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# GIS UTILIZATION IN LARGE SCALE HEALTH STUDIES AND SURVEYS: PENNSYLVANIA'S WEST NILE VIRUS SURVEILLANCE PROGRAM

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***ABSTRACT:*** *Effectively dealing with the rapid evolution and diffusion of modern viruses and diseases requires the implementation of large-scale health surveys and studies. Geographic Information Systems (GIS) allow for the efficient monitoring and tracking of viruses and diseases throughout large geographic areas. This paper details the advantages of using a GIS in large-scale medical surveys through a review of Pennsylvania's West Nile Virus Surveillance Program. Current and future applications of GIS related to this mosquito-borne pathogen, such as cartographic representations of the threat and the ability to predict future areas of concern, are among the issues discussed. These applications demonstrate the capability of GIS for computerized mapping and, more importantly, as a set of spatial analysis tools that can be utilized for important medical-related decision making.*

## INTRODUCTION

The importance of evaluating the spatial dimension of disease has been apparent to the public health community at least since the famous 1854 mapping of a London cholera outbreak by Dr. John Snow (Meade *et al.*, 1988). One recent publication aimed at presenting the public and policy-makers with a glimpse of geography's analytical contributions to some of the world's most critical issues has also prominently featured discussions related to patterns of human disease and the provision of health care (NRC, 1997). With rapid changes in population growth, evolving resistances by disease to antibiotic treatments, and the ease with which people, animals, and plants are transported about the world, an emergence of new diseases and the re-emergence of old ones should not be unexpected. Clearly, the importance of a geographical perspective to understanding disease is as important as ever, if not more so.

This paper deals with a heretofore unencountered problem – an outbreak of the West Nile Virus in the Western hemisphere. Occurring primarily in the New York City metropolitan region, this virus outbreak was responsible for seven deaths in the fall of 1999. Effectively dealing with the rapid evolution and diffusion of modern viruses and diseases like the West Nile Virus requires the implementation of large-scale health surveys and studies. We argue that such surveys can be most efficiently and effectively managed with geographic information system technologies. As such, we detail the advantages of using a GIS through a review of Pennsylvania's West Nile Virus Surveillance Program. Current and future applications of GIS related to this mosquito-borne pathogen are among the issues discussed.

## GEOGRAPHIC TECHNOLOGIES AND MEDICAL APPLICATIONS

The study of the geographic aspects of health-related issues has a long history, one that has often been hidden within the disciplines of demography and epidemiology (Curtis, 1994). Time and again, however, the contributions of geographers to medicine have been highlighted. Gould's monograph *The Slow Plague* (1993) – an exposition on the diffusion of the AIDS pandemic – is one such example.

One successful, and unsurprising, contribution by geographers to understanding the ecology of disease has been the utilization of cartography and other geographic techniques that include spatial statistics, remote sensing, and geographic information systems. A good map, for example, has for some time been recognized as an important tool for malaria control (Kleinschmidt et al., 2000). In the hands of disease control managers, a detailed incidence map allows for the efficient allocation of combative resources and a clearer understanding, given the appropriate conditions, of where the threat may next occur. Remote sensing technology is also seen as having useful health applications (Epstein, 1998). Satellite and other aerial imagery have been utilized to monitor biotic activity ranging from the delineation of the habitats of vectors harboring malaria (Dister et al., 1993) and African sleeping sickness (Epstein et al., 1993) to the modeling of El Nino/Southern Oscillation and its climatic affect on the distribution of disease (Bouma et al., 1994).

The utilization of geographic information systems (GIS) for medicine has been as useful and varied. Many recent works have focused on issues of health care provision such as an analysis of earthquake-related deaths (Peek et al., 1998), ambulance response (Peters and Hall, 1998), and treatment access for tuberculosis (Wilkinson and Tanser, 1999). Others have used the technology to chart stationary health hazards such as radon (Geiger and Barnes, 1994) or the dynamic threat of disease (Hightower and Klein, 1995; Boone et al., 2000). Future applications, such as those suggested within this paper, appear limitless.

## THE WEST NILE VIRUS

A mosquito-borne virus that can cause encephalitis or meningitis, the West Nile Virus (WNV) is a flavivirus previously found only in Africa, Eastern Europe and West Asia (Pennsylvania Department of Health, 2000a). Encephalitis is the inflammation of the brain; meningitis affects the brain lining and the spinal cord. While encephalitis may be caused by head injury or bacterial infections, viral infections are the most common cause. Yellow fevers are associated with flaviviruses due to the jaundiced condition of some victims (*flavus* in Latin means "yellow").

WNV is primarily transmitted by the *Culex pipiens* mosquito. Generally the mosquito acquires

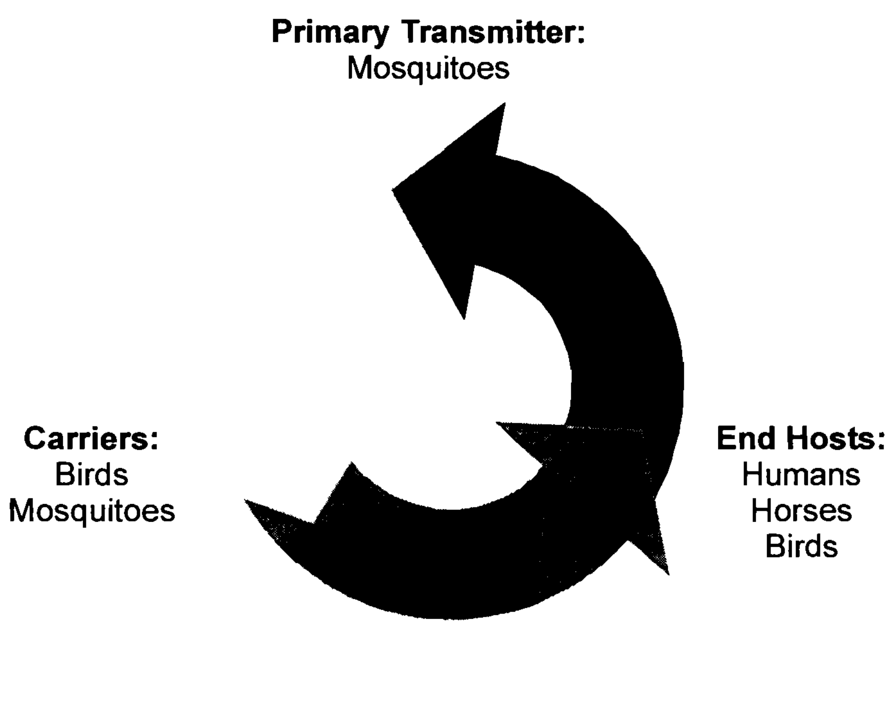


**Figure 1 West Nile Virus Transmission Sequence**
Humans and horses are always an end host. Birds too may be end hosts, or they may continue the transmission sequence by infecting additional mosquitoes.

the virus when it bites an infected bird; mosquito propagation depends upon the bird's blood meal to produce mosquito eggs. First identified in crows, WNV has also infected blue jays, swallows, and hawks. One 1999 survey of 550 birds found 194 were infected with WNV – an infection rate of 35% (Pennsylvania Department of Health, 2000a). Horses have also succumbed to this disease. Humans may be subsequently infected if a mosquito bites an infected bird and passes the virus to a human host. Humans are WNV "end hosts" and do not spread the virus from person to person (CDC, 1999). The typical transmission sequence is shown in Figure 1.

The 1999 appearance of WNV in the New York City region was the first time this disease was recorded in the Western hemisphere. This initial outbreak included 62 reported human cases, seven of which resulted in death. All recorded episodes occurred between August 2 and September 22, 1999. As such, the disease displays a seasonal as well as a spatial dimension. Mosquitoes are most active during the warmer May to October period, a time frame that coincides with northward bird migration.

WNV currently has no vaccination treatment. The population at most risk from WNV are the elderly and those with weakened immune systems. Generally speaking, those over 50 years of age have more difficulty fighting off disease. The vast majority of people bitten by a WNV-infected mosquito do not get sick. Those who do fall ill can expect some or all of the following symptoms within three to fifteen days after a bite: fever, headache, nausea, rash, stiff neck, muscle weakness, tremors, confusion, and coma. As these symptoms are also manifested by less problematic afflictions, many people do not seek early treatment. This then poses an additional problem: do we know for certain the number of fatalities from WNV? Some deaths may have been attributed to other causes. While we certainly do not want to underestimate the threat (for those infected persons showing the most serious symptoms, the fatality rate is between 3 and 15%), neither do we want to overestimate it. Human health resources are already thin, so we must be careful in allocating them to the most threatening health issues.

Whether or not the WNV will establish itself in the United States is unknown. The international shipment of worn tires from the United States to retread plants overseas is one hypothesized transmission link (DeLong, 2000). Re-treaded tires are sent by ship back to the United States, and some believe these tires are infested with infected mosquito eggs. Once the tires reach North America, the eggs hatch and the virus spreads. Irrespective of origin or cause, WNV has spread from its initial starting point in New York. Other cases have been found in New Jersey, Connecticut, Massachusetts, Maryland, and Rhode Island. Slowly encircled, Pennsylvania has prudently chosen to step up surveillance efforts that utilize geographic information systems.

## SURVEILLANCE AND GIS IN PENNSYLVANIA

The West Nile Virus Surveillance Program (WNVSP) is Pennsylvania's method of surveying the introduction and status of WNV within the Commonwealth[1]. The program is administered and managed by several state government agencies that include the Department of Health (health care outreach), the Department of Environmental Protection (mosquito monitoring), and the Department of Agriculture (bird and horse monitoring); local governments and other state agencies also cooperate in the program where needed. The WNVSP program is funded by a $9.8 million budget allocation by the current governor. The three key components of the program are public education, surveillance, and, if needed, mosquito abatement. WNV surveillance began in Pennsylvania on April 3, 2000; this program is slightly behind other northeastern states (particularly New York) given the time lag between initial discovery and the current lack of cases in Pennsylvania.

WNV monitoring (Figure 2) is conducted through the collection of field samples by state-funded county employees. Three sampling methods are utilized: larval dipping (larvae collection from an aquatic habitat), light trapping (adult mosquito collection through the use of light and CO2), and gravid trapping (an organic trapping method primarily for collecting female mosquitoes). Depending upon the sampling procedure, the WNVSP requests a lab submission of 10 to 30 samples from different locations in each county every week. Routine surveillance consists of collecting adult and larval samples and sorting them by species

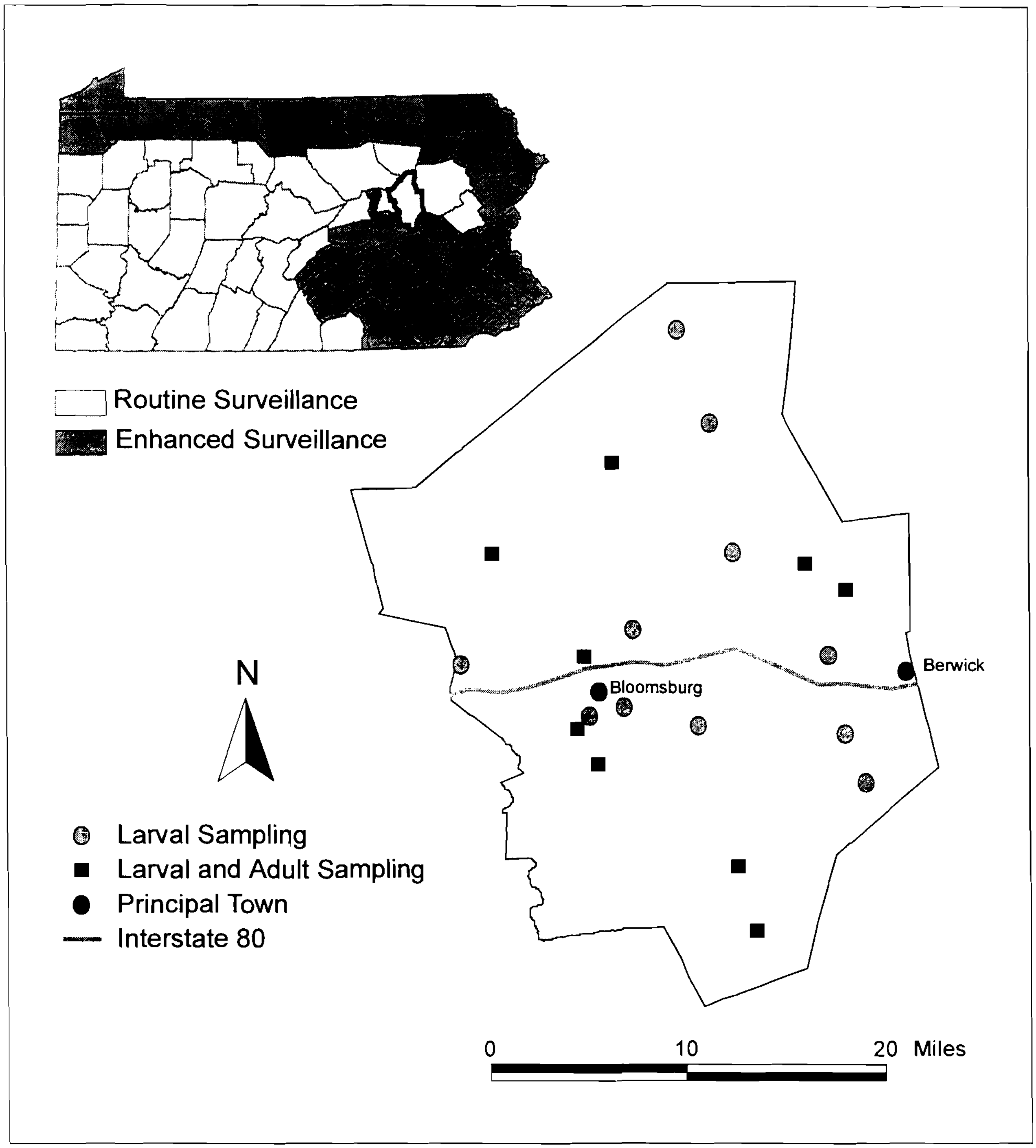


**Figure 2 West Nile Virus Monitoring in Pennsylvania and Columbia County**

to identify the number and distribution of mosquitoes in a county. Those counties practicing enhanced surveillance monitor more heavily to detect the presence of WNV. Mosquito control activities are also encouraged with state grants. A typical sampling site, such as those shown for Columbia County, Pennsylvania, is a stagnant wetland area well-suited as a mosquito breeding area.

The mosquito surveillance administered by the Department of Environmental Protection not only uses these standard testing methods, but also incorporates newly developed handheld GIS technology. The Environmental Systems Research Institute (ESRI) has developed GIS software, ARC Pad, specifically for use in field applications. The ARC Pad software is capable of map navigation, display, query, data capture, and works as a GPS interface. It may also be integrated with a desktop GIS. ARC Pad is a Windows CE based tool that runs off a personal handheld computer. The field data collection process primarily entails entering attribute data about the site and the sample for a given point (lat/long) or polygon. This information is subsequently downloaded into the state's WNV server for future analysis.

Several advantages of using GIS technology in this program are readily apparent[2]. First, the location of each sample site is known with great certainty, a crucial factor if future abatement is necessary for a positive test. Second, the technology allows for the efficient allocation of lab time, the mobilization of a large number of field collectors to the most active "hot" areas, and the easy tracking of samples. Each of these can result in tremendous cost-savings. A final benefit is a decrease in the "paper trail" and the subsequent lag time that can slow down the quick response needed to combat this pathogen. While each of these benefits on their face are important in WNV surveillance, the full analytical capabilities of a GIS – the power to manipulate and query data, and to create information – have yet to be discussed.

## GIS AND THE WEST NILE VIRUS

### GIS: Rapid Cartographic Representation

The promise of GIS in medical surveys lies in part in its ability to represent complex data in a visually understandable manner. Certainly more rigorous applications are possible, but the "computerized mapping" ability of a GIS should not be overlooked. For the day-to-day tracking of events by analysts and the presentation of findings to the public and political decision-makers, a simple and quickly updateable map may be quite useful. Communicating the seriousness of the WNV threat to Pennsylvanians in this manner is illustrated below.

Figure 3 specifically shows the diffusion of the West Nile Virus from the New York City area; the map generally supports the hypothesis regarding an international port introduction of the disease. Subsequent weekly categorizations of the first reported incidence of the disease detail the spread of the pathogen to adjacent areas – a pattern that moves increasingly closer and closer to Pennsylvania. This simple map is an effective tool for Pennsylvanians in three respects:

(1) The graphic details for the agencies charged with protecting the environmental and human well-being of Pennsylvania those areas likely to be affected first within the state. As such, monitoring efforts and the proper allocation of resources may be targeted with greater precision.

(2) The map clearly portrays in unmistakable terms the currency and reality of the threat for Pennsylvania lawmakers, the decision-makers who ultimately dictate many of the actions of the above group by controlling the state's purse strings.

(3) The public is better able to understand which areas are more problematic than others. This results in a more educated citizen

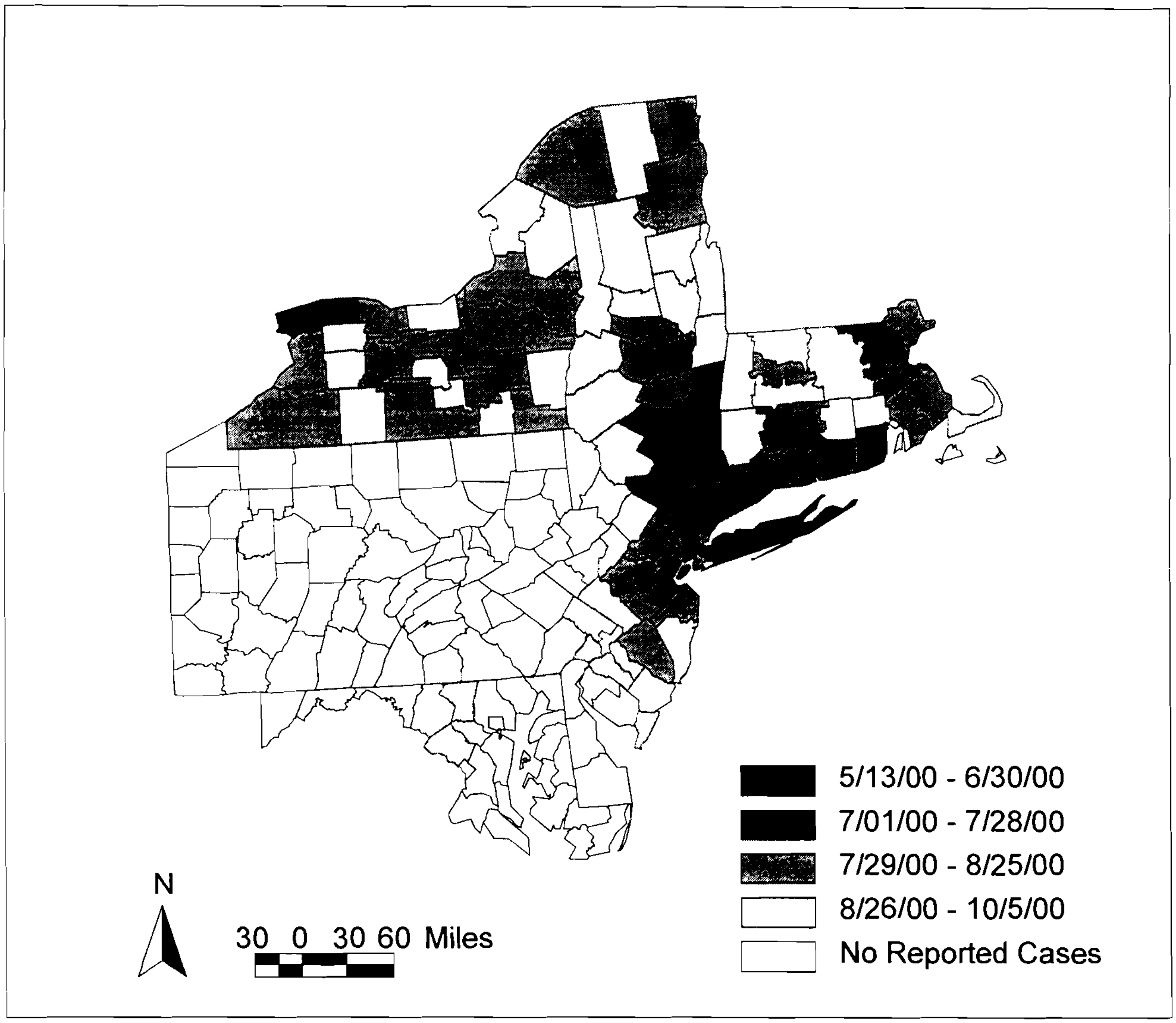


**Figure 3 Space/Time Diffusion of West Nile Virus in 2000**
(Data Classified by Date of Initial Virus Confirmation)

who is able to take precautions such as controlling/monitoring mosquito-breeding environments, using insect repellant, and dressing appropriately to reduce the risk of infection.

While useful and instructive for these reasons, this map raises other questions about the diffusion of WNV. In many respects Figure 3 is a population map. Cases were found in New York near Buffalo, Rochester, and Syracuse before they were found in the Adirondack region. Surveillance programs have been more active in populated areas and therefore turn up cases first. This creates the impression that some areas have been "skipped" over when in all likelihood the virus is present. It is certainly much more difficult to come across a dead crow or a pool of infected mosquitoes in a heavily forested area. The rugged and rural topography of eastern Pennsylvania, the most likely point of first introduction, makes monitoring difficult. While the map would have you believe otherwise, the WNV – as yet undetected – is probably present across northern and eastern Pennsylvania. Despite the caveats of reading this or any map, the usefulness of a GIS for rapid cartographic representation should not be underestimated.

## Breaching Uncertainty: Creating a More Accurate Depiction of Risk

At present, both Pennsylvania and New York collect WNV data with highly accurate locational precision. The level of detail for public display, however, is highly generalized. Like Figure 3 described above, both states present WNV case data only in an aggregated format at the county level (PA Department of Health, 2000b; State of New York Department of Health, 2000). This of course has the potential to obscure the real patterns of risk. Given the uncertainty of the presence of the virus due to the difficulty in identifying cases in all areas, data interpolation from known cases may be useful in creating a more accurate depiction of the risk. This point-oriented interpolation (Laurini and Thompson, 1992) is useful for estimating values for other positions where it is not possible to record values directly (an identified problem for WNV detection).

Two problems currently limit this spatial information manipulation in Pennsylvania. First, multiple sample observation sites exist, but we are currently without identified case data. Enhanced surveillance has been stepped up in those counties adjacent to New York positive counties, and theoretically interpolation could be made into Pennsylvania from those New York point locations. New York, however, and for that matter, Pennsylvania, is not releasing specific locational data at present, which is the second limitation. These management and institutional access barriers (including larger social constraints) have been noted elsewhere (Aronoff, 1989; Pickles, 1995) and at some level will continue to affect geographic information access. At some point, decision-makers (largely the Pennsylvania Department of Health) will have to reach some conclusion as to what level of data sharing is acceptable to best protect the public from WNV: general data detail and access for the public, or highly detailed information as is available for management decisions?

To sum, WNV risk depiction in Pennsylvania is currently hampered by issues related to spatial information detail and by institutional barriers both within and outside the state. In light of these limitations, Pennsylvania must still work toward presenting the public with a more accurate risk picture than a statewide county map. By utilizing a number of methods for visualizing uncertainty cartographically, such as creating bi-variate maps where both the data and uncertainty estimate are presented on the same map (MacEachren, 1992; MacEachren et al., 1998), the state may suggest to the public where the virus is likely present without hard confirmation. Pennsylvania must be careful, however, to deal with uncertainty about the WNV in a way that does not lead to a failure to notice real patterns while creating disease incidence patterns that do not exist (MacEachren, 1992).

## GIS: The WNV Decision-Making Toolkit

The West Nile Virus Surveillance Program in Pennsylvania is in its infancy, as is the use of GIS for health-related applications. As the program moves forward, the utilization of the supra-mapping features of GIS should become more commonplace. A GIS, through the use of features such as buffer analysis, spatial query, and polygon overlay analysis, can work as a predictive set of tools. Importantly, is there a way to utilize this technology to find WNV before it finds us?

Overlay analysis perhaps best illustrates the future potential of GIS in the WNV surveillance program in Pennsylvania. This GIS feature has been successfully used for estimating risk factors for Lyme disease (Glass et al., 1995) and malaria (Lang, 2000). By constructing databases with attribute data related to land use/land cover, vegetation, soils, elevation, climate, geology, and water – with the addition of

WNV case data previously collected in the field – it may be possible to identify likely sites of WNV occurrence beforehand. Program managers may then be proactive in spraying or practicing other integrated pest management techniques in the target areas. Further combining this information with human population data can assist in prioritizing intervention sites. The WNV program in Pennsylvania is currently in Phase I with a primary focus on software design and mosquito data collection. During Phase II, the system will be expanded to include some of the other databases noted above. When implemented, Phase II should allow for more informed decisions, decisions that result in a savings of resources and lives.

## CONCLUSIONS

Geographic Information Systems have powerful analytical capabilities that have not yet been fully harnessed for the West Nile Virus threat in Pennsylvania, but the potential is there. The program is succeeding in gathering a wealth of data that is not only locationally grounded, but also more efficiently managed and subsequently manipulated to create useful information for better decision-making. As with any new program, however, especially those experimenting with new technology, several problems have been identified. For example, the personnel needed to effectively use GIS for health-related tasks require a considerable amount of training. While the mosquito sampling procedures may be easily learned, the use of ArcPad, GPS, and a GIS is difficult (particularly in a trouble-shooting phase) without a background in GIS or geography.

Several recommendations for improving the WNV program in Pennsylvania include the following:

(1) Counties need additional state resources to hire analysts with GIS experience to more effectively manage the ever-increasing volumes of data – both locational and attribute. This personnel can also provide expertise for other pressing issues requiring analysis from a spatial perspective.

(2) Additional educational materials need to be produced to communicate the threat to the public. Incidence maps must be updated frequently and protective instructions provided. Currently the WNV threat in Pennsylvania is largely viewed as an issue of concern only in other states.

(3) The WNV program must fall under a larger regional coalition of state governments to share data and resources. An effort must be made to ensure that data are collected and documented in a uniform manner (including metadata) that permits useful epidemiological analysis. This coalition may need federal assistance from an agency such as the Centers for Disease Control.

Pennsylvania's West Nile Virus Surveillance Program has been successfully implemented. The program's next test is to see if it can proactively identify, monitor, and keep the public informed about this threat – a process well-suited to the strengths of GIS technology.

### Postscript

Most of the research for this article was completed in September 2000. Since that time, numerous cases have appeared throughout the Northeastern United States; these included dead birds and horses, mosquito pools, and human cases (including one fatality in New Jersey). New cases have also appeared in New Hampshire. Pennsylvania cases have been found in Bradford, Bucks, Chester, Cumberland, Dauphin, Delaware, Erie, Lehigh, Montgomery, Philadelphia, Pike, Schuylkill, Susquehanna, Tioga, Union, Wyoming, and York Counties. As such, accelerating the surveillance program is imperative since it appears likely that the WNV will be with us again next year and perhaps indefinitely. Pennsylvania is currently presenting these data at the county level only.

## NOTES/ACKNOWLEDGEMENTS

1. A brief program overview has recently appeared in *ArcNews* (2000).
2. For a review of the several advantages and disadvantages of using GIS as it applies to medical geography, see Richards et al., 1999 and O'Dwyer and Burton, 1998.
3. Mr. Eckhoff would like to thank the Columbia County Planning Commission for their assistance with a summer internship that provided opportunities to work in the Pennsylvania West Nile Virus Surveillance Program. Both authors thank Dr. John Bodenman, the two anonymous reviewers, and the journal editors for their comments on this work. Mr. Eckhoff is a recent graduate of the Department of Geography and Geosciences at Bloomsburg University; Dr. Mitchell is a faculty member in the same department.

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