)</td>
</tr>
<tr>
<td>2003</td>
<td>249 (17)</td>
<td>799 (166)</td>
<td>106 (0)</td>
<td>108 (22)</td>
<td>1,262 (205)</td>
</tr>
<tr>
<td>2002*</td>
<td>1,003 (45)</td>
<td>1,976 (386)</td>
<td>644 (7)</td>
<td>441 (209)</td>
<td>4,064 (657)</td>
</tr>
<tr>
<td>2001</td>
<td>286 (185)</td>
<td>26 (25)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>312 (185)</td>
</tr>
</tbody>
</table>

*Human outbreak of WNV in Cuyahoga County and Ohio in 2002

(x) = Cases in Cuyahoga Co.
Mosquitoes are counted, frozen on dry ice, and submitted to the ODH vector-bone disease lab in Columbus, OH, for analysis using polymerase chain reaction (PCR) techniques. ODH data for Cuyahoga County for the years 2003-2007 were used in this study. Periodically during the summer, the author conducted field trapping of mosquitoes with the Cuyahoga County, Franklin County, and Athens County Health Departments to verify collection techniques. Visits to Cuyahoga County were also conducted in the summer after risk mapping for observation and field verification purposes.
Mosquitoes are collected in traps and are typically tested in ‘pools’ consisting of up to 50 mosquitoes of the same species. ‘Pooling’ allows minimum infection rates to be calculated (MIR), while reducing the cost of analyzing individual mosquitoes. Although the pooling of mosquito testing data has been a mainstay in surveillance programs for many years, new pooling techniques have been suggested for some circumstances (29). Mosquitoes are pooled into groups of 50 by species and only one positive mosquito is needed to make the pool positive (1). This infection rate is termed the minimum infection rate (MIR) for this reason. The MIR per 1,000 mosquitoes is:

\[
\text{MIR} = \frac{\text{# positive pools}}{\text{# mosquitoes in the pools}} \times 1,000
\]

For example, in a positive pool of 43 mosquitoes, the MIR = 1/43 x 1,000, MIR = 23.3. The infection rate of the pool could have actually been higher, if more than one mosquito tested positive in the pool.

One positive mosquito in a pool of 50 (MIR = 20) is defined by the Center for Disease Control and Prevention (CDC) as a level of public health concern (ODH, Dr. Rich Gary, personal communication). ODH uses real time PCR (TaqMan) for mosquito and dead bird tissue testing and antibody capture ELISA for bird and human blood sample testing. Since 2008 ODH no longer tests human blood, as this test is now readily available through normal clinical sources (ODH, Dr. Rich Gary, personal communication). MIRs in the 1999 outbreak in NYC were generally less than 5.7 for Culex mosquitoes. In some outbreaks in North America MIRs have reached 15 (21).
Environmental Factors

Environmental factors other than bird migration are likely to be important in the transmission of WNV. Although there has been much interest in bird migration as a source of disease spread, some research does not support its importance. At least one study has noted these inconsistencies in the migratory bird hypothesis: (1) the rate of movement of the virus across the US is much slower than migratory bird transmission would predict, (2) migratory bird routes are generally north-to-south, however, WNV transmission has moved quickly westward, and (3) the number of cases is similar in previously infected and new areas (27). In addition, the migratory ability of sick birds is unknown. There is some evidence that viremia is not influenced by migration in catbirds and thrushes (30). Corvids have been shown to have a short period of viremia, less than 24 hours; whereas common species, such as sparrows, have now been found to have much longer periods of viremia. Corvids are especially susceptible to WNV morbidity, however many other species can carry the virus. This has generated additional hypotheses to explain disease epidemiology, such as the possibility of reduced migratory capabilities of sick birds, wind dispersed mosquito vectors, and the possibility of other arthropod vectors (27). The elliptical migration pattern seen in some bird migration paths may also contribute to WNV spread in the U.S. (20).

In addition to migration, the availability of suitable bird habitat and nesting sites may be an important consideration. Nesting and foraging is likely affected by the prevalence of roosting sites such as large trees, certain tree species, forests, abandoned buildings, landfills, source of food, or other sites frequented by birds (1). Corvids and
other common species nest predominantly in evergreen and deciduous trees (31). This study has concentrated on environmental factors related to mosquito breeding and mosquito-bird interaction, and some weather factors; but many other questions await future studies. Variables for this study were selected based on experience, biological plausibility, the literature, and the availability of suitable data sets for variables of interest.

**GIS use for WNV Studies**

In the study of environmental, ecological, and politico-social factors as they relate to the spread of West Nile Virus and other diseases, mapping can be useful. Dating back to the early efforts of John Snow, the Broad Street pump, and cholera, mapping has been an important tool in epidemiological analysis of disease (32). Mapping facilitates visualization of complex spatial information. Modern geographic information system (GIS) techniques are being used to analyze disease problems and elucidate factors associated with disease morbidity and mortality.

Although mosquito, animal, and human data have been collected by ODH for at least 30 years; analysis of the data, especially for environmental and spatial factors, has been limited. GIS techniques have been used to analyze WNV data by several larger health departments in Ohio and recently in Athens County as part of an 11 county public health initiative (33), but this has been for general mapping purposes only.

GIS technologies are particularly powerful for the analysis of environmental information. The utility of spatial modeling techniques in the study of vector-borne diseases, including WNV, is valuable because environmental factors are often important
and amendable to GIS analysis (30). Global Positioning Systems (GPS) are used to locate events geographically in a GIS. In addition, remote sensing (RS) of environmental data has become a tool for analysis in the study of disease and prediction of geospatial factors in disease causation (34). Remote sensing using satellite data from space to explore the earth’s surface has been adapted to the study of vector-borne diseases, including West Nile Virus. In a recent GIS publication, it was reported that remote sensing technology adapted from NASA was being used to map and study high risk vector habitat and WNV risk areas in order to protect the citizens of Monterey County, CA (35).

Recent GIS studies have centered on the location of dead birds as sentinels that may be capable of predicting WNV risk early in the mosquito season (36). This approach could help predict outbreaks and help prioritize mosquito abatement and control targets for the health jurisdictions. Dead bird density studies suffer several limitations, including lack of statistical significance, reporting bias, false assumptions regarding uniform bird density per area, edge effects, and inconsistencies with WNV pathology and ecology (37). GIS and spatial methodologies also have limitations, such as the ability of census tract borders to split cluster events and edge effects for example. Recently, mathematical and statistical models have been developed to overcome some of these limitations; however, they also have limitations (37). Geospatial models and methods will undoubtedly improve as their application to vector-borne and other diseases increases.

Environmental factors are often inter-related and can affect the incidence of diseases. Many environmental factors can be mapped in a GIS and used for disease analysis by
utilizing the large amount of geographic information available from government sources and other organizations. Many health departments and other agencies are starting to take advantage of this powerful analytical tool. Cluster and point source events such as positive mosquito pools, bird die-off, and human cases can be studied as they relate to environmental factors in the GIS. One such study was done in Chicago during 2002, in which environmental factors were studied in 680 cases of human illness with WNV within the region, clustering in two well defined areas (38). Risk factors found to be associated with human disease clusters were vegetation, income, age, race, and distance to WNV positive birds, age of housing, mosquito abatement activities, and geologic factors. Environmental factors are probably important in both urban areas and rural areas in the study of WNV epidemiology, but perhaps in different ways. Environmental factors are likely to be important in human, mosquitoes, and bird infection.

Environmental Factors Related to WNV

Many environmental factors may be associated with WNV and need to be more fully explained. Minter traced the progression of human West Nile Virus across the United States during 2002 and 2003, correlating WNV infections with river corridors, roadways, precipitation/temperature trends, rare bird sitings, and temporal trends in the Culex life cycle (39, 40). These factors may help explain the east to west spread of WNV in addition to possible effects of bird migration.

Hydrologic factors have been shown to affect local mosquito abundance and transmission of disease by increasing near surface humidity associated with rainfall, thus enhancing flight activity and host location, and affecting the availability of breeding sites
Kitron (43) and Glass (44, 45) have used GIS techniques along with regression analysis, spatial techniques, and other tools to study environmental factors related to tick abundance and Lyme’s disease in different states. GIS has also been used in epidemiological and wildlife studies (46). Landscape features, particularly those modified by man, can play an important role in disease transmission (47), and spatial analysis is now commonly used for epidemiological investigations (48, 49, 50, 51).

Various GIS models have been developed for the study of West Nile Virus in particular (35). GIS techniques have been used to successfully study vector-borne diseases such as dengue and environmental factors such as those in this study were included (52). GIS are particularly useful in that they can generate large amounts of tabular data easily, which would take enormous amounts of time to collect in the field, and which are amenable to traditional statistical methods.

Water and land features have been significant in other studies of vector-borne diseases and WNV in particular. Suitable habitat, temperature, humidity, precipitation, wind, seasonal weather patterns in mosquito micro-climates, and landscape features play a role in the success of competent vector species (53). Opportunity for bird and mosquito interaction is necessary for propagation of the WNV disease cycle to be maintained in nature. Water for breeding from precipitation and suitable temperatures for development are also necessary for mosquito breeding success; but they are much more variable than land and water features. This study examined the effects of ‘ecological niche’ factors, soil type, wetlands, slope, land use for mosquito habitat and bird nesting, temperature, and precipitation and their relationship to the WNV minimum infection rates (MIR) at
Soberon and Peterson (54) outline four classes of factors that determine where a species will be found or their ‘ecological niche’, that include:

1. Abiotic factors – climate, physical geography and such that impose physiological limits on a species.
2. Biotic factors – sets of interactions that modify the species ability to maintain its population in a positive or negative way.
3. Dispersal abilities - landscape and other features that allow regions to be accessible to the species, actual v. potential distribution.
4. Evolutionary capacity of populations to adapt to new conditions.

These factors are identifiable in this study, as well.

Significance

Although some environmental factors have been studied, including some in Ohio (55, 56, 57), studies of other factors need to be conducted. Small area geospatial studies are important to determine the effect of environmental factors at a local level, to study the effect of map scale, data variability, to refine variable categorization, to compare the transferability of information to other different or larger areas, for models, and to develop control strategies.

In Ohio, decades of mosquito pool, bird, and human case data have been collected by the Ohio Dept. of Health (ODH), Zoonotic Disease Program, Vector-borne Disease Laboratory, for a number of mosquito-borne diseases. The analyses of these data have
been limited by time, staff, and funding. Fortunately, these data were made available by the Ohio Department of Health (ODH) for this study.

Common larval and adult surveillance methods such as trapping and dipping are time consuming, labor intensive, and have considerable lag times before results are known and preventive activities can commence. It is likely that delaying treatment could have an effect on mosquito and disease prevalence in that area. Modeling offers great promise as a real time, cost effective adjunct to traditional methods of surveillance and adds a valuable tool to the arsenal of control measures used against vector-borne diseases. It is for these reasons that research such as this are conducted to explore these models and refine them for practical use in prevention.

Aims and Objectives of this Study

This research involved preliminary investigations of WNV in the Cuyahoga County Health District (CCHD), in northern Ohio (Figure 3 a, b). This health district includes all of Cuyahoga County, except the cities of Cleveland, Lakewood, and Shaker Heights, who have their own health departments. The CCHD agreed to collaborate on this project and was selected because of the relatively large amount of data collected and their use of GPS for spatial referencing of the trap locations.

Cuyahoga County is an urban-suburban county along the southern shore of Lake Erie in northern Ohio. The City of Cleveland is surrounded by an ‘inner ring’ of older suburbs and then an outer ‘secondary ring’ of newer suburbs. It is densely populated and has a large system of highways and roads. It has predominantly flat or rolling terrain and
poorly drained soils, becoming hillier and increasingly well drained to the southeast. It is generally served by municipal sewer and water, except in small areas in outlying suburbs.

This study examines local environmental factors and their association with WNV in mosquitoes using geospatial analysis. The overall objectives of this research were: (1) examine and map several environmental factors that may be related to MIR’s and determine risk areas, (2) determine the approximate endemic levels and spread direction of WNV in Culex mosquitoes based on five years of data and to make observations on their relationship to human cases during the 2002 outbreak in Ohio, and (3) study the importance of environmental factors on WNV positivity, from data ‘mined’ from the GIS. Steps 1 and 2 above where termed Phase 1 and step 3 termed Phase 2 in this study.

The variables explored in this study are limited, but have the potential to affect bird reservoir availability, mosquito breeding site suitability, mosquito activity, mosquito-bird interactions, home range, and vectorial capacity, based on past research cited above and decades of public health experience. The development of a relatively simple model to locate area’s where mosquito infection rates are likely to be highest on a county ‘risk area’ map would be very valuable to local health departments to target scarce preventive resources, with the hope of preventing disease.
Figure 3a. Map of the state of Ohio indicating the WNV study area in the Cuyahoga Co.

Figure 3b. WNV study area in the Cuyahoga Co. Health District
CHAPTER 2: MATERIALS AND METHODS

Phase 1: Environmental Factors and Risk Map Development

The mosquito life cycle involves four stages: egg, larva, pupa, and adult. Female adults require a blood meal in order to obtain nutrients required for egg development. Three of these stages occur in water, so the availability of water breeding sites is essential for mosquito development. Culex, the predominant vector species of West Nile Virus in the U.S., prefers still water high in organic content, which occurs in the natural environment, manmade entrapments such as catch basins, and in artificial containers. Culex in urban and suburban breeding sites are found where water with high organic content can stand undisturbed for at least a week. Roadside ditches, ponded water contaminated by sewage systems, woodland pools, catch basins, and artificial containers such as tires and children’s swimming pools, are ideal breeding habitats (23). For the West Nile cycle to occur however, suitable bird hosts must also be available and opportunity for mosquito-bird interaction must exist. These are key factors in the ‘ecological niche’ of mosquitoes and birds.

Because of its powerful analytical capabilities, ability to overlay many environmental factor maps simultaneously to visualize ‘risk areas’, automate multiple analyses, and to obtain complex spatial data in both graphical and tabular form, GIS is an ideal analytical tool for this study.

The variables and their source data can be examined in Table 2 and the data layers are available from these government sources. The variables were selected on the basis of their potential association with standing water (soils and drainage characteristics that
allow extended ponding), known breeding sites (catch basins, street ditches, and wetlands), mosquito and bird transmission opportunities (wet areas and bird nesting habitat), and temperature and precipitation. Of special interest is the role factors such as soil, slope, and weather have as opposed to man-made environmental factors such as

Table 2

Environmental Variables and Data Source

<table>
<thead>
<tr>
<th>Data Layer (Units)</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trap Locations ((x,y))</td>
<td>Cuyahoga Co. Health Department (GPS)</td>
</tr>
<tr>
<td>MIR ((\text{per 1,000 mosquitoes}))</td>
<td>Ohio Dept. of Health ((\text{calculated from mosquito trap testing data}))</td>
</tr>
<tr>
<td>Geographic Boundaries ((\text{base maps}))</td>
<td>Ohio University, Institute for Local Government and Rural Development (ILGARD)</td>
</tr>
<tr>
<td>Soil type ((\text{m}^2))</td>
<td>USDA/NRCS/SSURGO</td>
</tr>
<tr>
<td>% Slope ((\text{m}^2))</td>
<td>USGS/DEM</td>
</tr>
<tr>
<td>Streets</td>
<td>US Census/TIGER</td>
</tr>
<tr>
<td>Land Use Designation ((\text{m}^2))</td>
<td>USGS/National Land Cover Data (1992/Level II)</td>
</tr>
<tr>
<td>Wetlands Designation ((\text{m}^2))</td>
<td>USGS/National Wetland Inventory/USEPA</td>
</tr>
<tr>
<td>Human WNV ((\text{cases}))</td>
<td>Cuyahoga County Health Department</td>
</tr>
<tr>
<td>Catch Basin ((\text{type}))</td>
<td>Cuyahoga County Health Department</td>
</tr>
<tr>
<td>Temperature ((\circ\text{F}))</td>
<td>NOAA (Cleveland Hopkins Airport Weather Station)</td>
</tr>
<tr>
<td>Precipitation ((\text{inches}))</td>
<td>NOAA (Cleveland Hopkins Airport Weather Station)</td>
</tr>
</tbody>
</table>
catch basins, especially in urban/suburban areas. Global positioning system (GPS) readings were available for each mosquito trapping location and trapping data was provided for the years 2003-2007 by the Cuyahoga County Health Department.

These data layers were used in the GIS to construct maps and conduct various types of geospatial analysis in Phase 1, and to extract data for export into Microsoft Excel and SPSS for later analysis in order to develop a model that could help predict MIR positivity based on ecological niche concepts in half mile trap buffer micro-habitats in Phase 2 of this study (54, 58, 59, 60, 61, 62).

Temperature and precipitation will be referred to as ‘dynamic variables’ since they change frequently and will be used in the ultimate model. Although weather conditions such as temperature and precipitation are cited as important factors in mosquito-borne diseases, they have not been widely used for surveillance, until recently (63, 64). Environmental variables are termed ‘static variables’ as they are expected to change little over a short temporal time frame (65). The risk maps are based on the static variables (soil type, slope, land use, wetlands, catch basins), and show where high risk areas could be anticipated in the county, at times when the dynamic variable (temperature and precipitation) are optimal for breeding and disease transmission.

Mapping and Map Analysis

All mapping and map analysis in this study was done with ESRI’s Arc GIS 9.3 software (66). Since maps are generally two dimensional and the earth is a three dimensional spheroid, the worlds coordinate system must be transformed into one of the many types of projections for use on a two dimensional map surface. Therefore, all data
were transformed into the Universal Transverse Mercator projection, North American Datum 1983, Zone 17 north in Ohio (NAD83, UTM17N) for analysis. This projection was selected because it is used globally and by U.S governmental agencies (67).

The dependent variable in this study, five year average MIR, was selected in order to maximize the utility of trapping data over a five year time span after the 2002 outbreak in Cuyahoga County. Trapping grid areas were established by the Cuyahoga County Health Department in 2003 in response to the 2002 outbreak. The five year average MIR was used for mapping and the individual trap data MIRs were used in Phase 2 for the logistic regression model calculations.

The five year average MIRs can be viewed as an endemic level of WNV in Culex mosquitoes; although the long term endemic level may not be known for a while yet. MIRs are shown on most maps in this study. The ‘risk map’ concept used in this study is basically a ‘site selection process’ used routinely in GIS analysis. Various factors important in siting an item of interest geographically are mapped and then the maps are overlaid to find the intersection of the map factor areas that are in common, or the location of an optimal or ‘good site’. The researcher must define what optimal is and this differs based on the goals of the project. In this study, personal experience and the literature were used to guide this categorization process. Environmental factors were used as the selection criteria in an attempt to find optimal ‘ecological niche’ area for Culex mosquito breeding and mosquito-bird interaction. The static environmental factors were classified into optimal/not optimal categories based on their effect on mosquito breeding and interaction with bird hosts (Table 3). As described below, additional
geospatial techniques were also used in the study of WNV in Cuyahoga County for the study of endemic levels and disease spread.

GIS tools available in the software are based on sophisticated geostatistical techniques (68). The practical application of the techniques used in this study is summarized below (69):

**Reclass** – categorization of variables by replacing input values with new simplified output values, as seen in Table 3.

**Dissolve** – removing unnecessary category boundaries between features; for example, after reclassing, combine the area from several reclassed variables into one new area for study, such as optimal/not optimal.

**Overlay** – a spatial operation which superimposes several map layers in a common coordinate system in order to show relationships in the layers; such as areas in common in a ‘risk area’ map.

**Intersect** – integrating spatial layer datasets and preserving areas in common; like an intersection of sets.

**Clipping** – cutting out and using only a portion of a map layer for study and analysis, such as the half mile buffer areas around traps used in Phase 2 of this study.

**Buffering** – used in proximity analysis, a zone based on distance or time around a map feature, for example the half mile buffer areas around an individual trap site in this study.

**Kriging** – an interpolation technique where measured values are weighted to derive predicted surfaces for the unmeasured areas and then mapped. Weights are based on items like distance from known measurements and the arrangement of points. Indicator
Kriging separates the data into groups that are either over or under a set threshold value and calculates the probability that the surface area is over or under that set threshold value (68).

Table 3
Static Variables Reclassed as Optimal/Not Optimal (Good/Bad) for Mosquito Breeding

<table>
<thead>
<tr>
<th>Variable</th>
<th>Optimal (good for breeding and contact)</th>
<th>Not Optimal (bad for breeding and contact)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil drainage categories</td>
<td>Poorly drained (reclass category 2,3,4)</td>
<td>Well drained (reclass category 0,1)</td>
</tr>
<tr>
<td>*explained in this section</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope (%)</td>
<td>0-2/3, 2-6/8</td>
<td>&gt;6</td>
</tr>
<tr>
<td>NLCD, 1992 (land use category #)</td>
<td>41,42,43,91,92</td>
<td>11,12,21,22,23,31,32,33,51,61,71,81,82,83,84,85</td>
</tr>
<tr>
<td>USEPA wetlands designation</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td>Catch Basin Type</td>
<td>Old type (hold water)</td>
<td>New type (will not hold water)</td>
</tr>
</tbody>
</table>

It is well recognized that water ponding for periods of more than a week contribute to mosquito breeding (70, 71, 72). *Culex* breed especially well in standing water with high organic content; in such things as woodland pools, road ditches, catch basins, and artificial containers (73). Mosquito-bird interaction is necessary for the *Culex*-WNV cycle to take place (1, 70, 71, 72). The variables for this study were selected because they can contribute to water ponding and mosquito interaction with
birds. The effects of temperature on breeding, specifically the shortening of the extrinsic incubation period, is an important factor in disease dynamics as even small changes can effect breeding levels (10, 11, 14, 71, 72, 74).

For each trap site, the average MIR was calculated for that site over five years based on the trap results for each of the trapping event during that period for mapping in the GIS. Of the 1,783 samples collected over the five year period and used in this study, 11% were positive. The frequency distribution of the original samples can be seen in Table 4. The original and reclassed optimal/not optimal environmental factor mapping methods are described below and the resulting maps referred to presented in Chapter 3 - Results. All 1,783 MIRs were used individually in Phase 2 of the project for logistic regression calculations.

Table 4

Frequency Distribution of Positive WNV Samples (2003-2007)

<table>
<thead>
<tr>
<th>MIR</th>
<th>Number of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1,576</td>
</tr>
<tr>
<td>1-19</td>
<td>154</td>
</tr>
<tr>
<td>20-49</td>
<td>50</td>
</tr>
<tr>
<td>50-99</td>
<td>19</td>
</tr>
<tr>
<td>100-199</td>
<td>15</td>
</tr>
<tr>
<td>200-500</td>
<td>2</td>
</tr>
<tr>
<td>Sub-total</td>
<td>1,816</td>
</tr>
<tr>
<td>- Removed from study due to missing data</td>
<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>1,783</td>
</tr>
</tbody>
</table>
Soil Types and Drainage Characteristics

Various soil characteristics affect the drainage ability of soils due to the amount of water and air that exist between soil particles and other factors. This can be reviewed in the NRCS Soil Manual (75). Poorly drained soils with high clay content, very small particle sizes, and little space between particles tend to restrict downward flow of water and cause ponding on the surface when rain is sufficient and downward percolation of water is slow enough. Soils containing restrictive layers, such as rock or fragipans, also tend to slow percolation. On the other hand, well drained soils with high sand content and large particle sizes tend to drain effectively because of the larger spaces between particles and faster percolation rates. Many soils are somewhere in between. Soils with poor drainage characteristics pond more readily, facilitate water persistence, are more conducive to mosquito breeding after rainy weather, and would more readily allow for sufficient time for the mosquito life cycle to be completed. The water table and related hydrogeologic factors are closely associated with the surface ponding of water and are influenced by factors such as soils, vegetation, precipitation, temperature, topography, and humidity (42). Evaporation rates are important as well. Shaded areas may take longer to dry up than areas in full sun light; for example, in early season woodland pools. Natural drainage phenomena such as road ditch drainage and seasonal woodland pools are affected by natural factors such as soil type and slope, whereas artificial containers such as catch basins are not, holding water until evaporation occurs or they are emptied.

Data for Cuyahoga County, Ohio taken from the USDA/NRCS Soil Survey Geographic Database (SSURGO)/Soil Mart site in m² were downloaded for use in
mapping of soils with Arc Map. Cuyahoga County has 72 different soil types. Map unit
descriptions from the SSURGO data were analyzed for soil drainage class characteristics
and slope. In the Soil Survey, soil drainage class is subdivided into five (5) categories:
well drained, moderately well drained, somewhat poorly drained, poorly drained, and
very poorly drained for each soil type. Well drained soils are less optimal mosquito
breeding areas than poorly drained. The map unit descriptions were evaluated for all 72
soils and categorized each soil types (reclassed in GIS terms) into the 5 categories (0-4,
well to poorly drained). In the GIS, the 5 soil categories were further reclassed for the
risk maps into not optimal (well drained 0-1) and optimal (poorly drained 2-4) areas for
mosquito breeding (Table 2). Examination of other soil reclass categorizations was done
as well before selecting the categorization above. The original soil types with trap
locations and the reclassed soils with trap location five year average MIRs overlaid can
be seen in Figure 7a, b. This type of reclassing into optimal/not optimal areas was done
for all four static variables.

Slope

Slope is a measure of the grade (rise over run) or steepness in percent of the land
at the survey point for each soil type. Flat areas have low slopes and steep areas have
high slopes. SSURGO soil unit information records the slope in percent and the soils
were categorized in m² into those with 0-2/3, 2-6/8, and greater than 6% slopes. Slopes
of 0-6/8 percent were considered flat or rolling and more conducive to water ponding or
optimal and those with slopes greater than 6 percent as not optimal.
United States Geological Service (USGS) digital elevation model (DEM) data was used for this data layer. The slope was obtained from the DEM by using the Arc Map spatial analyst/surface analysis/slope tool to convert the DEM to a slope layer. The layer was then reclassed into three categories 0-2/3, 2-6/8, and >6%. For later analysis it was reclassed again into optimal (0-6/8%) and not optimal (>6%) areas for the risk map. The original slopes and the slope risk areas with trap location average 5 year MIRs overlaid can be viewed in Figure 8 a, b.

*Catch Basin, Ditches, and Streets*

It is well recognized by environmental health professionals that *Culex* mosquito breeding can be extensive in catch basins and roadside ditches in urban and suburban areas (76). An attempt was made to obtain spatially referenced catch basin data for Cuyahoga County, Ohio, but this was unsuccessful. Streets were considered as a surrogate variable for catch basins and ditches in the study area, as nearly all streets in these suburban areas are served by storm sewers with catch basins throughout the system or with street ditches in some areas (77). Street data was obtained and mapped for Cuyahoga County. To simulate a half mile flight path to the streets with catch basins, a half mile buffer was established around streets and mapped in Arc Map using the proximity tool and dissolved. This street buffer map with average MIRs can be seen in Figure 9. The street system is so extensive in this highly developed and populated county that when all the half mile buffers were dissolved together, there were no areas in the county discernable that were not within a half mile of a catch basin with the dissolved buffer areas (light green areas in Figure 9). This made discrimination between optimal or
not optimal impossible. Consequently, it was assumed that nearly every part of the study area had suitable breeding sites readily available. This analysis therefore can be seen as including suitable natural habitat factors, in addition to these ubiquitous catch basin sites. The street data were dropped from the risk map analysis at that point initially. Later catch basin design issues were revisited in the study as an explanation for why some of the suspected natural environmental factors did not appear significant in Phase 2 of this study. This is reviewed in Chapters 3 and 4.

Land Use

Land use has been found in many studies to be important in vector-reservoir relationships (44, 45, 78). Such data can target land uses that are suitable for vector habitat, reservoir habitat, and interaction between the two. How the landscape categories are reclassed for study is important. Data were obtained from the National Land Cover Data (NLCD, 1992) survey in m². The newer NLCD, 2001 was considered for use, but it was determined that the 1992 classification system better suited this study. This was because the categories were simpler, especially in the residential and water related categories, and judged to be better suited for a first exploratory study than the 2001 classification scheme. The NLCD land use data is the most readily available standardized land use data for use by agencies.

There are 21 land cover types designated in the 1992 scheme. While it is recognized that many of the land cover categories may provide suitable habitat for mosquitoes and birds, five (5) categories were identified initially as likely to be most important in mosquito-bird interactions. Land use 91-woody wetlands and 92- emergent herbaceous wetlands were selected for their mosquito breeding potential. Land cover 41-
deciduous forest, 42-evergreen forest, and 43-mixed forest were selected for their potential as bird nesting sites for corvids and other common species that carry WNV in Ohio. Infection occurs as reservoir bird’s nest and are bitten by female mosquitoes seeking a blood meal. *Culex* species are night feeders with peak biting activity between 11 PM - 2 AM (70, 79). These 5 categories were reclassed and dissolved into optimal areas and the other 16 as not optimal areas in the analysis initially. A map of the original land cover areas and the reclassed areas with average MIRs can be seen in Figure 10 a, b.

In this study, land cover was considered a static, or non-changing variable, as the intent was to look at current WNV issues in the county. The study area is limited in land area to one heavily urbanized and built up county. Land use has generally already been established here. It is recognized that at larger scales, over longer periods of time, in less populated areas, and in different environments or countries, especially developing countries, that land use is not static, but is changing (80, 81, 82).

**Wetlands**

Wetland habitat was included in this study as they typically can provide habitat for many species of mosquitoes, including *Culex*. In urban and suburban areas they may be subject to more contamination from storm run-off, sewage systems, lawn mowing, leaf debris, pollution, and other sources of organic matter than in more remote areas. They can also provide good areas for bird nesting and mosquito-bird interaction. Data from the National Wetlands Inventory measured in m² were obtained for use in the GIS. Since this data was already divided into wetlands/not wetlands it was used ‘as is’ in this study. Essentially optimal/not optimal areas for this study were already established, so it was not necessary to reclassify or dissolve data. Wetland area in Cuyahoga County is very limited
and takes up little land area. They are generally located in Westlake and adjoining far west suburbs. The Bradley Woods area is located here as well. The wetland areas and the average MIRs can be seen in Figure 11. It should be noted that although Culex mosquitoes can breed in degraded wetlands and similar habitats, they are better adapted to artificial containers and other habitat in urban areas and generally should not be a problem in healthy wetlands according to USEPA (83).

These four environmental factors were overlaid to generate an overall ‘risk map showing ideal habitat areas for mosquitoes and birds in Figure 12.

*Temperature and Precipitation*

The previously discussed variables have been termed ‘static variables’ as they are expected to change little over time at the local level and can therefore be used to generate ‘risk areas’ that are assumed to remain stable for a reasonable period of time. Weather parameters, on the other hand, are ever-changing and have been termed ‘dynamic variables’ in this study. Temperature and precipitation are key variables of interest in most studies involving vectors, as these variables often play a role in habitat suitability, breeding site location, vector physiology, activity, and behavior. Temperature related phenomena and precipitation have been noted as important in many studies of mosquito-borne diseases (7, 10, 11, 14, 63, 71, 84). Temperature and precipitation have been categorized in many different ways in the literature.

Mosquitoes go through three of their four life stages in water. The water must generally be quiescent and meet other requirements depending on species. Water for mosquito breeding is generated largely by precipitation events; especially winter snow
thaws and rain. This water fills catch basins, artificial containers, and natural habitats where \textit{Culex} breed. In natural habitats, mosquito breeding is likely more pronounced in areas where water tends to pond undisturbed for longer periods of time. Given that significant precipitation events occur, factors that contribute to natural ponding locally are soil type, slope, certain land use types, and wetlands designation. Once breeding starts in the spring; evaporation rate, temperature, precipitation, and wind speed effect the breeding process. The importance of natural breeding areas may be different in urban/suburban and rural areas. Artificial containers are filled by natural or man-made activities and are subject more to evaporation or emptying, as opposed to natural land related phenomena. Regardless of breeding sites, some water is needed and temperature drives the incubation period.

Temperatures are known to affect mosquito behavior, breeding, and activity levels (71). Activity generally begins in Ohio in spring and declines in fall. In warmer weather more generations may occur quicker, affecting the arbovirus extrinsic incubation period (10, 11, 14, 71, 72, 73). It is for these reasons that precipitation and temperature were selected for inclusion in this study. In Phase 2 of this study modeling was attempted using these static variables and dynamic weather variables to explore trap buffer micro-habitats using logistic regression analysis.

Temperature and precipitation data were obtained for Cuyahoga County, OH from the National Oceanic and Atmospheric Administration (NOAA) data at the Cleveland Hopkins International Airport weather station. Monthly averages were obtained for the months May through September for the years 2003-2007. Monthly averages and two
month averages were calculated for manipulation in the analysis. Monthly averages were obtained for the month of the trapping event and the two month averages were calculated by averaging the trapping month and the month preceding it. These two measured were used in order to test which one might be a better measure of the critical temperature period needed for the life cycle to occur prior to these mosquitoes being caught in a trap. These weather measures were used because actual measurements were not taken during trapping and finer scale measurements were not easily obtainable.

Since breeding cycles take around a week in the summer, the weather during the month prior to the trapping event is critical in the analysis, as mosquitoes emerging during these periods are likely caught in traps near their breeding sites. A flow diagram model of the original Phase 1 – GIS studies (prior to removal of streets as a variable and addition of catch basins) can be seen in Figure 4.

_Establishing Endemic Levels and Spread Direction_

One important feature of any infection cycle is the approximate endemic level of WNV infection in a vector or human population. Several kriging methods were used to explore the endemic WNV levels in the county and its spread direction. Ordinary kriging was used to generate a general risk map surface that would estimate the MIRs in mosquitoes in unsampled areas of the county, based on five years of sample data, in order to establish endemic levels in mosquitoes in the county. The risk map and a prediction error map for the kriged risk surface map, and can be found in Figures 17 a, b.

Indicator kriging is a geospatial technique that allows the investigator to set certain threshold levels in order to explore the probability that a threshold level might be
exceeded in the map area. This was done using the five year average MIRs, setting threshold levels at 20, 15, 10, and 5 (Figures 18 a, b), in order to analyze the direction of mosquito disease spread in the county after the 2002 outbreak. Additional analysis was done by setting the MIR>1, which essentially selects for positive/negative sample areas (Figure 19). This technique was also used in order to estimate the probability of positivity and as a measure of the spread of the virus in mosquitoes out from the focus of high MIRs in the northwest cities and to compare with human case data from the 2002 outbreak. Later in this paper, results are compared from these indicator kriging studies in mosquitoes with human cases during the 2002 outbreak in Cuyahoga County (57).
Figure 4: Original model of the Phase 1 – Geospatial Studies.
Phase 2: Model Development

In the CCHD, only optimal/not optimal areas in individual half mile trap buffers were studied in Phase 2 of this study. These local area micro-habitats identify where individual mosquitoes fly to individual traps from a half mile flight range around each trap. The Cuyahoga County Health Department had established a grid across the county in an effort to uniformly sample the entire health district (Figure 5). Trap locations were set up at the approximate center of each grid area and at a few additional sites as well. For the study period, 2003-2007, there were trap testing results reported from 119 trap sites. Gravid traps were set over the five year period and are selective for ovipositing Culex females. Mosquitoes were tested by PCR for WNV by the Ohio Dept. of Health. MIRs were calculated from the ODH data for each of the 1,783 trapping events. These 1,783 MIRs were used in model development.

The study hypothesis was that environmental factors within these half mile buffer ‘micro-habitats’ are important reasons for positive trap results. The half mile flight buffers were constructed around each trap site using the Arc Map proximity tool to simulate the geographic area from which most mosquitoes would travel to a specific trap location and be caught. Their flight distance is usually not more than about 2 km. (1.2 miles) for Culex (85) unless affected by wind (86), but they usually only migrate short distances from their breeding sites; so a half mile buffer was selected for this study (26, 78, 86). These buffer areas were then ‘clipped’ out by the GIS software to become the study areas; 119 individual study areas with 1,783 individual samples from these sites over a 5 year period. Each clipped half mile buffer is about 2,034,072 m² in area. There
were several buffers with less area located along boundary edges. An example of trap buffers area overlaid on soil types can be seen in Figure 6. Data for the clipped study areas were exported to Microsoft Excel for development of a master database for use in traditional statistical modeling in SPSS.

The general process in Arc Map was to use the spatial analyst tool to ‘reclass’ the four individual static variables as described. Then the original raster data were reclassed into optimal/not optimal area as described previously. Raster layers were converted to vector data which allowed it to be used in a geodatabase from which good land area figures could be obtained. The trap buffer areas were intersected with the variables vector data layer in the GIS using the overlay/intersect tool in order to ‘clip’ out the buffer and evaluate only the 119 half mile trap buffer areas. Finally the original geographic boundaries were dissolved into just two areas (optimal and not optimal) in each of the 119 study areas using the data management/generalization/dissolve tool. An area field was added to the resulting attribute table to obtain the optimal/not optimal area in m² for each of the 119 trap buffer areas.

The use and development of each reclassed variable is discussed below. Data can be obtained in many ways from a GIS and in different units. In this study the land area in m² of reclassed optimal and not optimal areas for each variable within each of the half mile trap buffer areas was ‘mined’ for use in Excel to try to develop a traditional statistical model that might have value in terms of predicting the probability of positivity for the individual trap site. The actual land area in m² for optimal and not optimal
Figure 5: Cuyahoga Co. original grid map and trap sites with half mile buffers.
Figure 6. Trap locations and surrounding buffer with local soil types mapped.

areas of soil, slope, wetlands, and land use area data were exported to Excel for the statistical analysis. The hypothesis was that the more ‘optimal land area’ that exists within an individual buffer micro-habitat for each of the four static factors, the more likely the area is to provide an excellent breeding area for mosquitoes and the more likely the buffer area is to draw more mosquitoes to the trap. When WNV is endemic in an area, more mosquitoes would likely be associated with increased probability of capturing mosquitoes with WNV infection in that trap (higher MIR).

Area data can be obtained in several ways from both raster and vector data, two different ways to represent a land area (68). Raster analysis maps individual cells on a grid and vector data is mapped as points, lines, and polygons for the map layer in use. Each has its own benefits. They can generally be converted from one to the other using GIS software.

Raster data is frequently used in environmental GIS work because certain layer manipulations and calculation are facilitated by this method. Raster data was problematic
for the buffer area analysis in this study because some of the half mile buffer areas overlap each other and this causes area calculation problems in Arc Map. There were a number of sites at which the half mile buffer areas overlapped. In addition, there were five sites at which the full half mile buffer could not be calculated due to issues such as their location in Lake Erie for samples taken close to the shore. Four of the sites were because of close proximity to Lake Erie and one because of close proximity to the Lorain County line. In the SSURGO soil mapping survey, bodies of water in excess of 40 acres are not mapped as soil (87). Consequently, the four sites along Lake Erie had less that the amount of square meters of optimal and not optimal areas as the normal half mile buffers and these areas had to be calculated and added to the database by hand. Calculation problems with overlapping buffers could not be reconciled in the raster format. Consequently, the Spatial Analyst, Raster to Features (vector) tool was used to convert raster layers to feature or vector layers which allow the shapefile layer to be stored in a Geodatabase in Arc GIS as previously discussed. In vector format, overlapping buffer area calculation problems do not occur.

The original mosquito trap data included the PCR testing results for all the test sites from the Ohio Department of Health, Vector-borne Disease Laboratory in Columbus, Ohio. As stated above, the tabular data was ‘mined’ from the GIS analysis attribute tables and exported into the Excel database as well. New columns were then added, one for the MIR by calculating the \([\frac{\text{positive mosquito pools}}{\text{total mosquitoes caught in the trap}}] \times 1,000\) for each of the 1,783 trapping events in the study and another column for simply positive/negative. The database was generated to see whether a model
could be constructed that might have value in predicting future MIRs or at least the
probability of positivity at a trap location based on environmental factors. Statistical
Package for the Social Sciences, SPSS 16.0 was used for all statistical analysis in this
study (88). The Excel database was imported into SPSS for data analysis.

The infection rate for the study period 2003-2007 in this county was relatively
high at 11% overall; 196 positives of 1,783 samples tested (21). K-S tests for normality
indicated that the MIRs were not normally distributed. Since the data was not normally
distributed, the actual MIR number was not compared to the environmental factors.
Rather, the dependent variable MIR, was separated into positive or negative MIRs. The
logistic regression model was selected for the analysis. This model is used when the
dependent variable is dichotomous (positive/negative). The logistic regression model can
be reviewed in basic statistical texts (89, 90) and a few examples of its application in land
use studies are presented in the references (80, 81, 82). The logistic regression model
predicts the probability of a positive MIR, and is described by:

\[ P = \frac{e^{a+bX}}{1 + e^{a+bX}} \]

Optimal amounts of land area in m² and percentage for each independent variable in the
119 half mile trap buffer areas were calculated in an Excel database from the data mined
from the GIS attribute tables, prior to import into SPSS for analysis. An attribute table is
the data base in the GIS that a map is generated from.
Covariates (continuous variables) explored in the logistic regression model were: optimal slope area, optimal soil area, optimal land use area, and wetland area in m², one month average temperature and two month average temperature in degrees Fahrenheit, and one monthly average precipitation and two month average precipitation in inches. Factors (categorical variables) explored were: old or new catch basin types. Variable combinations were explored in a step-wise manner for inclusion in the final model. A significance level of p<0.05 was used to test the effect of the independent variables on mosquito positivity and calculate the odds ratio. Probability of positivity was calculated for each of the 1,783 trap locations, using the appropriate beta values from the logistic regression model.
CHAPTER 3: RESULTS

Phase 1 - Environmental Factors and MIR in Mosquitoes

Initially, the layers outlined in Chapter 2 where reclassed and dissolved in order to visualize optimal areas for individual variables in the study. The original and reclassed optimal/not optimal area maps are presented for comparison in Figures 7 a, b, 8 a, b, 9, 10 a, b, and 11. These individual optimal/not optimal area reclass maps were then overlaid and intersected to generate an overall risk area map for the county based on these four initial static measures. The resultant risk map can be seen in Figure 12. The average five year MIR for each trapping location was used on most maps for comparison purposes. It can be seen on the risk map in Figure 12 that an arc of higher MIRs lies just to the east of an arc of high risk areas on the western side of the county. It should be noted that prevailing winds in the county are generally from the west/southwest to the east (91). Areas with more risk factors as seen in the reclassed environmental factor maps are more prevalent in the northwest corner of the county where higher average MIRs occur on this risk map.

Because the amount of wetland area was small, this factor was not important county-wide and it greatly restricts the size of the intersected risk area, possibly obscuring important information. In addition, the amount of optimal land use in the northwest suburbs did not seem to track the high MIR trap sites as closely as expected. Consequently, it was determined that additional field visits should be conducted to high risk MIR areas to observe land use categories in various neighborhoods.
Figure 7a. All 72 soil types in Cuyahoga Co., OH.
Figure 7b. Reclassed soil risk areas (poorly drained) in Cuyahoga Co., OH.
Figure 8a. Slope areas in Cuyahoga Co., OH.
Figure 8b. Good slope areas (flat or rolling) in Cuyahoga Co., OH.
Figure 9. Streets with half mile buffers dissolved included all of Cuyahoga Co, OH.
Figure 10a. All 21 land uses in Cuyahoga Co., OH (NLCD, 1992).
Figure 10b. All land uses good for breeding and interaction in Cuyahoga Co., OH (NLCD, 1992).
Figure 11. Areas with wetland designation in Cuyahoga Co., OH.
Figure 12: General WNV risk map of Cuyahoga, Co., OH.
Field observations were conducted at 19 of the top 32 sites with the highest average MIRs over the five year period and many low sites as well, to look for commonalities or anomalies with the first land use reclass mapped in Figure 10b. These high MIR sites were invariably in more affluent areas with many large old trees, lower human population density, larger yards, and fewer streets. In fact, only one site had a backyard abutting closely behind it. Almost all sites had woods behind and around the houses. These sites were ideal for extensive bird nesting and roosting, and mosquito bird interaction. In addition, because of the poorly drained soils in this area, seasonal woodland pools abound in these woods, and can be wet much of the early season. Looking at these sites from the air, the tree canopy is extensive; while areas with lower average MIRs as in many of the inner ring suburbs have more modest homes with much higher home density and very little tree canopy (Figure 13). Interestingly, in the 2002 human outbreak the inner ring suburbs actually had higher rates of human cases, which will be discussed in Chapter 4.

Land cover categories were evaluated again in light of these field observations. The optimal neighborhoods observed in the field were classed as ‘low density residential’ in the 1999 NLCD data. Land cover was re-examined and reclassed again using deciduous, conifer, mixed forest, wet areas, and adding the ‘low intensity residential’ category seen predominantly in the neighborhoods where high MIRs occurred. The resultant risk map can be viewed in Figure 14. It is clear that there is a higher concentration of land cover optimal for mosquito breeding and mosquito-bird interaction in the northwest cities and townships by this second classification and this more closely
tracks field observations in these high MIR areas. This will require re-evaluation in future studies, along with other factors which will be discussed in Chapter 4. It is important to note that these same observed land use factors exist in many other parts of the county as well, including those where mosquito MIRs were low in the southern and eastern second ring suburbs of the county. Catch basin type and well drained soils may explain this apparent anomaly. This will be discussed in Chapter 4.
Figure 13: Bay Village/Westlake with higher MIRs and Parma with lower MIRs in mosquitoes (Source: Google Earth).
Figure 14: Land Use reclassed for bird habitat including low density housing.
The catch basins and roadside ditches were investigated further in the Phase 2 logistic regression studies (reported later in this chapter). Natural environmental factors were not significantly related to MIR positivity, with the exception of two month average temperatures. The existence of many catch basins that allow mosquito breeding was suspected to be more important in these urban/suburban areas than natural environmental factors. It is also noted that smaller artificial containers, like tires and such, contribute to breeding in urban/suburban areas as well. As mentioned in Chapter 2, when streets are mapped and the buffers dissolved the resultant area takes in the entire county; in essence, all areas in Cuyahoga County have catch basins and road ditches within a half mile for breeding (Figure 9). This brings up an important question: how important then are natural environmental factors like soil and slope in areas where ground ponding is not essential to support large populations of mosquitoes? Perhaps natural environmental factors may be contributory, but not essential to the mosquito-bird cycle in heavily sewered urban areas. Are catch basins and catch basin density driving breeding in urban/suburban areas? Catch basin differences were still felt to be important. Are they in some way different in these suburbs? Could this account for the high MIRs in certain areas? Exploration of catch basin issues was added to the study methods in order to evaluate this. Catch basin design was reviewed with the Cuyahoga County Engineers offices (77). The City of Cleveland and the ‘inner ring suburbs’, outside of the Cleveland city limits, generally have an older style catch basin that can hold 30-100 gallons of water from one rain event, until it evaporates (Figure 15). This was confirmed with the Cuyahoga County Health Department as well (19). These sources are especially good for
Culex breeding as they are inundated with leaf debris and other organic matter washed off the streets and are generally quiet until the next water event, protected from wave action, and shaded to prevent evaporation. It should be noted that in periods of excessively high rainfall in a short period of time, trapped catch basin water can be ‘washed out’ and this can actually reduce breeding effectiveness in the catch basin for a period of time. The newer second ring suburbs have a newer style catch basin that generally does not hold significant water. In addition, suburbs in the second ring are more likely to have road ditches instead of catch basins in some areas which would generally dry quicker after rain events, depending on soil types, slopes, weather, and related issues. Natural factors such as soil and slope may be more important in these cities. These are important differences. Mapping of the catch basins by suburb was added to the study methods. Figure 16 shows a map of the catch basin types. The significance of this important issue will be discussed in Chapter 4 of this study, as catch basins are known to be major sources of Culex breeding in urban/suburban areas (73).

![Typical Catch Basin](source: ASCE 1990)

Figure 15: Old style catch basins in Cuyahoga Co., OH.
Figure 16: Catch basin distribution in Cuyahoga Co., showing trap sites in old and new type catch basin suburbs.
Endemic Level and Spread of Infection

The estimated mosquito MIR risk map may be viewed as the approximate endemic level of WNV in *Culex* mosquitoes in this county after the 2002 outbreak. This map can be seen in Figure 17a. In the northwest suburbs, the average MIR would be expected to be consistently around 5-10, and in the ‘inner ring’ suburbs around Cleveland 1-5; but in the southern and southeastern suburban edges positive infection is less likely to occur. This map compares favorably with environmental factor maps already generated in this study. This map allows prediction of likely MIRs in the county after the epidemic. The RMS standardized prediction error for this map was 1.046 and is accurate (Figure 17b). These endemic levels will need to be adjusted when the long term endemic level has been reached.

It can be seen from the threshold maps (Figures 18 a, b) that the highest MIR threshold (MIR>20) is in the northwest lake front area. The probability of exceeding an established threshold increases as the threshold is lowered, extending eastward into the western inner ring suburbs of Cleveland and across the greater Cleveland area. In Figure 19, the positivity map indicates that there is a greater than 50% probability of positive samples extending from the northwest focus of infection and extending east across the greater Cleveland area, and 75% in west Cleveland and the western inner ring suburbs. The importance of this finding and its relationship to human cases in the 2002 outbreak in Cuyahoga County will be discussed in Chapter 4 (19, 57).
Figure 17a: Estimated mosquito MIR risk map in Cuyahoga Co., OH, 2003-2007.

Figure 17b: Prediction Standard Error for MIR Risk Map.
Figure 18a: Probability of a threshold MIR set at 20 and 15.
Figure 18b: Probability of a threshold MIR set at 10 and 5.
Figure 19: Probability of a threshold MIR>1 (positivity).
Phase 2 - Modeling Environmental Factors

SPSS was used to explore various combinations of environmental factors and their relationship to MIR positivity. All analyses were conducted on half mile buffer area micro-habitats. Good soils and slopes were not significantly associated with WNV positivity in the half mile micro-habitats regardless of how many environmental factor combinations were attempted. Land cover, defined as wet areas and deciduous, conifer, and mixed forest, was not significant using the first classification scheme. Wetlands designation was not significant. This would support the theory that catch basins, and not natural factors like those tested and reported here, may drive breeding in some urban/suburban areas.

Temperature and precipitation were evaluated in two ways. The average monthly temperature for the month of the trapping event and the two month average temperature for the month of the trapping event and the previous month were evaluated. Similarly, the one and two month precipitation was evaluated as well. As seen in Table 5, only the average two month temperature was significantly associated with WNV positivity (p<0.0001). The odds ratio is reported below.

Table 5

Environmental Risk Factors Related to WNV Positivity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta</th>
<th>SE</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>Significance (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Mo. Temperature Average</td>
<td>.295</td>
<td>.0600</td>
<td>1.343</td>
<td>1.195 - 1.511</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
The probability of getting a positive trap sample (positivity) was calculated for each of the 1,783 trap events over the five year period, using the logistic regression formula (89):

\[
p = \frac{e^{a+bx+cx}}{1+e^{a+bx+cx}}
\]

\[
p = \frac{e^{(-22.617 + (0.295*T2) + (.419*CBT))}}{1+e^{(-22.617 + (0.295*T2) + (.419*CBT))}}
\]

where, \( p \) = probability of positive
\( e \) = base of the natural logarithm (~2.718)
\( T2 \) = the average two month temperature
\( CBT \) = catch basin type

This formula allows the probability of obtaining a positive sample to be calculated based on the type of catch basin type in the area and the two month average temperature. Catch basin type was not significant in this study; however this was likely due to inadequate land cover categorization in reclass1 and its effect on the multi-factor model. Although old catch basin type (\( p = 0.182 \)) was not significant at the 0.05 level, it was left in the analysis for demonstration purposes only, as preliminary data from on-going studies are showing catch basins to be significant when land cover categories are reclassed to include low density residential use (Figure 14). This will be discussed in Chapter 4.

The range in probabilities calculated for the model can be reviewed in Table 6 below. It can be seen that old catch basin type has higher probabilities than new catch basin type. Although the probability of positive trap samples predicted below is not
persuasive, additional refinements of the land use categories, catch basin issues, and issues related to the unique aspects of the city of Westlake discussed in Chapter 4 may increase the significance of both catch basins and land use as important factors related to MIR positivity when reassessed in future studies.

Table 6
Summary Table: Range of Probabilities of Positivity by Catch Basin Type from Logistic Regression Analysis

<table>
<thead>
<tr>
<th>MIR Positivity +/-</th>
<th>Catch Basin Type</th>
<th>Average Probability of Positivity (2003-2007)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>old</td>
<td>0.185 (0.167-0.203)</td>
<td>0.021</td>
<td>0.330</td>
</tr>
<tr>
<td>+</td>
<td>new</td>
<td>0.125 (0.110-0.140)</td>
<td>0.026</td>
<td>0.245</td>
</tr>
<tr>
<td>-</td>
<td>old</td>
<td>0.112 (0.097-0.127)</td>
<td>0.001</td>
<td>0.330</td>
</tr>
<tr>
<td>-</td>
<td>new</td>
<td>0.086 (0.073-0.099)</td>
<td>0.001</td>
<td>0.245</td>
</tr>
</tbody>
</table>
CHAPTER 4: DISCUSSION

Phase 1 - Environmental Factors and Mosquito Infection

Soil permeability, slope, and weather help determine whether water ponds on the surface of the ground for extended periods of time. Ponding for extended periods of time allows for buildup of more organic matter in water pools that are attractive to ovipositing Culex females. This could contribute to increased breeding of mosquitoes in the area. Soils reclassed into not optimal areas for ponding (well and moderately drained soils) and optimal areas for ponding (poorly drained soils) were mapped in Chapter 3 (Figure 6b). An area of higher MIRs in the northwest corner of the county coincides with areas of poorly drained soils good for mosquito breeding. This is evident in seasonal woodland pools seen behind houses by the health department, especially early in the year (Figure 20a). The same situation exists for slope (Figure 7b). The northwest suburbs have higher MIRs and flat topography, optimal for mosquito breeding. This is understandable since soil types and slope are related in the county soil survey data. Old type catch basins that hold water are located in the inner ring suburbs. All of these factors should promote increased mosquito breeding and higher MIRs. Conversely, well drained soils, flat terrain, and new type catch basins in the southern and eastern second ring suburbs create conditions where the area was low or devoid of positive WNV samples during the study period.

Wetland areas are minimal in Cuyahoga County, but they are located in the northwest suburbs (Figure 20a). The large Bradley Woods area where the Cuyahoga County Health Department has historically found large numbers of mosquitoes breeding
is in this area as well (Figure 20b). In fact, during the 2002 human WNV outbreak in Cuyahoga County aerial spraying was done in the Bradley Woods area.

Figure 20a: Seasonal wet woodland pools in a northwest suburb.

Figure 20b: Bradley Woods.
On the wetland map, the areas of high mosquito MIRs are seen just to the east of the wetland areas. The prevailing winds in Cuyahoga County are from the west-southwest, which likely increases the trap catch to the east of these wetland areas. Though these wetlands may be important to mosquito breeding locally around Westlake, they do not contribute significantly to the breeding problem countywide.

Mapping of the land cover in the northwest part of the county initially was not as closely aligned with high MIR areas as expected. This is likely due to how they were initially classified for analysis. Three of the categories were deciduous, conifer, and mixed tree areas favored by local birds for nesting and two categories where wet areas subject to ponding favorable for mosquito breeding. The second reclassification of land cover seen in Figure 14, adding the ‘low density residential’ classification, more closely tracks with the mapped high MIR areas. This reclassification of land cover will be explored in future studies along with some issues of interest in Westlake which are discussed below.

The role of the county catch basins continues to be of interest. Health Department personnel have noted catch basin design differences in their catch basin treatment program. Catch basin design was reviewed with the county engineer’s office and county design documents examined. As urban sprawl progressed out from the city, a new type catch basin was instituted that did not hold water. They were used in the newer second ring suburbs. These catch basin areas were mapped in Figure 16. It can be seen that higher MIRs were associated with older inner ring suburbs with the old style catch
basins. The secondary ring suburbs have the newer catch basins that do not hold water. Lower MIR’s were found in theses suburbs (with the exception of Westlake). This helps to explain the lack of positive MIRs over the study period in the southern and eastern second ring suburbs, as these areas have the newer catch basins (Figure 16), are hillier, have well drained soil (Figure 6b, 7b), and few wetlands (Figure 10). Thus, even though land use shows very good bird habitat in the southern and eastern second ring suburbs, they are not likely to be as good for Culex mosquito breeding. They may not be able to sustain the mosquito-bird infection cycle as well as areas with old catch basins and poorly draining soil conditions, like the northwest suburbs. These areas have both optimal bird habitat and optimal mosquito breeding areas.

One interesting area is Westlake, which is one of the higher MIR areas in the northwest suburbs, but has the newer style catch basins. This area does have poorly drained soils. There are two additional unique factors to consider in Westlake however. Urban sprawl has extended out to this second ring suburb and development is extensive. This area used to contain extensive vineyards. Although the vineyards are largely gone, many of the flat areas still have extensive furrows from the vineyard days according to health department staff (19), which may hold water and serve as a unique mosquito breeding factor in this community. In addition, the counties wetland area is located in and near Westlake as can be seen in Figure 10 and Figure 20 a, b. These two factors along with poorly drained soils, may contribute to mosquito breeding in this community due to natural factors, despite having new style catch basins. They may be compensating for the lack of breeding due to the new catch basins and providing alternative breeding
sites in this community. This issue will need to be evaluated using more complex models in future studies, as these two factors are likely to be affecting the logistic regression model conducted in this study as well. Two measures of temperature and precipitation were tested. More generations of mosquitoes can hatch during times of high environmental temperatures. Warmer months such as August and early September have been associated with peak periods of WNV case reports in mosquitoes. Both bird and human activity is affected as well. High temperatures later in the summer may delay migration in some desirable bird species in Ohio. Outdoor activities, exposure opportunities, population density, and age distribution (57), and other factors may put humans at additional risk of exposure as well.

Experimentation with the logistic regression model was conducted with numerous combinations of environmental factors in a step-wise manner. Only the two month average temperature was significant in the analysis. This was puzzling initially, as precipitation (rainfall) is necessary to perpetuate mosquito breeding in nature. Part of the explanation might be that given some rainfall in urban/suburban counties, the actual amount of rainfall might not be critical in some cases because of the effect of massive numbers of catch basins. Once a rain event occurs, the catch basin has the ability to hold the water for a long period of time, making continual rain less important for breeding than in natural areas. Mosquito breeding may go on for a long period without further rain events. This work has shown that in urban/suburban counties catch basins are available within a half mile of nearly all parts of the county, except for some areas in the second ring suburbs where ditches are available and soils are well drained. Consequently, if
catch basins are a key factor in urban breeding, the mosquito-bird cycle may continue
under these circumstances with moderate amounts of new rain. Analysis of catch basin
density needs to be done in future studies to determine whether higher densities are
associated with increased MIRs. Alternative catch basin filling methods such as lawn
watering and car washing may contribute as well in urban/suburban areas.

Field staff has also observed the ‘wash out’ phenomena. During times of extreme
rain events catch basins overflow and mosquito eggs, larva, and pupae are washed out of
the catch basin and down the drain, resulting in less breeding. Thus, deluges may
actually reduce breeding numbers. More rain may not be necessary for mosquito
breeding in highly populated areas with catch basins. Urban and rural breeding sites
differ significantly in regard to availability of common breeding sites. Rural areas likely
rely more on natural environmental factors for breeding and urban areas rely on both
natural areas and extensive catch basin systems.

Cities with old style catch basins that hold water when compared to cities with
newer type catch basins were 52% more likely to be associated with WNV positivity
(OR=1.52; 95% CI – 0.821-2.812). Although this was not significant at p< 0.05 in this
study, mapping showed strong associations between the type of catch basin and
positivity. This was not the case in the second ring suburbs. In addition, half mile micro-
habitats around trap sites may be too small an area to evaluate for relationships with high
MIRs. Larger geographic areas may be needed for comparison to see significant
associations with positivity and more advanced models to evaluate the effect of
confounders. This issue will be explored in future studies.
Around the city of Cleveland and the inner ring suburbs south and east of Cleveland, there is a mix of catch basin types, soils, slope, land use and the like. Many areas of the county in both the inner and second ring suburbs have favorable land use features for mosquito breeding and interaction with birds. Numerous large deciduous, conifer, and mixed forest trees and low density residential areas abound in these areas, but have well drained soils and new type catch basins. Excellent bird habitat may be necessary, but not sufficient to cause high MIRs in a given area. Conditions must be right for the appropriate mosquito vector as well as for birds in order to complete the transmission cycle. This may account for modest MIRs and inconsistencies in MIR levels in these area maps.

Another issue that needs analyzed in more detail in the future in terms of the land cover and high MIR area is the issue of the dense tree canopy in the northwest suburbs versus sparse tree canopy in inner ring suburbs and Cleveland (Figure 13). Tree canopy is a significant factor in mosquito-bird interaction. Several researchers, including Dr. Nicholas Komar, at CDC’s Vector-borne Infectious Disease Center at Ft. Collins, CO, have documented interesting infectivity issues related to tree canopy and communal roosting in birds (92, 93). In studies of sentinel pigeons at three locations in NYC, using lard can traps at different elevations in the tree canopy, Deegan, Komar, et al., were able to document more mosquitoes and increased seroconversion in predominantly Culex pipiens and Culex rustuans Theobald mosquito populations at 7.6 - 9.1 meters (22.8 - 27.3’) height (92). They were twice that of those at 1.5 meters (4.5’). This would require larger trees like those seen in northwest Cuyahoga County. Communal bird roosting
areas in tree canopy also increased infection. Anderson, et al., demonstrated in Connecticut that Culex pipiens trapped in the tree canopy at ~7.6 meters drew more Culex and had higher MIRs than traps set at ~1.5 meters; and indicated that bird nesting and roosting in trees would likely enhance female feeding success during night time feeding and may partially account for the large number of corvids, owls, and raptors affected by WNV (94). Areas of dense large tree canopy would allow nesting at optimal heights for interaction with mosquitoes and may facilitate WNV transmission.

In studies of bird communities in urban areas some authors have found that moderate urban development, such as golf courses and residential use, increases bird diversity locally at the expense of native species. This is due to increasingly diverse resources, alterations in the local plant community by ornamental plants, and it may provide increasing perching sites and increase edge habitat due to habitat fragmentation. Habitat fragmentation was found to decrease desirability however, with increasing urbanization (95). In studies of the 2002 human WNV outbreak in Cuyahoga County, mosquito habitat fragmentation (road density) was positively associated with human cases (57). It is likely that road density is a surrogate for human population density which was found to be significant in their study.

Reisen, et al., have shown a relationship between communal roosting behavior and higher infection rates in Culex pipiens quinquefasciatus in corvid clusters near Los Angeles, CA (96). Kent, Komar, et al. found that Culex tarsalis in Colorado infected with WNV were associated with communal roosting sites in house sparrows (97). Komar, et al., showed that communal roosts serve as a focus for vector-reservoir
interactions, but may be affected by bird age especially in late summer. They also showed that engorged Culex tarsalis mosquitoes collected in resting collections at roosting sites outnumbered those at control sites by 100 to 1 (93).

Nesting heights and communal roosting could be an integral part of the WNV infection cycle in mosquitoes and birds in suburban neighborhoods, such as northwest Cuyahoga County, where extensive canopy of old, large trees exist and mosquitoes and birds interact. This too could help to explain why higher MIRs are found in Cuyahoga County in these areas. Favorable catch basin designs and natural conditions like poorly draining soils also coexist with extensive tree canopy in the high MIR areas. In addition, suburbs with larger yards, plenty of woods, fewer neighbors, streets, and businesses intersecting the area may favor infection in the tree canopy and at roosting sites, but significant transmission to humans likely requires different host factors, such as higher human population densities found closer to Cleveland.

**Endemic Levels and Spread of Infection in Cuyahoga County Mosquitoes**

One goal achieved in this study was to approximate the endemic levels of infection in mosquitoes after the 2002 WNV outbreak and to explore their geographic location in the county (Figure 17 a). The highest WNV infection rates were found in mosquitoes in the northwest suburbs in Cuyahoga County due to factors reported in this paper. The positive MIRs decrease in magnitude however, but increase in probability, as they spread out eastward. The establishment of this pattern could have been due not only to optimal breeding conditions, but perhaps to where the first infected birds arrived in Cuyahoga County after the 1999 NYC outbreak. The northwest part of the county may
have been involved with the initial entry of WNV into Cuyahoga County and Ohio by migrating birds in 2001.

If bird migration is an important factor in the spread of this disease in mosquitoes, as has been suggested, it would seem reasonable that the northwest part of the county might have seen the first infected birds from Canada migrating south over western Lake Erie. CDC data indicates that by 2001, the year before the Ohio outbreak in humans, WNV had reached states north and south of Ohio moving westward. The Mississippi flyway bird migration corridor also runs through these states, also in a north-south orientation (Figure 21). The Atlantic and Mississippi flyways meet and bird co-mingle in the Great Lakes region of Canada, just before southern migration through western Ohio. Some north/south flight paths are elliptical and may account for divergence from a strict north/south orientation (20). These flight patterns over western Lake Erie into Ohio could be one explanation for higher infection rates in the northwest part of the county. They might have been the first positive birds having contact with these new mosquito and bird populations in the county, in an area where catch basins and environmental factors were optimal for mosquito breeding and bird nesting and foraging.

This scenario might also help explain how it got here from its original focus in the New York City area. Cuyahoga County was one of only two counties in Ohio submitting positive samples of mosquitoes in 2001, accounting for 25 of the 26 positive samples in Ohio that initial year. Michigan’s initial cases in 2001 were near Lake Erie and western Ohio as well (Figure 22). Again, this supports a spread of infection in Cuyahoga County from the northwest, possibly related to the southward bird migration activity in the western Lake Erie area. There were also positive mosquitoes found in Erie County, PA in 2001 which adjoins Ohio along Lake Erie on the east; however, they could also have
entered the state from the eastern Lake Erie migration. It is likely that CCHD also did more mosquito surveillance than other smaller health departments early in the WNV entry into Ohio around 2001.

If one considers the spread of WNV from the northwest corner of the county, looking at the threshold maps in Figures 18 a, b, a directional spread of mosquito infection from west to east from its high MIR focus area is evident. This would again make sense if one considers the favorable mosquito breeding and bird habitat in northwest Cuyahoga County and the prevailing wind direction from west to east in northern Ohio near Lake Erie. Wind affects most animal flight, including mosquitoes and birds. Prevailing winds and winds off Lake Erie may affect mosquito and bird flight eastward in northern Ohio. Infected vectors are carried by weather events into new areas. This has been observed in a number of countries, including the U.S. (72). Mosquito dispersal mechanisms, such as wind and storms, can be reviewed in the literature (98). Possible effects from Lake Erie, especially in the northwest suburbs, were not evaluated in this study.

If one considers only positivity, represented by threshold MIR>1, there is a 50-75% probability of positive samples across greater Cleveland and the near inner ring suburbs. There is a high probability of positivity in mosquitoes where the eastward directional infection spread meets the higher population densities of Cleveland and the inner ring suburbs on the west-southwest side. This may have contributed to the 2002 outbreak of human cases and will be discussed later in this chapter.
Source: CDC and Health Canada, 2002.

Source: USGS, website access 10/12/09.

*Figure 21:* WNV spread to Ohio and migratory bird routes.
Figure 22: West Nile Virus in Ohio and Michigan, 2001 (Source: USGS).
Phase 2 - Model Discussion

Outbreaks of vector-borne disease, including West Nile Virus, are associated with temperatures above normal, and precipitations at or below normal (90). This study seems to support these findings. The relationship between the two month temperature measure and MIR was found to be very significant (p<0.0001). Traps collected early in the month would suffer from insufficient breeding cycle time and even later in the month only recently hatched and infected mosquitoes would be seen in traps. Monthly temperature averages do not appear to allow enough time for hatching, infection, and trapping to occur in order to see an effect on MIR. Two month average temperatures, however, would allow 4-7 weeks for this cycle to occur and appears adequate to capture relationships with positivity in trap collections. It is a better measurement of temperature effect on MIR.

Temperature has consistently been associated with increases in mosquito infectivity, vector competence, and human cases of WNV (64, 100, 101, 102, 103). When temperatures are high, the extrinsic incubation period can be as short as 4-5 days (14, 53). Even very small differences in temperature can have a profound impact of transmission of the virus in mosquitoes (103). This study supports these finding in Cuyahoga County. In this study, a one °F increase in average two month temperature prior to the trap date resulted in a 34.3 % increase in mosquito positivity in Cuyahoga County (p<0.0001). Over the five year period, the average two month temperature was 69.9 °F for positive samples and 66.6 °F for negative samples. Studies have shown that
wet springs with dry, hot summers have been associated with human outbreaks of WNV (73, 98), although this pattern may be different in southern states (41).

Although the two month average temperature is significantly associated with mosquito positivity in this study, temperatures at smaller scales may need to be studied to determine the magnitude of these effects on MIR at the local trap level as small changes in temperature can be critical. In the lab, it has been shown that small differences in breeding temperatures have an effect on vector competence. *C. pipiens* is a significantly more efficient vector at 30 °C (86 °F) than at 26 °C (79 °F) or lower (11). In addition, Shaman and Day argue that smaller scale hydrologic measurements might also be necessary to study the dynamics of mosquito populations. General weather station data in counties may be at too large a scale for some local studies (41). In addition, different mosquito life stages may be affected differently by air and water temperatures.

Neither one nor two month average precipitation measures were significant in this study. Precipitation has been found to be important in other studies of vector-borne diseases; however, findings have been mixed and the negative effect of heavy rains has been noted (63). Several studies have found that precipitation in the weeks before trapping events have been negatively correlated with *Culex pipiens* trap numbers (40, 98). Although some precipitation is necessary for breeding, it may be that the amount of rain may not be as critical at the local level in urban/suburban areas with extensive catch basins that hold water for considerable time, have many other artificial containers, and soils that allow ponding for long periods of time in ditches and woodland pools. Moderate rain is sufficient for breeding in these areas. Excessive amounts of rain can be
unnecessary or even detrimental in heavy rain events were ‘wash out’ occurs as
discussed. There is evidence that early season rain, followed by drought conditions favors
mosquito breeding and infectivity in mosquito-borne disease and favors increased organic
content in water left in urban catch basins (40, 104). In urban/suburban environments the
amount of precipitation may not be critical, as long as you get some rain during spring
and early summer. The actual amount of precipitation near trap sites needs to be more
precisely measured and compared to the MIRs. Perhaps there is an optimal precipitation
range or a minimum amount during critical months. Temperature and precipitation
measurements should be taken at each trap site when collected and recorded in order to
obtain more accurate local temperature data in order to refine these initial findings. This
data would be an important addition to trap location data collection and is easy, quick,
and inexpensive to do.

A number of studies have reported a shift in host preference from birds to
mammals, like humans, by Culex species later in the summer. Molaei, et al., noted that
Culex pipiens prefer feeding on robins, but shift to different species later in the summer,
and occasionally biting humans (6). Kilpatrick, et al., reported a 7 fold increase in Culex
pipiens biting mammals compared to birds in late summer and early fall, which coincides
with early season dispersal of favored hosts such as robins and with increases in human
cases (105). He also found that in emerging vector-borne diseases that these host
preferences likely have genetic roots (105). Kilpatrick (106) and Kent, et al.,
documented this behavior in Culex tarsalis in Colorado (97). This behavior has not been
studied in Cuyahoga County to my knowledge.
In Cuyahoga County, during the study period, only one positive Culex pool was trapped in June. Invariably, WNV positivity starts in July and proceeds through September. This is related to mosquito genetics and overwintering mechanisms that establish a new cycle each year. Turell, et. al., have shown that incubation temperature is important in overwintering success in Culex pipiens (11). Perhaps the rising temperatures through early summer favor viral infections in mosquitoes transitioning from non-disseminated infections to fully disseminated infections later in summer, allowing biting behavior to become more effective at transmission. In addition, Kunkel, et. al., reported that Culex rustuans to pipiens ‘crossover’ (the time when the abundance of C. rustuans is surpassed by the abundance of C. pipiens) is related to increasing temperature, with C. pipiens in more abundance later in the summer. (99). In Cuyahoga County, LaBeaud, et. al., reported appearance of Culex species earlier in the summer during the 2002 outbreak year (57). These studies, along with those demonstrating increased infectivity with tree canopy height, may have implications for timing and nozzle directionality when conducting ultra low volume (ULV) spraying for adults during mosquito control activities (99).

In this study, the natural factors in a traps half mile buffer micro-habitat, the amount of m² of good soil, slope, land use, and wetlands were not significant predictors in urban/suburban counties where artificial containers and catch basins are plentiful. Larger area may be more important than the trap micro-habitats when it comes to the importance of environmental factors. The half mile trap micro-habitats are likely to be too small a scale to see individual trap effects. Mosquitoes at an individual trap sites,
breeding in close proximity to catch basins or other artificial containers, need not rely on
natural local micro-habitat conditions. Good land cover is extensive in areas with high
trap MIRs and extensive tree canopy. Catch basins, artificial containers, ditches, seasonal
wet woodlands, and extensive tree canopy are likely more important than the individual
trap micro-habitat. The trap buffer micro-habitat, even if relevant, may only be important
for mosquito breeding. Bird nesting, foraging, and bird-mosquito interact are also
necessary for infection rates to rise locally.

Although not significant in this study, the average probabilities for old catch
basins and positive samples were higher over five years than for new catch basins and
negative samples (Table 6). The 1,783 individual trap probabilities calculated from the
model were highly variable, so this model is of limited value as is. Consequently, there
are other, as yet undetermined factors that affect this relationship. In addition, the two
month temperature averages is not adequate alone to predict positivity and negativity at
each trap location and to discriminate between the two without other important factors
being added to the model. As mentioned, additional studies are needed to explore some
of these other issues discussed in this paper.

One of the objectives of this first study was to try to develop a model that a health
department could use to predict likely MIR or at least positivity, using static
environmental factors, and the entering appropriate weather data like temperature and
precipitation into the model in order to predict the probability (p) of positivity. Because
of the factors discussed above, a persuasive model was not found in this study. These
findings do show promise that this can be done, once the appropriate variables, classified
in the best format are developed as discussed. Attempts to further refine the model in future studies as discussed in this paper are being planned. Even without the model, however, the GIS mapping alone is a very beneficial technique for monitoring WNV activity in the community.

Mosquito Infection and the 2002 Human Outbreak

Although this study looks at the MIR’s in mosquitoes and environmental issues related to mosquito and bird interaction, the ultimate goal of such studies for environmental health and epidemiology professionals is to learn things that might be important in the prevention of human WNV disease. In order to explore this issue, map information from this study was compared with human case data for the 2002 human WNV outbreak in Cuyahoga County published by others (19). Human cases in the Cuyahoga County outbreak in 2002 were concentrated around the outer edges of the City of Cleveland and the older, inner ring suburbs close to the city. There were 221 human cases in the county during that outbreak, by far the most in the state (22, 24). The next highest was 30 in Cincinnati/Hamilton County (22). The year before the outbreak, in 2001, Cuyahoga County had 25/26 positive mosquito samples in Ohio.

The human cases in 2002 were not in the northwest suburbs where mosquito MIR’s were found to be the highest in this study. Figure 23 shows the human cases and demographic data from the Cuyahoga County Health Department (19, 57). The county population density and amount of people older than 65 years parallels the human cases very closely (57). This makes sense. If there is WNV infection in the mosquito-bird population, one would predict more human cases where there are more humans to bite
per unit ground area. Since the more serious symptoms and neurological effects are more common in the elderly, the age distribution makes sense as well. Older populations would likely suffer more serious disease and result in a diagnosis of WNV. The close proximity to major diagnostic centers is also a likely factor. But how does this relate to the findings in this study of infection in mosquitoes?

The maps in Figure 18 a, b demonstrate that the high MIR focus in the northwest suburbs lessen in magnitude but increases in probability, moving eastward toward the more densely populated and elderly city of Cleveland and inner ring suburbs. Figure 19 shows mosquito positivity around the city. Mosquito positivity has been found to be associated with WNV in other human studies (78). There is a greater than 75% chance of positivity on the west side. LeBeaud, et al., (57) and the Cuyahoga County Health Department (19) have done case cluster analysis on the human case data that can be seen in Figure 24. Note that the human cases cluster on the west side. In Figure 19 the highest area of WNV positivity in mosquitoes in my study is on the west side in the same area as the human case clusters. Given WNV positivity in mosquito-bird populations and a dense enough human population, especially one with a matching elderly profile, human WNV cases will occur in years when weather and other factors are favorable.

The 2002 WNV outbreak in Cuyahoga County was an example of a new disease, an emerging pathogen, in an immunologically naïve population of people, under the right conditions. Many cases were seen that year in Cuyahoga County. In future years the county population is not likely to be as susceptible as in the initial year; however this study has shown that conditions are conducive to mosquito breeding and interaction with
birds, especially in the northwest suburbs. The endemic level may be nearing establishment. This area should receive special attention during annual surveillance and treatment efforts, especially early in the season and when mild winters and other weather conditions contribute to successful overwintering and the spread of vector-borne diseases the following summer.

This study compared mosquito infectivity during 2003-2007 with the 2002 human cases in Cuyahoga County. It would be informative to see whether the mosquito MIR patterns seen in this study were actually similar during the 2002 human outbreak year also. Although the systematic grid system of sampling that was used in this study had not been initiated yet during the 2002 outbreak, sampling was done in the county during that year. In order to explore this question the sampling data was obtained for the 2002 season. Although not directly comparable site by site, the 2002 data was calculated as % positive pools and mapped by political subdivision in Figure 25a. As expected, there is a high concentration of % positive pools in the northwest suburbs where 50-75% of pools were positive. There are mixed lower levels around the inner ring suburbs, and lower levels in the south and eastern second ring suburbs. This map compares favorably with 2003-2007 experience in this study (Figure 25b). It is likely that the current pattern of mosquito positivity started with the 2002 outbreak year and has persisted.

The existence of adequate bridge vectors, mosquito species that bite a wider range of hosts than birds, is also a likely factor in WNV transmission in Cuyahoga County to humans. Many nuisance species other than *Culex* can become infected from infected birds or other animals and can transmit WNV to humans. It is not known how this might
have affected the Cuyahoga County outbreak in 2002. It is likely that many of the environmental factors that affect *Culex* breeding will affect other species as well. The favorable conditions of bird habitat, poorly drained soils, other animal reservoirs, and such would favor other species as well and they too may have higher MIRs in the northwest suburbs. The extensive old tree system also makes ideal habitat for tree hole mosquitoes such as *Aedes* that can serve as bridge vectors for WNV and transmit other mosquito-borne diseases in Ohio such as California group encephalitis viruses. These environments may also be attractive to other mammal hosts involved in the life cycles of other mosquito species.

There were a number of limitations in this study. Data from Cuyahoga County were only available for 2003-2007 at the gridded locations. Few counties in Ohio collect trap information in such an organized manner and with GPS locators. Data for the human outbreak year 2002 was not available for this study at the grid locations. Environmental variable databases that were used were only those readily available from standard government sources. This can also be seen as beneficial however, as it insures that these data sources are standardized, readily available to environmental health professionals to use, and allows better comparisons with other areas. Catch basin locations were not available by GPS location. This will be an important task to accomplish in the county and in other areas, not only for health departments and researchers, but for the utility departments as well. This information will be required in order to study catch basin density and related factors that may be important in mosquito-borne illness investigation.
in urban/suburban areas. Temperature and precipitation data used was only that which was available during the immediate study time frame. Better measures may be available.

Another important factor is ‘edge effects’, the effect of boundary edges where no data is available, on the data for the area under study. This is one important drawback to analysis by political subdivisions, such as counties. Whenever one analyzes GIS data, the fact that data is not available outside the political boundaries in the study decreases the overall quality of the data in the study area. In this study, Cleveland, Lakewood, and Shaker Heights did not participate in the gridded five year sampling included in this study. This introduces some error into the Cuyahoga County Health District data for areas adjoining the political subdivisions where data is missing. The same is true for the counties surrounding the Cuyahoga County borders. When some counties do extensive GIS analysis and GPS large amounts of data, but their neighbors do not, edge effects can occur. This is an important point and argues for the establishment of statewide GIS data collection system to minimize these effects in Ohio and increase the quality of surveillance data overall. Given the study limitations however, much has been learned during this study of value in Cuyahoga County for immediate practical use by the health district and for general application in the design and hypothesis development for additional studies in the future.

If communication between different health districts does not occur regularly, important effects may be missed. In this study, for example, the focus of high MIRs in the northwest suburbs of Cuyahoga County is very close to the eastern Lorain County border. If WNV had spread toward the west instead, the effects on Lorain County could
have been considerable, but perhaps unnoticed unless the two health districts were communicating frequently. If multiple counties are doing GIS analysis, tracking these trends, and sharing information, this would be much less likely to occur. In fact, Lorain County has done some GIS tracking and although the data is not directly comparable with Cuyahoga County; their trap locations are concentrated in the northeast corner near their county line where the high MIR focus is located in northwest Cuyahoga County (107). In addition, the higher density cities of Lorain and Elyria are in this area as well. Could the high MIR area in northwestern Cuyahoga County actually include part of northeastern Lorain County?

A basic GPS unit for every health district in Ohio and standardized collection and statewide data sharing might be one of the best investments we could make in environmental health epidemiology at the local and state levels in the upcoming years. GIS modeling on the statewide level can be very useful in disease surveillance and has been demonstrated in studies like this one in Mississippi (65).
Figure 23: Human West Nile Virus cases and selected demographics, Cuyahoga Co., OH, 2002 (19).
Figure 24: Human case clusters, Cuyahoga Co., 2002.
Figure 25a: Percent positive WNV pools, Cuyahoga Co., 2002.
Figure 25b: Percent positive WNV pools (2002) and comparison average five year MIRs (2003-2007), Cuyahoga Co., Ohio.
Extension of this Study

There are a number of issues that were brought to light in this work that warrant additional study and have generated new hypotheses for consideration in the future. The environmental and biological factors surrounding mosquito-bird interactions in large areas of tree canopy is one topic of interest. Types of bird species and their density per unit ground area in heavily treed areas compared to areas with little tree canopy would likely be an important habitat factor to look at. Could the density of birds available to mosquito vectors be the key feature in tree canopies? The species available locally could be important, as well as the time of year they are active. It has been demonstrated that favored hosts for *Culex* mosquitoes, like robins, are more important earlier in summer while host preferences may change toward other mammals, like humans, later in the summer (6, 105). Could large areas of tree canopy with extensive nesting make nest-bound juvenile birds more available to mosquito vectors within small geographic areas, like northwest Cuyahoga County, early in the season? Is the general height and density of a community’s tree canopy important?

The inclusion of the ‘low density residential’ land use that was reclassed in this study as ‘optimal area’ (Figure 14) needs to be explored for significance in new logistic regression models. This category, catch basin type, and possibly other variable classification schemes may change the nature of the model relationships in the trap buffer micro-habitats. Experimentation with the land use categories in the 2001 NLCD classification system may be needed to find the optimal reclass categories for the logistic regression model. Reconciling unique breeding issues in Westlake must also be accomplished.
The difference between areas that have new and old type catch basins needs further study. Positive and negative trap sites need to be compared and contrasted. Mapping and field experience has shown that catch basin type is associated with areas of higher or lowered MIRs, yet this was not significant in the logistic regression analysis. Inner ring suburbs however do not show such a clear association in mapping. In addition, other factors may be confounding this effect, such as the presence or absence of optimal soils, slopes, and land use. The effect of road ditches in areas mapped for catch basin type should be considered as this may dilute the catch basin significance in certain areas of a community, especially if they have well drained soils. A measure of catch basin density needs to be devised, such as catch basins/lineal road mile or catch basins/mi², to explore whether the number and proximity of the catch basins are a significant factor in predicting trap positivity.

It would be helpful if temperature could be taken at each trap site at each trapping event so that real time temperature could be attained at each site and consistent temperature periods prior to sampling could be established for study. Real temperature effects would be better assessed at measured trapping temperatures in the months before the trap event. Perhaps the use of multiple temperature stations could be an improvement if individual trap temperature readings are deemed impractical by local staff. More localized precipitation measures would likely be of value as well.

This study should be duplicated (with any necessary changes) in rural areas that do not have extensive catch basin systems and where natural conditions like soil type and slope are likely more important, in order to compare differences in urban/suburban and rural environments. Some of the natural factors that were not significant in this study may prove significant in rural areas with few catch basins available for breeding. Franklin
County (a comparable urban/suburban county) and Athens County (a rural county) have indicated interest in possible expansion of these studies in their area.

There are also two other issues of interest. The possible influence of wind and Lake Erie on trap catch and positivity is one issue. The other is likely more significant. This study has been done without regard to mosquito abatement efforts conducted by the health department in the county during the study years. Control measures have a significant effect on trap catch and MIRs. Treatment schedules of adulticiding and catch basin treatments in each city should be obtained and analyzed in terms of frequency of treatment, location of treatment, and time before or after trapping, to evaluate the relationships with trap data and MIRs.

Applicability in Ohio and Other Areas

The utility of this study and other GIS analytical work lies in its ability to better understand disease and to generate new hypotheses. This study has established the endemic levels of WNV in mosquitoes in Cuyahoga County by area after an outbreak in mosquito, bird, and human populations. It has demonstrated the likely direction of spread and relationship to the 2002 human outbreak of WNV. It has brought to light some of the environmental factors, both natural and man-made, that likely contribute to positive samples at the trap micro-habitat level and those that don’t, at least with this first classification scheme.

The findings in this study are important. Knowing there is a higher focus of mosquito MIRs in the northwest corner of the county will allow health department personnel to target early season surveillance efforts in this area and assist with the establishment of larviciding and adulticiding schedules in order to get out in front of the annual disease cycles. This information can assist in practical matters of targeting control
intervention at the local street level and even in routing of spray equipment through the streets of a community. This is possible by overlaying maps like the ones in this study with parcel (when available) and street layers to work local neighborhood. An example of this is presented in Figure 26. The GIS can then be used to help target areas of high infection rates for treatment, prioritizing treatment order, and to set up the most efficient routes through the neighborhoods in order to save fuel. In addition, much was learned that will be useful in generating additional hypotheses for future studies of WNV and other arboviruses in urban/suburban communities.

Health Departments and researchers in Ohio would benefit greatly from a statewide vector surveillance system that would include GPS trap locations and integration into a state GIS system. All health departments could participate in an on-line data submission system. This would include standardized data forms, collection of basic environmental information, GPS trap locations, and related data fed into an on-line state system for statewide and local use in vector-borne disease analysis and statewide reporting. A system like this has been established in other states such as Pennsylvania using portable GPS and Arch Pad software from ESRI (108). The use of GIS for local health departments is currently a topic of much interest. The existence of many local health departments across Ohio, advances in health information technology, GIS, and recent bioterrorist events, have sparked interest in the use of GIS and other technologies in local health departments (74).

The state of Ohio has used federal bioterrorism money to assist local health departments with disease surveillance efforts in recent years. Many have hired epidemiologists to staff this effort and GIS use has become more prevalent in Ohio’s local health departments. Still many are small, understaffed, and the cost and technical
requirements of GIS are beyond their capabilities. An enterprise-wide GIS system for all health department epidemiology should be established in Ohio, hopefully under the leadership of the state health department.

‘Ecological niche modeling’ is useful in the study of vector-borne diseases such as WNV. Its use in the study of disease can differ significantly from traditional uses of the model for the study of geographic and ecological distribution of species and is affected by local and regional conditions (109). There is a complex relationship between multiple vectors, hosts, and humans, in the local environment. The abiotic requirements of one host involved in a disease transmission cycle may be more restricted for one host than another and may thus restrict the geographic area of the disease phenomena of interest (109).

In addition to ecological factors, man-made and social factors affect natural cycles of vector-host relationships as well. During the recent economic crisis in the U.S., concern was raised in California over the number of delinquent mortgages that led to abandoned swimming pools and increased breeding of mosquitoes in them (111). These types of issues must always be considered as well as environmental and ecological factors when looking at complex disease processes. Vector-reservoir interactions and their relationship with WNV in humans in the natural environment always play out within a political and social context. This has been pointed out by a number of investigators (57, 65). Public health professionals must understand all of these systems if they are to successfully intervene in the disease transmission process in their communities and prevent disease.

_Culex_ species which are effective vectors in the bird-mosquito cycle are abundant in Cuyahoga County and throughout Ohio. Many species of more non-selective
mosquito bridge vectors that readily bite humans are also abundant in Ohio. Although WNV numbers are dropping in Cuyahoga County and the state, the fact that we have suitable habitat and environmental factors for WNV, will likely mean that as we reach the endemic level in Ohio, WNV will be here to stay at some low level in mosquito and bird populations. Human cases may continue to occur when environmental and other conditions are optimal. Continued mosquito surveillance and control programs will remain important public health preventive measure in the foreseeable future. Modeling of environmental, weather, and habitat factors using GIS and other technologies will become increasingly important tools in these efforts. Ecological niche type models in particular have the advantage of allowing for prediction (3). Once key ecological factors are known and associated with species activities and geography, one might more easily predict what might happen if a vector entered a new range or habitat such as the entry of WNV into the U.S. or what might happen from anthropometric (man-made) activities such as urban sprawl, urbanization, catch basin design, climate change, increasing sea levels, and the like. Ecological niche modeling has received much attention in the study of invasive species. Known ecological niche is compared to available new habitat and predictions of where a species might invade next have been attempted (59, 61). This is not unlike the occurrence of a new disease, such as WNV in the U.S. The emerging field of landscape epidemiology is exploring geographic spatial relationships and disease causation, and has been used successfully to study numerous diseases (61). Multi-disciplinary studies are becoming increasingly important in many disciplines, and this trend is evident in the field of arbovirus biology and environmental health as well.

The results of this study have applicability for other areas as well. Geospatial techniques such as those demonstrated in this study and many more can be used in any
area to study risk factors, map endemic levels, follow spread, analyze cluster events, and
the like. GIS software has tremendous capabilities that can be brought to bear on
environmental health problems. There are ample government databases for some of these
purposes already and investigators can generate new data using GPS location and
generating their own spatial data sets. This study developed information on the important
differences between man-made and natural breeding sites in urban/suburban areas, how
these sites may differ in rural areas, and outlines environmental factors that may differ in
importance in different settings. This study has also illustrated the importance of catch
basin design in planning, in terms of health. These differences have important
ramifications for surveillance and control of mosquitoes for environmental health
professionals in different types of communities. This work has also demonstrated that
GIS is a valuable tool in disease investigation and that models such as those used here to
predict WNV activity and MIR positivity may indeed be possible, when different types of
communities are studied and models better refined.
Figure 26: Probability of MIR>20 on local streets in northwest Cuyahoga Co.
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