The Incorporation of Geographic Information Systems into a Local Mosquito Control Program

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Christopher Bauer, R.S.
cbauer@ccbh.net

Tim Gallagher, R.S.
tgallagher@ccbh.net

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Abstract

Cuyahoga County is located in northeast Ohio and is part of the greater Cleveland metropolitan area. The Cuyahoga County Board of Health Mosquito Control Program has increased its operation as a result of the West Nile Virus outbreak in the summer of 2002. This paper presents the development of a GIS based data management system for the existing mosquito control program. The system will utilize ESRI's ArcGIS software with support from Microsoft Access. Cartographic outputs will include operational maps, surveillance maps, and other outputs. The completed system will enhance the department's ability to protect the public from vector borne disease.

Project Summary

Cuyahoga County is located in northeast Ohio and is part of the greater Cleveland metropolitan area. In 1975, an outbreak of mosquito borne encephalitis in the State of Ohio prompted local county health officials to implement a mosquito control program. This program has been in operation since the outbreak and is a successful public health based program.

In the summer of 1999, the State of New York experienced an outbreak of the West Nile Virus, a mosquito borne arboviral disease previously confined to areas outside North America. Since the 1999 New York outbreak, the virus has been detected in all states east of the Mississippi River. It was detected in Ohio's avian population in the summer of 2001. Rapid movement of the West Nile Virus into Ohio has heightened public awareness regarding the operation of mosquito control programs. With vectors present to support the transmission cycle, the West Nile Virus will become endemic to the area. The Board of Health will be stressed to provide additional functions with little or no additional funding.

This paper depicts a Geographic Information System (GIS) based Spatial Decision Support System (SDSS) to streamline the data management portion of the mosquito control program. The SDSS will allow program managers to focus their resources on the public health implication regarding disease transmission and less attention on daily program tracking functions. With the power of GIS to handle spatially referenced data, the level of accuracy and focus of the program activities will be greatly enhanced.

A major portion of this paper is devoted to the technical make-up of the GIS based data management system. The incorporation of existing operational paper maps was undertaken to provide base maps and operational data needed to create the new system. A Microsoft Access database supports the new system and controls the information generated by routine program activities. The database is linked to a GIS providing up to date cartographic outputs to be used by field personnel. The data management system is currently under implementation.

1.Introduction

"GIS are powerful tools that enhance a health department's ability to protect the community"(Richards 1998).

The following research paper has been completed by a State of Ohio, Registered Sanitarian employed by the Cuyahoga County Board of Health. Mr. Bauer has nine years of experience in the environmental field and five years with the Board of Health. Mr. Bauer's title is Senior Sanitarian with district responsibilities in the communities of Gates Mills and Mayfield Village. Contributing author is Tim Gallagher, Research Supervisor. Additional assistance from Joe Lynch, Mosquito Control Program Manager, and Chris Kippes, Research Supervisor, was obtained to verify the system design would meet the changing needs of the program.

Cuyahoga County is located in northeast Ohio and is part of the greater Cleveland metropolitan area. The Cuyahoga County Board of Health created a mosquito surveillance and control program in 1976 in response to a 1975 human epidemic of St. Louis Encephalitis (SLE). The program has been in operation since the outbreak and is a successful public health based program.

The Cuyahoga County Board of Health is comprised of three divisions; Nursing, Community Health and Environmental Health. The Board of Health currently serves all of the municipalities in Cuyahoga County with the exceptions of; The City of Shaker Heights, The City of Lakewood and The City of Cleveland. The municipal infrastructure in these cities contain local public health agencies.

In the summer of 1999 the State of New York experienced a West Nile Virus outbreak, a mosquito borne disease previously confined to areas outside North America. Since the 1999 New York outbreak, the virus has been detected in all states east of the Mississippi River and was detected in Ohio's avian population in the summer of 2001. Rapid movement of the West Nile Virus into Ohio has heightened public awareness regarding the operation of mosquito control programs. With vectors present to support the transmission cycle, the West Nile Virus will become endemic to the area. Mosquito control programs will be stressed to provide additional functions with little or no additional funding.

With the amount of spatially referenced data contained in the mosquito control program, the inclusion of a GIS is a natural fit. A pilot study was developed and tested as part of the Cleveland State University graduate program in Geographic Information Systems. Full implementation into the program will be a beneficial activity. The completed product will be a strong spatial decision support system (SDSS) for the mosquito control operations.

In addition, the full implementation will demonstrate the power of GIS to enhance other environmental health programs within the Cuyahoga County Board of Health. The Division of Environmental Health currently operates more than 22 programs (Board of Health Sanitarian Manual 2002). The amount by which Geographic Information Systems (GIS) can enhance program operations varies widely, from a simple map of swimming pool locations to a distribution of home sewage systems

2. Background and Related Research

2.1 Background and Overview

Research has been done on GIS and its relationship to public health programs (Vine, 1998) (Richards, 1998). The ability to monitor disease locations as they relate to other spatial entities is not a new practice and has been done by medical professionals for years. There are various examples of environmental organizations and their ability to track the impact of different incidents with GIS (Vine, 1998) (Marvin 2000) (Lee and Glover 1998).

The underlying biological process driving this research is the mosquito's ability to transmit disease. Information is presented on various types of mosquitoes, there habitat and life cycles. It is presented to define the activities involved in controlling the mosquito population. The current program functions are described and the tracking and recording system in place is evaluated. To understand the activities of this complex program and how GIS will support it, a basic understanding of mosquito biology and the program operations is necessary.

2.2 Basic Mosquito Biology

The life cycle of a mosquito contains four stages; egg, larva, pupa and adult. The process may vary from species to species, however the basic progression is similar. Eggs are laid in or around areas of still or standing water. Following an incubation period, the eggs hatch into larva. During the larval stage, mosquitoes are confined to water and feed on organic matter as they develop through four stages defined as larval instars. The major distinction during instar development is the size of the larva, increasing size with each progressing instar. Following the fourth instar, the larva develop into pupa. Pupa are also confined to water and do not feed during this period. The pupa is the final stage of development and an adult mosquito will emerge. The time frame for development through the four stages varies depending on the species and the environmental conditions in the area. Adult female mosquitoes are ready to take blood meals in two to three days. Male mosquitoes feed only on plant nectar (OSU Bulletin 641).

There are as many as 60 species of mosquitoes found in the State of Ohio. Information on the most troublesome, as identified in the Ohio State University Bulletin 641 are briefly described:

Aedes canadensis is a serious pest in woodlands. The species survive through the winter in the egg stage and is one of the first to appear in the spring. The eggs are laid singly on the ground in the area of woodland pools and can survive long periods of drying. The eggs hatch when the area is flooded. There is typically one generation per year with the adults living for several months. This species is known to be a secondary vector of LaCrosse encephalitis. Larvaciding activities in the early spring can have a significant impact on the population of this mosquito. Aerial applications are conducted in areas of Cuyahoga County to control this species.

Aedes triseriatus breed in tree-holes, tires and other artificial containers. This species survives the winter in the egg stage and has several generations per year. Ades triseriatus is the primary vector of LaCrosse encephalitis.

Aedes vexans is a very abundant mosquito and breeds in rain pools, flood waters, roadside puddles and ditches, and most temporary bodies of fresh water. Eggs are laid on the ground above the water line and hatch when an area becomes flooded. Larva can be found in very large numbers, up to 500 larvae in one pint of water. The adults fly long distances of up to 5 to 10 miles from the breeding site. The adults are vicious biters and most active at night where they are attracted to light. Ades vexans is considered to be Ohio's primary pest mosquito as well as a secondary vector of Eastern Equine encephalitis.

Anopheles quadrimaculatus breed primarily in permanent, fresh water pools, ponds and swamps that contain aquatic vegetation or floating debris. Eggs are laid singly on the surface of the water. One hundred or more eggs may be laid at a time with a single female laying up to 12 batches each year. Adults fly about _ mile from there breeding sites and the females can survive the winter fertilized. This species is the most important vector of Malaria attacking humans in the eastern United States.

Culex pipiens breed in rain barrels, tires, storm sewer catch basins, street gutters, and road side ditches. Eggs are laid in rafts of up to 100 to 400 eggs per raft. Breeding continues throughout the warmer months of the year. Adults are active at night and are attracted to carbon dioxide baited light traps. This mosquito is a vector of St. Louis encephalitis.

2.3 Disease Transmission

Transmission cycles for the major vector borne diseases in Ohio are very similar. The virus reservoir is the bird population with the exception of small mammals as the reservoir for LaCrosse encephalitis. Mosquitoes which feed on infected birds or mammals can carry the disease and in some cases reproduce the virus in the gut of the insect. Humans and other mammals can become infected when bitten by an infected mosquito. As a female mosquito takes a blood meal, an anti-coagulant is injected by the mosquito into the bite location. This anticoagulant contains the virus and is injected into the blood stream of the victim. Humans are dead end hosts and the diseases are not communicable.

2.4 Cuyahoga County Board of Health Program Components

The Board of Health mosquito control program contains the following:

- A strong educational component for individuals to understand the risks associated with mosquitoes and disease.
- Surveillance activities to monitor the mosquito population and the location of viruses in humans, mosquitoes, and reservoirs.
- Individual homeowner complaint responses.
- Breeding site inspection and treatment component along with adult mosquito control capabilities.
- Data management.

A successful program requires all of the above functions to effectively control the mosquito population and reduce the potential for disease transmission. The educational component of the program will receive little attention as part of this research; however the author does understand the negative implications to a program without this. Brief information regarding the program functions are described below.

Surveillance activities include the use of various types of traps to collect specific species of adult mosquitoes. The collected mosquitoes are quantified, identified and submitted to State laboratories for testing. The location of dead crows and blue jays found in the health district are also recorded and in some cases submitted for virus activity. Dead bird clusters can identify areas with increased virus activity. Additional surveillance activities include the collection of blood samples from the avian population, these blood samples are also submitted to laboratories for disease testing.

The program responds to various complaints by individual homeowners. The response and actions taken vary regarding on the nature of the complaint. Most complainants are presented with educational materials for protecting themselves from mosquito borne disease.

Larvaciding is the responsible application of U.S. EPA approved pesticides to active breeding sites for the control of mosquito larvae and pupae. The products are applied to areas of standing water, storm sewer catch basins and roadside ditches. The pesticide is ingested by developing larva and either kills the insect or introduces a hormone which will not allow the pupa to develop into an adult mosquito. The most effective larvaciding effort is to eliminate the standing water and breeding locations.

Adulticiding is the responsible application of U.S. EPA approved pesticides to kill adult mosquitoes. These products give rapid knockdown of adult mosquitoes. The pesticide is distributed via Ultra Low Volume (ULV) equipment. The ULV machines distribute the pesticide in a controlled and consistent fashion. Trucks are used to progress the ULV equipment at 10 miles per hour. Adulticiding activities are conducted in the evening hours during periods with low winds, no rain and temperatures above 55 degrees Fahrenheit.

The data management system for the existing mosquito control program was basic and outdated. The location of the routine treatment sites were hand drawn on local road maps. These maps lacked accuracy and had to be re-drawn several times per season. The data regarding treatment activities at the sites was contained on paper manifest with no computer based files. Complaints were handwritten and many were difficult to read. Several complaints, in various locations, were contained on a single complaint sheet, this led to scheduling difficulties. Adulticiding tracking was also basic. Spray routes were highlighted on local road networks. These were difficult to read and lacked the accuracy needed in the current program. While this data management system was not technocologically current, is was sufficient for the control program prior to the arrival of the West Nile Virus. With the increased activity and awareness regarding mosquito control efforts, the data management system needed to be enhanced.

3.0 GIS Implementation
Methods and Procedures for Shapefile Generation

3.1 Overview

The software packages chosen were Environmental Systems Research Institute (ESRI) ArcView 3.3 and Microsoft Access 2000. These software packages were selected as they are operating in the current Board of Health network.

The system has been developed to track all functions of the mosquito control program and is broken down into 4 major components: Surveillance, Routine Treatments, Complaints Responses and Adult Mosquito Control Activities. Each of the four components are described below.

3.2 Surveillance

The surveillance system was developed to increase efficiency and allow for additional volume. The system contains three sub-sections.

- Dead Birds
- Other Trapping Locations and Shelter Collections
- Routine Trapping Locations

The locations of dead birds are reported to the Health Department by the public and are geocoded on a routine basis. The Other Trapping Locations and Shelter Collections will be selected on an as needed basis and assigned their spatial location with GPS, geocoding or by hand.

The routine trap locations were selected to allow for increased activity and a more uniform approach for additional research. The locations were selected utilizing a 4 square mile grid pattern placed over the county. A free script, “GRDMAKER”, was used to obtain the grid. The centroid of each grid cell was selected as a routine trapping location, a total of 92 sites were selected. The grid cells along the borders have been manipulated to incorporate all areas of the health district. Routine Location identification labels were selected based on the municipalities the centroid was located in. Each municipality in the county has a unique numerical identification number. This number was also used for the trap location ID. For example Routine Location 42-1 is the first trap in city 42.

3.3 Routine Treatment Shapefiles

The previous data management system contained operational maps to track areas of the health district which receive routine larvaciding activities. These routine locations are storm sewer catch basins, road side ditches and areas of standing water including woodland pools and storm water retention basins. Each category was coded by hand on paper maps. Street segments highlighted in blue indicate storm sewer catch basins in this area need to be evaluated and treated. Line segments with red highlights are areas with open road side ditches and also need to be inspected and treated. Areas with green highlights are areas of standing water and need to be visited and treated also on a monthly basis, with a major focus for early spring treatments. The information in these maps was the foundation of the program and had to converted into the GIS. This was accomplished by assigning values to the various line segments in the base road network to identify the treatment type. These values were queried and converted to shapefiles. The areas of standing water were drawn by hand in a new polygon theme. This resulted in three shapefiles of raw data; two line themes and one polygon theme.

The locations of complaints are recorded in the main database and are geocoded on a regular basis. Areas with increased complaint can identify increased mosquito activity.

Adult mosquito control activities are the last tool utilized. As mentioned above, adult activities are conducted primarily on city streets. Trucks are used to transport machines which distribute pesticides in a controlled and consistent fashion. The products will drift and can cover a 300 feet swath on either side of the road. Adult control activities are conducted based on surveillance activities. Buffers are placed around sites in question and all street segments with in this buffer are selected for treatment. The selected streets are converted to a shapefile and generate the spray maps for field use and display on the internet. Each spray is assigned a unique identification number. The total miles of streets in the spray area are calculated for pesticide application rates. If a spray is to cover multiple cities, then a separate unique number is assigned. In essence an additional spray is generated. No single spray ID can span multiple municipalities.

3.4 Data Aggregation and the Generation of Treatment Units for Routine locations

The newly created information was grouped into treatment units to allow for more efficient field activities and data management. Each treatment unit received a unique numerical number for tracking purposes. They are referred to as Treatment Unit Identification numbers, (TUID). All treatment units were specific to the type of application needed and did not encompass everything in a section of a municipality.

Each area of standing water was identified as a single spatial entity and a treatment unit. Each polygon was assigned a TUID and a total of 320 TUID's were identified. The information extracted from the paper map books was vague regarding the actual size of the areas in question. Therefore the actual size in the GIS is not a accurate representation as to what actually exists. As time progresses the sizes will be adjusted to obtain more accurate data.

The road side ditches were grouped based on information from the Program Manager. A series of streets in a single city were aggregated together as one TUID. The size of the TUID in this section is more accurate and the information is contained in the theme. The length in miles of road segments was obtained and doubled, to account for both sides of the street. An average width of 3 feet was used to obtain a square feet measurement for pesticide application rates and comparisons.

The creation of catch basin treatment units was more complex. The level of accuracy contained in the existing map books with regards to catch basins was questionable. There were many road segments believed to be in need of treatment which were not coded in the map books. To increase the level of accuracy for the catch basin treatments units, US Census tract data was obtained. When the average age of housing stock in a census tract was before the year 1960, all street segments in that census tract were selected as in need of treatment. This process identified all street segments in need of catch basin treatments. Due to the number of segments selected, a repeatable data aggregation method needed to be developed to create TUID for the catch basins.

The level of aggregation chosen was to utilize the preexisting Census geography, notably the block groups. These are ideal TUID as they follow municipal boundaries and the road network. The maps read as "treat all of the streets colored blue inside the block group 7654". For example, 100 catch basins were treated inside block group 7654. Special attention is needed when working on a street segment which is also a TUID border. Only the side of the street on the inside of the polygon is treated with the TUID in question.

The processes described above generated effective GIS based tools for the mosquito control activities. The next step was to create easy to read and useable cartographic outputs for field activities and to support program management decisions.

4. Map Book Generation

To properly display the information generated, a series of mosquito control map books were generated. The map books were created in GIS utilizing a free script from ERSI.com titled "Creating Automatic Tiled Layouts". Three separate map books were developed; Area Treatment, Roadside Ditch Treatments and Storm Sewer Catch Basin Treatments. Due to the size of the Arcview projects, separate project files were generated for each map book.

The Area Treatment Units are displayed in a single 37 page map book. The cartographic output contains the area TUID theme, road network, municipal boundaries. A tabular index is located in the map book containing the address of the TUID, the map page it is located on and a notes section. A master map index is located on the first page. (appendix #3)

The Roadside Ditch treatment units are displayed in a 17 page map book. Due to the limited number of TUID's, the number of pages was reduced. The information is also displayed with the Road Network and Municipal Boundaries. A tabular index is located in the map book containing the address of the TUID, the map page it is located on and a notes section. A master map index is located on the first page. (appendix #4)

To effectively display the storm sewer catch basin information as a scale which is easily understandable, a tiling approach was used. The county was broken down into three subsections, East, South and West. A separate map book was developed for each subsection. A tabular index was produced for each sub-section and contains the TUID, map page, municipality and a notes section. A master map index page was created and is on page one.(appendix #5)

5. Database Design

A relational database was developed in Microsoft Access to track and control the program activities. Six primary tables and three destination tables are the foundation of the database. Unique data tracking ID's are generated in the six primary tables utilizing ranges of preset auto numbers. A macro was developed to copy the ID from the primary table to the destination table upon data entry. These ID's are the linking field throughout the database. A main switchboard and a series of data entry forms have been developed (appendix #1). A series of preset reports were generated along with new field activity sheets. This sound database design presents the ability to query various program functions and produce high quality outputs. Combined with the consistent design of the GIS themes, cartographic outputs are also quickly and easily developed.(appendix #2)

At the end of each season, a copy of the database and the Shapefiles will be archived for historical studies. The existing database will be purged of all information and the ID's reset for the coming year.

6. Conclusion

The system developed is currently under implementation. While no major design flaws have been identified, polishing of the system is ongoing. The data entry forms in Access have been adjusted and the field activity reports have been reworked to allow for increased efficiency in data recording and entry. Actual field activities have been increased and the system was adjusted to handle the increased volume. The Shapefiles have been and will continue to be adjusted to remove data errors. Goals for the 2004 control season include: incorporate hand held field devices to reduce the amount of administrative and data entry time devoted to the program and upgrade to ArcGIS 8.x.

The potential of GIS in public health has been well documented. The research conducted here proves a properly constructed GIS can strengthen public health programs. Research and academic information presented by the Cleveland State University, Graduate Certificate Program in Urban Geographic Information Systems identify GIS as a strong tool for local public health agencies. The ability to control, analyze and display spatially referenced data will increase a public health agency's capabilities.

The goal of the Cuyahoga County Board of Health Mosquito Control Program is to reduce the potential of vector borne disease transmission through education, surveillance and responsible pesticide application. Increased efficiency in time management, pesticide tracking and resource allocation are the result of the GIS based data management system. Surveillance activities viewed simultaneously with treatment activities will further guide program functions and allow for significant spatial analysis.

The Cuyahoga County Board of Health mosquito control program has been greatly enhanced with the inclusion of the GIS based data management system

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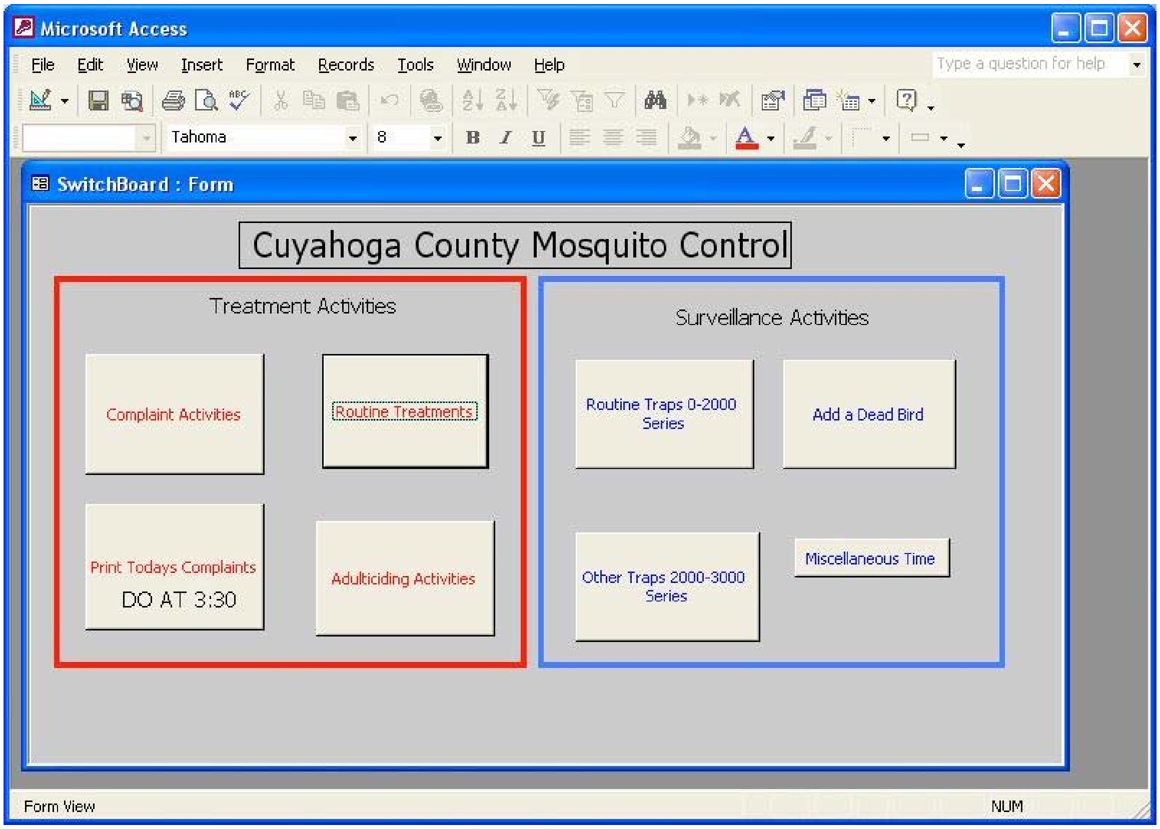
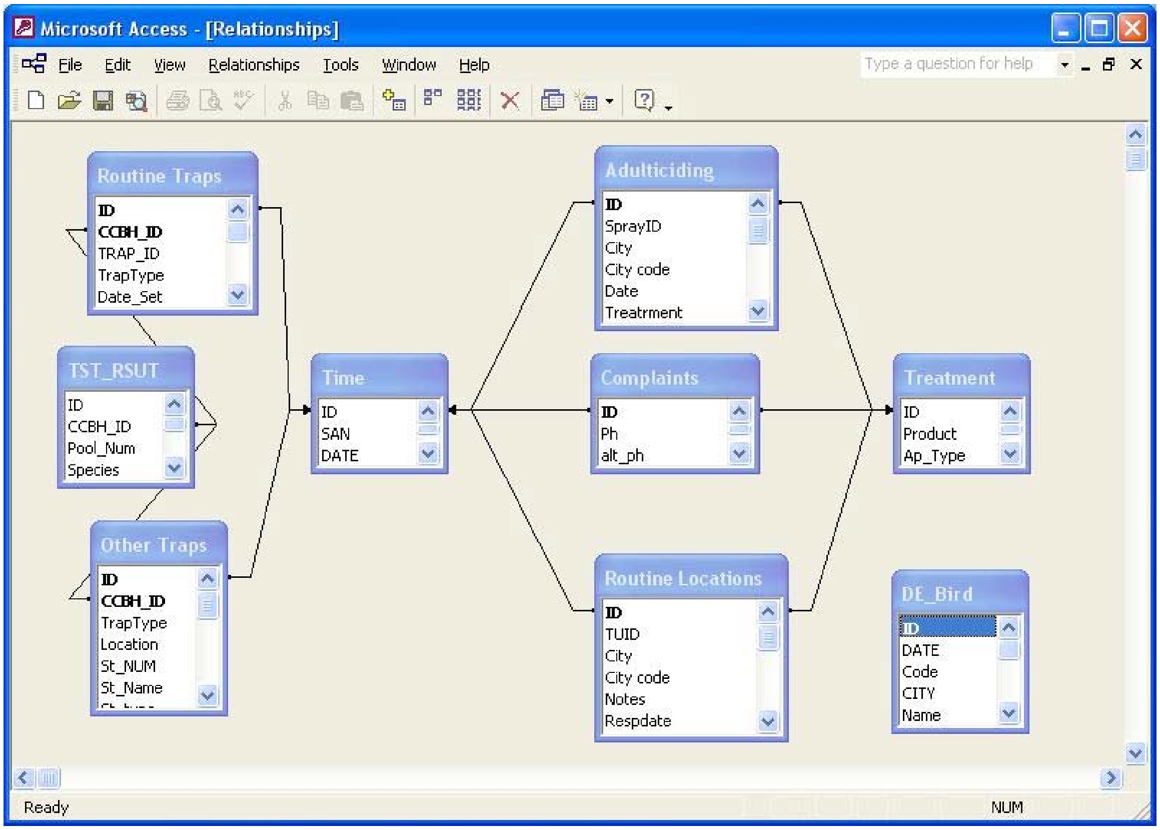
APPENDIX #1



Microsoft Access
File Edit View Insert Format Records Tools Window Help
Type a question for help
Tahoma
8
SwitchBoard : Form
Cuyahoga County Mosquito Control
Treatment Activities
Complaint Activities
Routine Treatments
Print Todays Complaints
DO AT 3:30
Adulticiding Activities
Surveillance Activities
Routine Traps 0-2000 Series
Add a Dead Bird
Other Traps 2000-3000 Series
Miscellaneous Time
Form View
NUM

APPENDIX #2



Microsoft Access - [Relationships]
File Edit View Relationships Tools Window Help
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Routine Traps
ID
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Date_Set
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ID
CCBH_ID
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Species
Other Traps
ID
CCBH_ID
TrapType
Location
St_NUM
St_Name
Time
ID
SAN
DATE
Adulticiding
ID
SprayID
City
City code
Date
Treatrment
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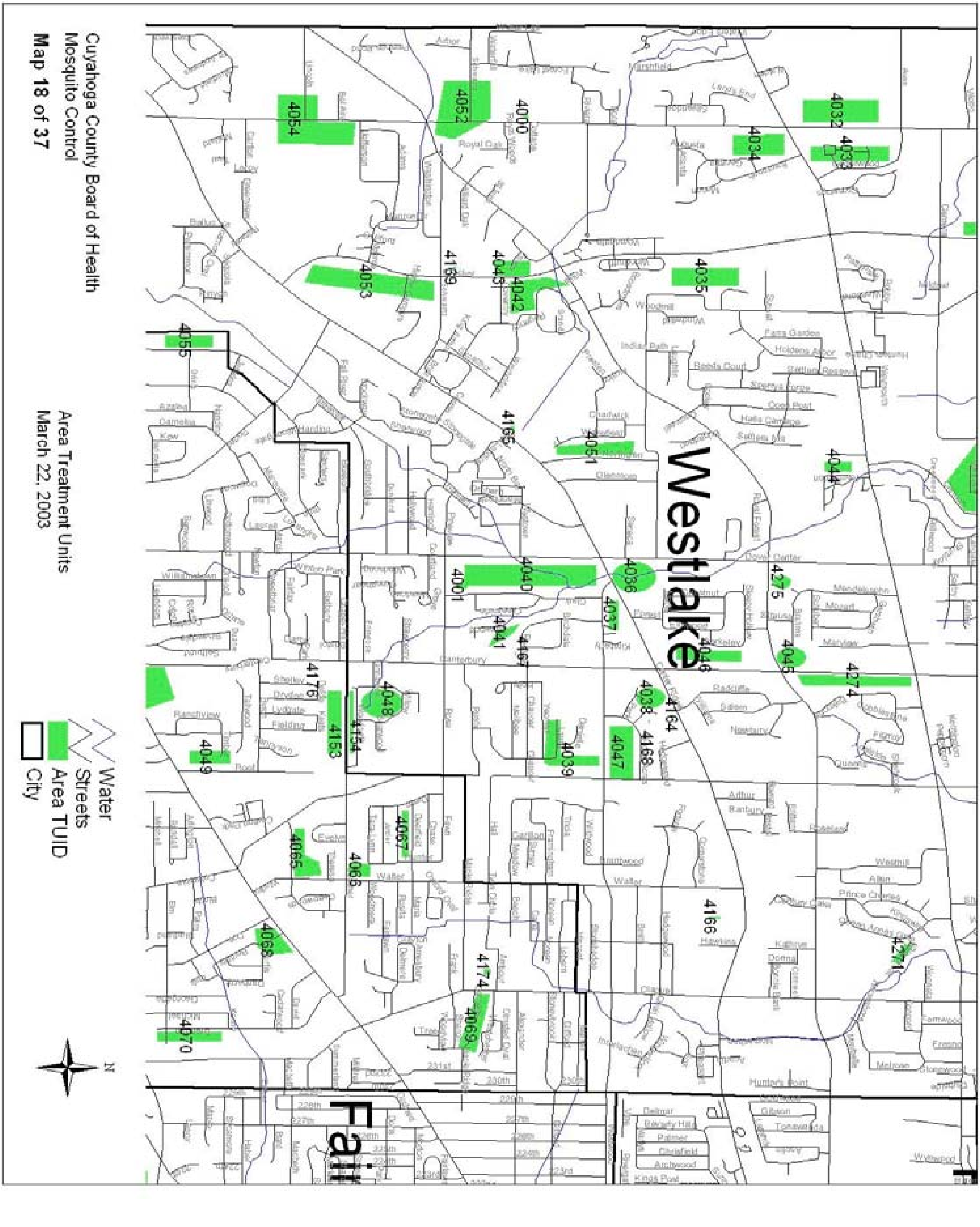
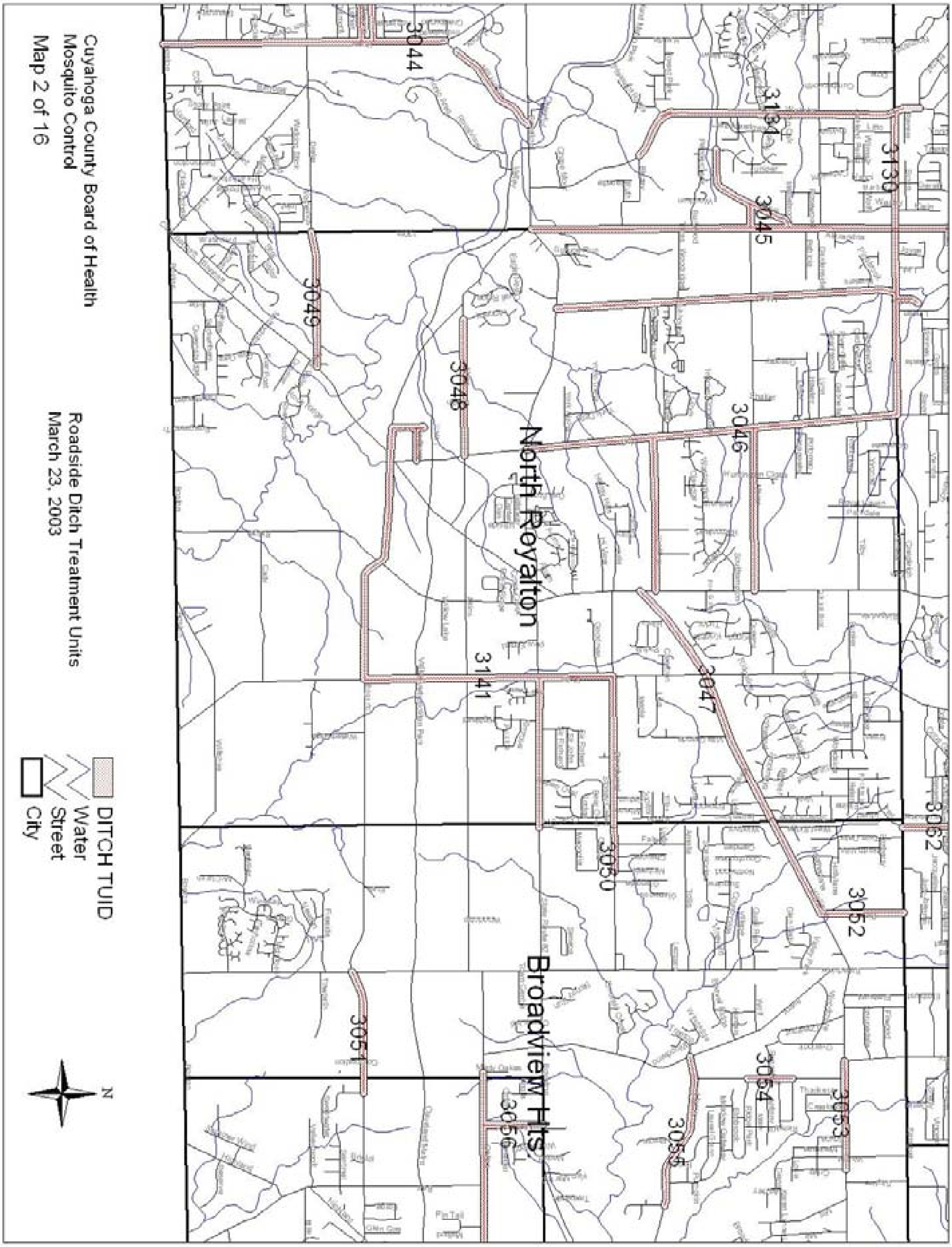

Cuyahoga County Board of Health
Mosquito Control
Map 18 of 37
Area Treatment Units
March 22, 2003
Water
Streets
Area TUID
City
Westlake
N


Cuyahoga County Board of Health
Mosquito Control
Map 2 of 16
Roadside Ditch Treatment Units
March 23, 2003
DITCH TUID
Water
Street
City
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North Royalton
Broadview Hts
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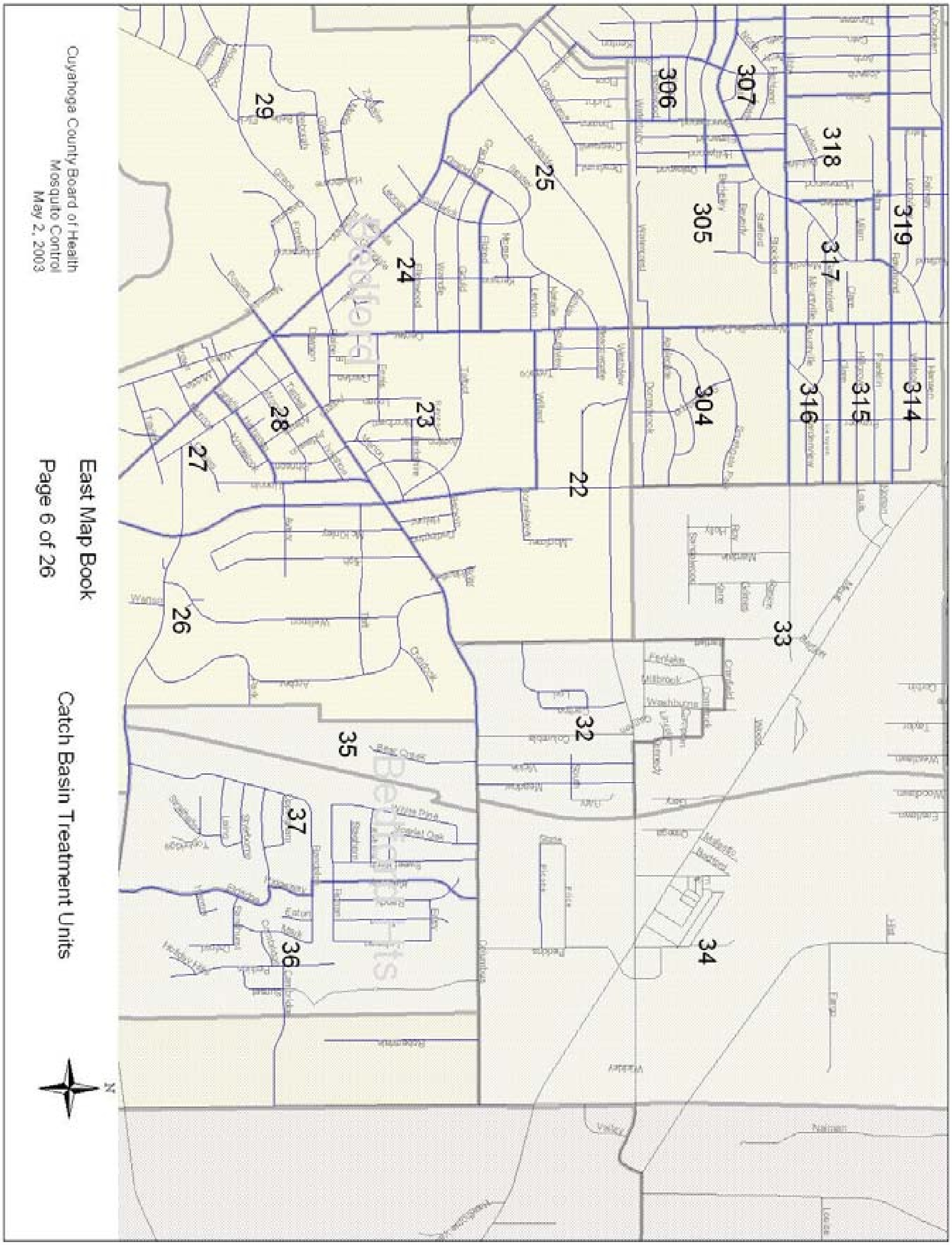
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East Map Book
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Catch Basin Treatment Units
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