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Source Water Assessment Using Geographic Information Systems

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Notice

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

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Abstract

The 1996 amendments to Section 1453 of the Safe Drinking Water Act require the states to establish and implement a Source Water Assessment Program (SWAP). Source water is the water taken from rivers, reservoirs, or wells for use as public drinking water. Source water assessment is intended to provide a strong basis for developing, implementing, and improving a state's source water protection plan. This program requires individual states to delineate protection areas for drinking water intakes, identify and inventory significant contaminants in the protection areas, and determine the susceptibility of public water supply systems to the contaminants released within the protection areas. SWAP can be used to focus environmental public health programs developed by federal, state, and local governments, as well as efforts of public water utilities and citizens, into a hydrologically defined geographic area.

The Environmental Protection Agency is assisting the states in conducting source water assessment by identifying potential sources of data and pointing to methods for assessing source waters. This report provides guidance to states, municipalities, and public water utilities for assessing source waters using geographic information system (GIS) technology. The GIS platforms can be used to organize, analyze, and manipulate available data and generate new data for source water protection areas, as well as provide capabilities for presenting the data to the public in various forms, including maps and tables. Included as appendices to this document are three case studies demonstrating the use of selected GIS-based software and hydrologic models to conduct hypothetical source water evaluations.

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Acronyms

BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
CAD	computer-aided drafting (or design)
CD-ROM	compact disk read-only memory
DD	decimal degrees
DEM	digital elevation model
DLG	digital line graph
DMS	degrees, minutes, seconds
DoD	U.S. Department of Defense
DOQ	digital orthophoto quad
DOS	a computer operating system platform
DRG	digital raster graph
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FOV	field of view
GIS	geographic information system
GLIS	Global Land Information System
GPS	global positioning system
GRASS	geographic resources analysis support system
GUI	graphical user interface
HMPF	Hydrologic Simulation Program - FORTRAN
HUC	hydrologic unit code
IWI	Index of Watershed Indicators
LAN	local area network
LULC	land use/land cover
MSS	multispectral scanner
NAD	North American Datum
NAPP	National Aerial Photography Program
NATSGO	National Soil Geographic data
NPS	nonpoint source
NPSM	Nonpoint Source Model
NRCS	Natural Resources Conservation Service
OST	EPA Office of Science and Technology
PC	personal computer
PWS	public water supply
QA/QC	quality assurance and quality control
RDBMS	relational database management system
REMM	Riverine Emergency Management Model
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SPOT	Le Systeme Pour l'Observation de la Terre
SQL	structured query language

STATSGO	State Soil Geographic data
SWAP	Source Water Assessment Program
SWTR	Surface Water Treatment Rule
TAME	terrain access made easy
TM	thematic mapper
TOT	time of travel
UNIX	a computer operating system platform
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WCP	Watershed Control Program
WHPP	Wellhead Protection Plan

Chapter 1

Introduction

1.1 What is the Purpose of this Report?

The 1996 Safe Drinking Water Act (SDWA) amendments to Section 1453 require the states to establish and implement a Source Water Assessment Program (SWAP). Source water is water taken from rivers, reservoirs, or wells by public water supply (PWS) systems for use as public drinking water. The objective of a SWAP is to provide a strong basis for developing, implementing, and improving source water protection plans. A sound strategy for source water assessment relies on “a clear lead by the states in program development and management and a strong ethic of public participation” (EPA, 1997a), including participation by public water utilities and municipalities. The SWAP must include a methodology for conducting the source water assessment. States are required, through the SWAP, to submit a plan to the U.S. Environmental Protection Agency (EPA) that details how they will:

1. delineate protection areas for drinking water intakes,
2. identify and inventory significant contaminants in the protection areas, and
3. determine the susceptibility of the public water supply (PWS) systems to the contaminants in the protection areas.

The SWAP may use information provided by existing programs such as sanitary surveys and Wellhead Protection Plans (WHPPs) to meet these requirements. The SWAP can provide a framework in which these programs can integrate and mutually benefit each other and reduce duplicate efforts. This program can also be used to focus environmental public health programs developed by federal, state, and local governments, as well as efforts of public water utilities and citizens, into a hydrologically defined geographic area.

It is EPA policy to assist the states in conducting source water assessment by identifying potential sources of data and pointing to methods for assessing source waters (EPA, 1997a). This report provides guidance to states, municipalities, and public water utilities for assessing source waters using geographic information system (GIS) technology. A GIS can organize, analyze, and manipulate available data and generate new data, i.e. simulation modeling, for source water protection areas. A GIS also provides capabilities for presenting the data to the public in various forms, including maps and tables.

1.2 Why Assess Source Waters?

Contamination of water supplies may be responsible for more human sickness than any other anthropogenic activity (Anderman and Martin, 1986). Since limited water resources are increasingly shared by competing consumers, there is a growing concern about the quality of source waters. This concern has led to the establishment of laws and programs designed to help protect drinking water sources.

1.2.1 Water quality degradation

Frequent evaluation and identification of sources of contamination are required by federal and state rules. The agents that degrade water quality affect the water's physical, chemical, biological, or radiologic characteristics as defined below.

- Physical:* presence of many types of contaminants can affect water color, turbidity, temperature, taste, and odor.
- Chemical:* presence of mineral constituents such as fluoride, sulfide, and acids may alter hardness or softness of water.
- Biological:* presence of organisms such as viruses, bacteria, algae, and mosquito larvae and their metabolic products can contaminate water.
- Radiologic:* radioactive material that comes in contact with water can contaminate it.

A water-quality change in any of these categories indicates the presence of contaminants. Pollutants, which result from various naturally occurring processes, as well as some land use practices, are introduced into the surface water system by runoff and infiltration from precipitation and snow melt, or by industrial and municipal discharges.

1.2.2 Safe Drinking Water Act and its amendments

As mentioned earlier, Section 1453 of the 1996 Safe Drinking Water Act amendments requires the states to develop and implement a SWAP to reduce the risk of contamination of drinking water sources. A successful SWAP reduces the cost of water treatments and disinfections required. Following enactment of the SDWA, a number of programs were developed for public water supply protection and supervision, including watershed protection and control, sanitary surveys, and WHPPs. An EPA document titled "States Source Water Assessment and Protection Programs Final Guidance" (1997a) discusses how a SWAP can use information provided by the current water programs. A brief description about some of the programs and a list of their basic elements are presented below.

1.2.2.1 Watershed Protection and Control Program

The Surface Water Treatment Rule (SWTR) requires unfiltered water supply systems to develop a watershed control program (WCP). A WCP provides protection for source water quality, thereby reducing the level of disinfection needed. The basic elements of a WCP are summarized below (EPA, 1990):

1. Watershed description, topography, hydrology, geology, land use, etc.
2. Inventory of sources of contamination: manmade, natural
3. Control of pollution practices
4. Monitoring: routine and specific evaluation of raw water quality
5. Management: organization, personnel, operation, and communication
6. Agreements and land ownership for watershed control

1.2.2.2 Sanitary Surveys

A sanitary survey is an on-site evaluation of a public water system's ability to continuously produce and distribute safe drinking water. For this purpose, a sanitary survey evaluates the system's sources of water, facilities, equipment, operation, maintenance, and distribution (EPA, 1995). Before conducting a sanitary survey, the water supply system should be described and clear goals for the survey, as well as a methodology for achieving these goals, should be defined. The contents of the sanitary survey are based on the goals and methodology defined for each water supply system. The following list specifies eight elements that should be evaluated in a sanitary survey (EPA, 1995).

1. Water source
2. Treatment
3. Distribution system
4. Finished water storage
5. Pumps, pump facilities, and controls
6. Monitoring, reporting, data verification
7. Water system management and operation
8. Operator compliance with state requirements

1.2.2.3 Wellhead Protection Plans

A WHPP is designed to safeguard public drinking water supplies by preventing, detecting, and remediating groundwater contamination in a zone around public water supply wells or well fields. Section 1428 of the SDWA requires the states to develop plans describing the following elements:

1. Delineation of the wellhead protection area
2. Inventory of contamination sources in the protection areas
3. Identification of appropriate protective strategies
4. Development of a groundwater monitoring plan (if needed)
5. Contingency plan for alternative water supplies
6. Public involvement and education program
7. Planning for protection of future well fields from contamination

1.3 How is this Report Organized?

Chapter 2 provides a review of general GIS concepts and components including GIS data formats; structure and analysis techniques; topology; scale and projection issues; data creation and collection; and software, hardware, and personnel requirements. This chapter introduces GIS to those not familiar with this technology but it is not intended to replace existing GIS manuals or instructional material. Experienced GIS users who are already familiar with the concepts presented in this chapter may want to skip to Chapter 3.

Chapter 3 presents a step-by-step approach to using a GIS for source water assessment including building the GIS database, analyzing the data to delineate source water protection areas, and presenting the analysis results. The method presented is a general approach. This method is then applied to specific source water types (river, groundwater, and reservoir) and described in the case studies in Appendices A, B and C. These case studies apply the methodology described in Chapter 3 and discuss any problems and issues that arose during the process.

Chapter 4 provides an evaluation of available GIS data sources and analysis tools and includes information on how to obtain the data or tool. This information can assist the user in determining the best tools and data to meet the defined needs and is condensed in a table at the end of the chapter.

Appendix D is a list of state-level contacts and offices that can provide information on Wellhead Protection programs and other source water protection programs being conducted by the states. Appendix E is a priority setting and risk weighing guide for contaminants in wellhead protection areas.

Chapter 2

General GIS Concepts and Components

A geographic information system (GIS) is defined as “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information” (ESRI, 1992). A GIS provides a powerful analytical tool that can be used to create and link spatial and descriptive data for problem solving, spatial modeling, and to present the results in tables or maps. The following sections discuss each of the components of a GIS including data, hardware, software, and personnel.

2.1 Geographic Data

In a GIS environment, digital information is stored as logical, thematic layers which may be given a variety of names, such as coverages, grids, and shapefiles. For example, a GIS database of a city may include separate thematic layers representing streets, buildings, streams and rivers, utility lines, population, zoning, and land ownership.

2.1.1 GIS Database Structure

There are two types of data in a GIS thematic layer: spatial features and descriptive information. The spatial data is a geographic location for a physical feature such as a road, a well, or a parcel of land and is represented as an X,Y coordinate or series of connected X,Y coordinates. The descriptive information is attribute data describing the physical feature. For example, a road can be represented as a line with attributes for number of lanes (4), type of road (interstate), and year built (1965). These two types of data are stored in separate spatial and attribute files that are related by using relational database techniques.

2.1.2 GIS Data Formats

The two most widely used GIS data formats are vector and raster. Vector data represent physical features as polygons, lines and points. Features with areas such as counties, agricultural fields, and water bodies are represented as polygons. Linear features that are too narrow to display as an area are represented as lines, also referred to as arcs. Roads and streams are examples of linear features. Discrete locations with areas too small to be shown as lines or polygons are represented by points. Examples of point features are wells and springs. A point is stored in the computer as an X,Y coordinate. Arcs are made of two or more connected points, and polygons are composed of one or more arcs enclosing an area.

Raster data are stored in a matrix of grid cells or pixels representing a rectangular geographic area. The spatial resolution of a raster image refers to the size of the geographic area that the pixel represents and is dependent on the resolution of the sensor or scanner. Raster data also have attribute data associated with each pixel or point. An example of raster data is a satellite image or scanned photograph. Raster data can also be represented by a lattice. A lattice is a rectangular array of mesh points spaced, at a constant sampling interval, that represent a surface. A lattice is stored as a grid, but it represents the surface only at the mesh points, not the entire cell formed by the mesh points. Lattices are often used to represent elevation.

2.1.3 Topology

Topology is the spatial relationship between geographic features within a GIS data layer. Topology is implied by pixel position in a raster image but must be explicitly defined in a vector data layer. One of the basic tasks of GIS software is to create and maintain topology. There are three major aspects of topology with respect to GIS: connectivity, area definition, and contiguity. Connectivity indicates the arc-node topology. Arcs start with a node and end in a node. The points between the nodes, referred to as vertices, define the shape of the arc. Nodes also form the connection between arcs. Area definition refers to the arc-polygon topology. One or more arcs enclosing an area form a polygon. Contiguity means every feature occupies its own space, ensuring that no two features will lie on the same physical space at the same time.

Using these topological definitions, the information recorded for each arc includes a starting point (from node), an ending point (to node), the length of the arc determined from the coordinates of the nodes and vertices, and the polygons to the left and right of the arc. This information can be stored in an arc attribute table and uniquely identifies each arc. Similar information about point features and polygon features can be stored in a point attribute table and a polygon attribute table, respectively. The topological relationships among the spatial features is maintained internally by the GIS and gives the data user the ability to perform spatial analyses.

2.1.4 Spatial Analysis Techniques

Spatial analysis techniques vary depending on whether vector or raster data is used. The vector spatial data analysis techniques pertinent to assessing source waters include proximity analysis, buffer analysis, overlay analysis, and network analysis. Likewise, the pertinent raster data analysis techniques include multispectral analysis for land cover classification and elevation modeling.

2.1.4.1 Proximity Analysis

GIS is often used to study the proximity of one spatial feature to another. Spatial features located in a neighborhood share common locality and may affect each other.

For example, the pumping rate of a well may affect other wells and streams that are within some distance if they share the same aquifer. Other proximity issues include closeness of one set of features (e.g., hospitals, schools, fire stations) to another (e.g., workplaces, homes).

2.1.4.2 Buffer Analysis

Buffering is a useful analytical technique that creates a polygon around selected features. For example, buffering can be used to identify the chemical factories located within some distance (buffer) of a stream. These factories can be evaluated as potential sources of contamination to the stream.

2.1.4.3 Overlay Analysis

Overlay analysis effectively overlays two different layers of spatial data for the purpose of creating a new data layer that, in some way, combines information from the two layers. Data combinations can involve combining the data layers or using one data layer to extract a subset of data from the other layer.

2.1.4.4 Network Analysis

Network analysis takes advantage of the arc-node topology in GIS and is useful in studies of linear flow such as traffic flow or stream flow. Network analysis requires the arc-node topology of the stream coverage to simulate stream flow so that the to-nodes are always “downstream” from the from-nodes. Also, characteristics such as flow rates can be assigned to the arcs or nodes to simulate real-world situations.

2.1.4.5 Multispectral Analysis

Some remote sensors use multispectral scanner (MSS) technology to collect data about the earth’s surface. The MSS records the amount of light being reflected from the surface. The scanner is capable of recording specific wave lengths of the electromagnetic spectrum such as red light, green light, near infrared, far or thermal infrared for a parcel of land. The reflectance data for each wave length is recorded as separate numerical values for each parcel of land. The parcel of land is represented as a pixel in the final image data set. Multispectral analysis is a highly complex process using statistical techniques and matrix algebra to determine the dominant land cover for each pixel in an image based on the amount and type of electromagnetic energy being reflected. For a better understanding of multispectral data and remote sensing image analysis, review one of the numerous texts written on the subject.

2.1.4.6 Elevation Modeling

A digital elevation model (DEM) is a raster data set that contains an elevation datum for each grid cell. Digital elevation models can be used to represent topography and to delineate watershed boundaries in the landscape.

2.1.5 Scale, Resolution, and Accuracy

Spatial data scale, resolution, and accuracy are all related. Scale is defined as the ratio of a distance on a map to the corresponding distance on the earth's surface represented by the map. A large-scale map (e.g., 1:24,000) represents a smaller geographic area but contains more detail compared to a small-scale map (e.g., 1:250,000) which represents a larger geographic area but contains less detail. Resolution is an indication of how well a feature's location and shape are depicted for a given map scale. A higher resolution means more details can be depicted. Accuracy is a measure of the amount of acceptable error in a data set. For instance, a 10-meter accuracy means that the placement of features on a map is at least within 10 meters of their true location. Table 2-1 provides examples of map scales and accuracies available from the United States Geological Survey (USGS). The USGS has this data available as paper maps or digital files.

Table 2-1. Example Maps and Relative Scales

Scale	Map Series	Accuracy (meters)	Ground distance represented by map distance of	
			1 centimeter	1 inch
1:24,000	7.5 minute	10	240 meters	2000 feet
1:100,000	Intermediate	50	1 kilometer	1.6 miles
1:250,000	United States	125	2.5 kilometers	2 miles
1:500,000	United States	2500	5 kilometers	8 miles

The choice of map scale and accuracy should be based on the intended use. Small-scale maps may be chosen for regional studies covering several states. On the other hand, large-scale maps may be suited to studies at watershed levels. For example, the USGS 1:24,000 series maps depict rivers, streams, water bodies, roads, and urban and agricultural areas in an average watershed but should not be used for analyses requiring spatial accuracy better than 10 meters. Studies involving small watersheds should use local maps that provide greater detail or other methods for acquiring data, such as global positioning systems (GPS) or surveying. High-resolution data sets require more computer resources for storage, processing, and display; therefore, unnecessarily large scales should be avoided.

2.1.6 Projections, Datums, and Geographic Reference Systems

The importance of understanding map projections, datums, and geographic reference systems in the construction of a GIS database cannot be understated. As noted in the ESRI Map Projections handbook (ESRI, Inc., 1994):

For data automation to be accurate and all subsequent phases of GIS application to be successful, those people who make early decisions about database design must understand map coordinate systems, map projections, datums and their applications.

Map projections are the mathematical transformation of the earth's three-dimensional spheroid to a flat two-dimensional surface. All map projections contain distortions that are inherent in taking a round surface and flattening it out. The key is to choose a projection that minimizes the distortion for your area of interest. Map projections are depicted in some unit of measure such as feet or meters.

A geographic reference system such as decimal degrees (DVD) or degrees, minutes, seconds (DMS) is not a projection, but rather a system using latitude and longitude positions to define the locations of features on the earth's spheroid. Data sets stored in geographic reference system coordinates can be converted or "projected" to different map projections using projection software routines available in many GIS software packages.

Datum are the reference points and measurements used to define the earth's spheroid. All projections must reference the specific datum used in the projection's mathematical transformation. Because the earth is not a perfect sphere or spheroid, the datum used to define the spheroid in one part of the earth is not necessarily the one used for another part. Until recently, most geographic data created in the U.S. were based on the Clarke 1866 datum; this datum is commonly referred to as North American Datum 1927 (NAD27). With the advent of satellite and other technologies, more accurate measurements of the spheroid have been taken. The most commonly used new datum for the United States is called NAD83.

When building a GIS database, it is essential to know the coordinate system, datum, and projection parameters of each data set so that data can be projected or converted to one spatial reference system. Data layers that are in different projections or datums will not overlay accurately.

2.1.7 GIS Data Collection and Creation

There are many sources for geographic and GIS data including federal, state, and local agencies. Some of these data sources are discussed in greater detail in Chapter 3. Data from local sources will tend to be more detailed but will cover a smaller area and may have to be purchased. State and federal data will be less detailed, but will cover a larger geographic area and may be free or cost very little. Be sure to explore existing data sources before planning to create GIS data which can be time-consuming and expensive. If, however, existing data is inadequate, GIS data can be generated

using a variety of techniques including digitizing maps or images, remote sensing, or field surveying.

2.1.7.1 Digitizing

GIS data can be created by manually digitizing or scanning maps or images. Manual digitization requires a digitizing table and manual capture of geographic features. The result is a digital map in vector form. Feature attributes can be assigned during or after digitizing. Scanning involves feeding a map or image through an electronic scanner, resulting in a raster image. The scanned image must then be geographically referenced. Alternately, the scanned raster data can be converted into vector data with special software or displayed on a computer screen for manual digitizing using a mouse.

2.1.7.2 Remote Sensing

Remote sensing requires the use of a sensor or device that captures geographic data remotely. Examples of remotely sensed data include satellite imagery and aerial photographs. Satellite imagery is in digital raster format and is processed using image processing software to create land cover data. Aerial photographs are not in digital format and must be digitized or scanned for use in a GIS. Digital orthophoto quadrangles (DOQ) are a digital product of aerial photography which has been geographically corrected, scanned, and geographically referenced.

The pixel resolution depends on the sensor altitude and field of view (FOV). Generally, images acquired at high altitude result in low spatial resolution. Digital images with pixel resolutions of less than 1 meter can be obtained by airborne systems; however, less area is covered by each image as the pixel spatial resolution increases. Due to higher spatial resolution, airborne data require more image processing resources (equipment, personnel, time) than do satellite images covering the same area.

High-resolution satellite data that are widely used for land cover classification are provided by the U.S. Landsat or the French SPOT (Le Systeme Pour l'Observation de la Terre) satellite systems. The Landsat system has two sensors: the multispectral scanner (MSS) with four spectral channels and the thematic mapper (TM) with seven spectral channels. The SPOT images come in two modes: panchromatic and multispectral with three spectral channels. Spectral channels are sensitive to narrow bands of the electromagnetic radiation (e.g., blue, green, red, and near-infrared), while the panchromatic channel senses the entire visible radiation (for more information on radiation and sensors see Campbell [1987] and other remote sensing literature). Table 2-2 shows the ground pixel spatial resolution for the above satellite sensors.

Table 2-2. Ground Pixel Spatial Resolution for Satellite Sensors

	Landsat MSS ^b	Landsat TM ^c	SPOT ^a Panchromatic	SPOT Multispectral
Number of spectral bands	4	7	1	3
Pixel resolution (meters)	56	30	10	20
Scene width (kilometers)	296	296	60	60

^aSPOT = Satellite Probatoire d'Observation de la Terre

^bMSS = multispectral scanner

^cTM = thematic mapper

2.1.7.3 Field Surveying

Field surveying requires the use of specialized equipment and software such as Global Positioning System (GPS) receivers to capture digital positional data in the field. The GPS is a space-based radio positioning system that provides information about position, velocity, and time to suitably equipped GPS users on the Earth. The NAVSTAR system, funded and operated by the U.S. Department of Defense (DoD), consists of 24 satellites that provide GPS data to civilian users. The GPS receivers are specialized radio receivers that determine the current position (latitude, longitude, altitude) and time using simultaneous radio signals from at least four of the satellites. Receivers intended for mapping have high accuracy and provide user interfaces that allow rapid data collection. Capturing GPS data is manually intensive but can also provide highly accurate locational data. This data can also be used to verify or correct the accuracy of other digital data sets.

2.2 Hardware

The GIS hardware includes the computer on which the GIS operates and the peripherals used for data entry, transfer, and output. A wide range of hardware types are used, from centralized computer servers to desktop computers used as stand-alone stations or in networked configurations. The type and number of components in a system is dependent on the needs of the organization. Software vendors can help in recommending appropriate system configurations. The input and output devices (e.g., digitizers and plotters) are usually shared within an organization with more than one GIS user. Centralized computer servers and networking software can be used to enable multiple users to share GIS hardware and software. Hardware costs are not provided because costs are constantly changing, usually in favor of the buyer. Examples of GIS hardware components are listed below.

2.2.1 GIS Workstation

A GIS workstation should at a minimum include a high-speed central processing unit, keyboard, mouse, disk space, high-resolution color monitor for graphics display, and a compact disk read-only memory (CD-ROM). An external disk drive may be used for additional disk space. The GIS workstation can be either an IBM-compatible personal computer (PC) using a Windows operating system or a high-end graphics workstation using a Unix operating system.

The Unix systems provide a more powerful environment for GIS than PCs. Unix workstations are usually faster than PCs in the analysis and display of complex digital data. However, they also cost more. A set of workstations loaded with GIS software may use a common server with a large amount of disk storage space. Also, data input and output devices may be attached to the server so all users can share them.

2.2.2 Data Transfer and Backup Devices

A GIS should include one or more data transfer and backup devices such as a compact disk writer, tape drive, or disk drive. These devices allow the user to transfer GIS data to a compact medium that can be easily stored or physically transferred. These devices are useful for performing data backups or transferring data between workstations or organizations that are not networked.

2.2.3 Data Output Devices

Output devices allow the user to print data and displays from the GIS. Printouts of GIS data are useful for data quality assurance and quality control (QA/QC) checks and for displaying results. The common GIS output devices are printers and plotters. These devices are available in a variety of sizes, produce output in color or black and white, and can vary widely in price. Most organizations will want at least a standard laser jet printer as well as a large-format color output device for plotting color maps for display and presentations.

2.2.4 Data Input Devices

GIS data input devices include digitizing tables, scanners, and GPS receivers. These devices enable a user to capture geographic information in digital form. A digitizing table is used for generating vector-based coordinate information directly from hard copy maps or photographs. A scanner is used to generate raster-based data from hard copy maps or photographs. A GPS receiver enables the user to capture coordinate data for features in the field. Once captured, GPS data must be post-processed on a workstation with specialized software to generate real-world coordinates.

2.3 Software

Three categories of information processing software are used to assess source waters when using GIS technology: GIS, image processing, and relational database management. Examples of software for each of these categories are listed below. A software package listed in one category may also be capable of performing functions in another category. For example, a GIS package such as GRASS can be used for image processing. Similarly, some of the image processing software packages can be used as GIS tools. The names of the software are listed for informational purposes only and do not indicate endorsement.

The PC-based software packages such as GRASS and ArcView can range in cost from free or low-cost (\$200-\$300) to several thousand dollars. High-end software packages such as ArcInfo, ERDAS Imagine, or Intergraph GIS will cost \$10,000-\$20,000. Prices for all software packages depend on current market value, whether the purchaser is eligible for discounts, and what additional modules are purchased in addition to the baseline package.

2.3.1 GIS Software

The GIS software is used for storing, analyzing, and displaying geographic data. The main components of a GIS software are the tools for data input and manipulation, database management, geographic query and analysis, and visualization and output. Several GIS packages are presented below for information.

2.3.1.1 Arc/Info

Arc/Info is a commercial software package developed by the Environmental Systems Research Institute (ESRI) and Henco Software, Inc. (Henco). Arc/Info provides tools for automation, management, display, and output of geographic and associated data. Arc/Info is a vector-based GIS software that runs on Unix and Windows NT workstations. Arc/Info costs between \$10,000 - \$20,000. For more information contact ESRI at <http://www.esri.com>.

2.3.1.2 ArcView

ArcView is also produced by ESRI and is a menu-driven GIS with a subset of the functionality provided by Arc/Info. What ArcView lacks in functionality, it makes up for in a less steep learning curve and an easy-to-use graphical user interface (GUI). ArcView is a vector-based GIS software that runs on Unix or PC workstations. ArcView costs approximately \$1,000. For more information contact ESRI at <http://www.esri.com>.

2.3.1.3 GRASS

The Geographic Resources Analysis Support System (GRASS) is a public-domain, raster-based GIS software used for geographic data management, image processing, graphics production, spatial modeling, and data visualization. GRASS was

written by the U.S. Army Construction Engineering Research Laboratories (USA-CERL) branch of the U.S. Army Corps of Engineers and is currently maintained at the Department of Geology at Baylor University. GRASS runs on Unix and PC workstations. More information on GRASS can be found at <http://www.baylor.edu/~grass>. Additional information on some of the hydrology models that have been integrated into the GRASS GIS is available on <http://soils.ecn.purdue.edu/~aggrass/models/hydrology.html>.

2.3.1.4 IDRISI

IDRISI is a raster-based GIS software that provides GIS, image processing, and spatial statistics analytical capabilities on DOS and Windows-based PCs. IDRISI provides analytical functionality of GIS, remote sensing, and databases for resources management. IDRISI was developed and is maintained by Clark Labs, a non-profit research organization within the Graduate School of Geography at Clark University. A commercial/private single-user license for IDRISI costs \$990. Licenses for non-profit, government, and academic institutions cost less. For more details see <http://www.clarklabs.org>.

2.3.1.5 Intergraph GIS

Intergraph provides Windows-based software and a range of computing services for engineering, design, modeling, analysis, mapping, information technology, and creative graphics. The GIS MGE package provides data collection and editing, data import, image display and analysis, advanced spatial query and analysis, and cartographic quality maps. MGE costs approximately \$10,000-\$20,000. More information on Intergraph GIS is available at <http://www.intergraph.com>.

2.3.2 Image Processing Software

Image processing software is used to process raster data, particularly remote sensing imagery data such as satellite imagery.

2.3.2.1 ENVI

The Environment for Visualizing Images (ENVI) is an image processing system which provides analysis and visualization of single-band, multispectral, hyperspectral, and radar remote sensing data. ENVI can process large spatial and spectral images, and runs on Unix; LINUX; Windows 3.1, NT, 95; the Macintosh; and the Power Mac. For more details contact ENVI at <http://www.envi-sw.com/index.htm>.

2.3.2.2 ERDAS Imagine

The ERDAS Imagine software is an image processing and raster GIS package that has a variety of applications ranging from simple image mapping to advanced remote sensing. Imagine provides tools for geometric correction, image analysis, visualization, map output, orthorectification, radar analysis, advanced classification

tools, and graphical spatial data modeling. Imagine runs on Unix workstations and Windows platforms. ERDAS Image costs approximately \$10,000-\$20,000. More information on Imagine is available at <http://www.erdas.com>.

2.3.2.3 ER Mapper

ER Mapper provides integrated mapping software featuring image processing, map production, 3-D presentations, and GIS integration for Windows 95/NT and Unix. The ER Mapper software uses a concept that separates data from the image processing steps allowing the user to apply and view results from a single enhancement procedure in real time. The PC version of ER Mapper costs \$4,300; the Unix version of ER Mapper costs \$18,300. See <http://www.ermapper.com> for more information.

2.3.2.4 PCI

EASI/PACE image processing provides a variety of applications including image processing, geometric correction, vector utilities, and multilayer modeling. PCI implements the Generic Database (GDB) concept, which allows PCI programs to access image and other external data files without import and export. Contact PCI for more details at <http://www.pci.on.ca>.

2.3.2.5 TNTmips

TNTmips is a map and image processing system that contains fully featured GIS, CAD, and spatial database management systems. TNTmips has tools that interactively integrate elements of on-screen image processing and photo interpretation, and provides a diverse set of tools for registering, rectifying and stitching imagery, which are particularly useful for low-altitude aerial photography and videography. More information on TNTmips is available at http://www.sgi.com/Products/appsdirectory.dir/Applications/GIS_Defense_Imaging/ApplicationNumber7857.html.

2.3.3 Relational Database Management Software

Relational database management system (RDBMS) software enables large amounts of data to be entered, updated, related, viewed, queried and, otherwise, managed in an efficient manner. The data in an RDBMS is stored in a series of related tables which are designed to optimize the effort required for data entry, maintenance, and retrieval. RDBMS software is available for use on PCs, Unix workstations, networked systems, and mainframe computers. Most GIS software packages use an RDBMS to manage data such as maintaining topology and providing ways to efficiently enter, update, and query attribute data. For example, Arc/Info uses Info, an RDBMS developed by Henco. Other major RDBMS software includes dBASE, MS Access, Ingres, Informix, Oracle, and Sybase.

2.4 Personnel Requirements

To use a GIS effectively in any project, it is important to have personnel with a variety of specific skills. All of the software mentioned above (GIS, image processing, and RDBMS) require lengthy learning curves to be used effectively. Experience in GIS is highly desirable and may be mandatory if time is critical.

2.4.1 Data Entry Technician

Data entry includes automation or digitizing of maps, creating attribute tables, and importing databases. The data entry technician should have some knowledge of spatial concepts and experience in basic GIS use for creating thematic layers, and attribute data entry. Depending on the amount of data entry required, one or more technicians may be needed.

2.4.2 Spatial Data Analyst

The spatial data analyst is skilled in manipulating geographic data to retrieve pertinent, project-specific information such as mapping sources of contamination and their proximity to source waters, and delineating protection areas. This person must have a thorough understanding of the concepts presented in this Chapter and be experienced in using GIS and image processing technology. The spatial data analyst should also have some experience in working with utilities, hydrogeology, soils, environmental engineering, or sanitary engineering.

2.4.3 Field Surveyor

A field surveyor may be required if geographic or attribute data is not available and must be gathered in the field. The surveyor should be skilled in field survey management, GPS technology, and database development and have knowledge of sanitary or environmental engineering, soil science, or hydrogeology. Depending on the amount of field surveying required and the size of the area being surveyed, the field surveyor may require a support staff to assist with gathering information.

2.4.4 Soil Scientist

A soil scientist may be needed to evaluate the condition and physical properties of soils in the survey area. The Natural Resources Conservation Service (NRCS) formerly called the Soil Conservation Service may be contacted for technical assistance in this area.

2.4.5 System Administrator

A system administrator may be needed to administer the GIS and its peripherals such as digitizers, printers, and plotters. This is especially true for systems that require a network and have multiple users. A system administrator can help with hardware and software maintenance and replacement, network maintenance, system backups, and other administrative duties.

Chapter 3

A Method for Assessing Source Waters Using a GIS

Using a GIS for any application involves following some basic steps including designing the GIS database, building the GIS database, and using the GIS to analyze the data and show results. For assessing source waters, elements of the design of a GIS database include establishing the study area and delineating the watershed, determining data needs, inventorying data sources, determining coordinate system and scale, and deciding on the GIS infrastructure. Building the database requires collecting data to characterize the study area and inventorying sources of contamination. And analyzing the data entails assessing potential sources of contamination, delineating source water protection areas, and producing display products. The methodology used for completing these steps is described in the subsections in this chapter. Appendices A, B, and C present three case studies that illustrate the use of this methodology.

3.1 Design the GIS Database

Investing time in the GIS database design at the beginning of a project saves time and effort over the life of the project. Delineating the study area is important to limit the scope of investigation and to design a database specific to the area of interest. Inventorying existing data sources not only identifies useful data sets but helps to determine which coordinate system, data scale, and GIS software, hardware, and personnel to use. Many of the decisions made concerning these issues are interdependent and should be investigated and decided on concurrently. These issues are discussed in the following sections.

3.1.1 Delineate the Study Area

Source water is at risk for contamination by pollutants entering the source water catchment or recharge area. If the source is a surface water feature such as a river or reservoir, then the recharge area is a watershed. A watershed boundary is defined as the perimeter of the area that drains into the surface water feature (river, stream, or reservoir) and is delineated by drawing a line along the highest elevation surrounding the surface water feature. If the source is groundwater then the area of interest is the recharge area for the underground aquifer.

The first step in delineating the study area is to determine the geographic location of the source water intakes for the PWS system. The geographic locations can be derived by digitizing from maps or by conducting a field survey and obtaining GPS point

locations. In any case, these locations must be known and recorded in a digital file that can be used in the GIS to delineate the source water recharge area.

The surface water intake's watershed can be identified in a GIS by overlaying the intake location with the watershed boundary data layer for the same area. The study area may be defined as the entire watershed or a portion of the watershed depending on the location of the source water intakes along the river or reservoir. A national standard watershed boundary data set is available from the USGS as hydrologic unit code (HUC) data. See Table 3-2 at the end of this chapter for additional information about some data sets available from federal agencies. More detailed or accurate watershed data may also be available from state and local government sources. The overlay process is also used to identify the source water aquifer for a well intake. Aquifer data is most likely available from state government sources. Because aquifers are recharged from surface waters, it is important to take into account what watersheds may also need to be included in the study area.

3.1.2 Determine Data Needs

A source water assessment should identify the source water recharge or study area and its characteristics, current and potential sources of contamination, and methods of contaminant control. This process requires building a GIS database that includes the physical characteristics of the study area, the locations of sources of contamination, and physical features affecting contaminant flow. Determine the GIS data needs by reviewing the local characteristics of the study area such as whether the source water is derived from wells or surface water or whether dams are present. GIS data sets and types that are typically used to assess source waters are listed in Table 3-1.

3.1.3 Inventory Data

After compiling a list of data sets required for the source water assessment, find out if any of these data sets are available from other sources. Many federal, state or local sources for GIS data sets (Table 3-2 at the end of this chapter) already exist and may be suitable depending on scale and accuracy needs. Many states also maintain repositories of GIS data. See Appendix D for a list of state contacts for source water protection and other related information. Many regional government consortiums and local governments are building and maintaining detailed, large-scale GIS databases containing land parcel ownership, landscape characteristics, and other pertinent information.

When inventorying data, record information about each data set (such as data set name, source, software format, scale, projection and projection parameters, extent of

coverage, attributes, cost, and any other pertinent information) that will help determine if the data set can be used in the assessment. Data at the federal and state level tends to be free or cost very little. Data from local sources usually must be purchased and

Table 3-1. Data Sources for Source Water Assessment

Source Water Assessment Data	Data Type
1. Characterization of the watershed	
a. Boundary and area of the watershed	polygon
b. Terrain	polygon
c. Soils	polygon
d. Streams	line
e. Springs, wells, cisterns	point
f. Land use (wilderness, farmland, urban, etc.)	polygon
g. Land ownership	polygon
h. Vegetation cover	polygon
i. Dam locations	point or line
2. Sources of contamination	
a. Sewage, storm water, industrial discharge	point
b. Highways, railroads	line
c. Pesticide usage, logging, recreation	polygon
d. Animal population density (domestic, wild)	polygon
e. Turbidity fluctuations (precipitation)	descriptive
f. Fires, inorganic contaminants (soils)	polygon
3. Source water intakes	
a. Surface intakes, springs, catchments, wells	point
4. Pumps, pump houses, and controls	point

covers a more limited area, but it is often more detailed and accurate. If a required data set does not exist or is too small in scale, it may need to be created. See Section 2.1.7 for an overview of various methods used to create GIS data.

3.1.4 Determine Coordinate System and Scale

Choose a coordinate system that requires the least amount of data conversion from one projection to another. Data conversions are always risky and potentially can introduce error in the data. Make this decision early in the database design process so that data sets are systematically converted to the proper coordinate system prior to use. Because data layers that are not in the same coordinate system will not overlay accurately, converting them to one coordinate system at the beginning of project can help to eliminate confusion later on.

The level of detail required for the source water assessment determines the data scale required for the database. Different scales of data can be used together with the understanding that smaller scale data is less accurate and detailed and decisions made based on smaller scale data have a greater margin of error and uncertainty. For more information, see Section 2.1.5 for a discussion of scale and accuracy issues.

3.1.5 Decide on GIS Infrastructure

The GIS infrastructure includes the hardware, software, and personnel needed for the task. See Sections 2.2, 2.3, and 2.4 for information on some of the choices available. It is important to determine early in the database design process what GIS tools will be used because that choice affects the amount of data conversion required, what other analysis capabilities have to be obtained, and what personnel training may be required. In addition to the basic GIS software packages, numerous GIS-based source water assessment support tools are available that run within some of these packages; these support tools are evaluated in Chapter 4.

3.2 Build the GIS Database

Building the GIS data base includes obtaining or creating the required data sets, converting the data sets to the required data format and coordinate system, verifying the accuracy of the data sets, and, if needed, making corrections to the data. It is important to document all processing steps taken for each data set so that if the data becomes corrupted or the computer system crashes, the data base can be more easily recreated. Likewise, computer system backups should be done daily.

3.2.1 Characterize the Study Area

After deciding on the data requirements of the GIS database, the data should be obtained and converted to the chosen projection and units (feet, meters). Section 3.1.2 outlines some of the GIS data required for source water assessment. The data types include descriptions of physical watersheds and contamination sources and types. To understand how contamination from a source reaches a drinking water intake, the factors that affect its flow should be described. These factors include, but are not limited to terrain, soils, hydrography, land use and land cover, and contaminant characteristics. For example, after a precipitation event, the type(s) of contamination

resulting from surface runoff into a stream depends on the land use and land cover interactions (e.g., pesticide and fertilizer from agriculture, salts and grease from parking lots). The directional flow of surface runoff depends on the topography, and soil infiltration properties affect how much surface water reaches the groundwater. The following sections provide information about some of the data sets needed for assessing source waters.

3.2.1.1 Watershed Boundaries

Watershed or HUC boundaries are available from the USGS. The HUC boundaries are available at 1:2,000,000 scale and 1:250,000 scale. The USGS also provides information describing the hydrologic unit coding scheme. A watershed boundary data set can be created by delineating the boundary on large-scale maps that have elevation contour lines; the boundary can then be digitized. See Table 3-2 listings 1 and 8 for data access information.

3.2.1.2 Terrain

Terrain data can be derived from Digital Elevation Models (DEMs). DEMs are digital records of terrain elevations for ground positions that are horizontally spaced at regular intervals. The SPOT Image Corporation provides DEMs at 10-meter spacing created by digital autocorrelation of SPOT satellite image stereopairs which are stored in a format known as Terrain Access Made Easy (TAME) (ESRI, 1991). The USGS also provides 30-meter spaced DEMs at four scales: 7.5-minute, 15-minute, 2-arc-second, and 1-degree. See Table 3-2 listing 6 for USGS DEM access information.

The 7.5-minute (large-scale) data are produced in 7.5- by 7.5-minute blocks from digitized cartographic map contour overlays or from scanned National Aerial Photography Program (NAPP) photographs. The DEM data are stored as profiles in which the elevations are spaced 30 meters apart. The number of elevations between each profile will differ because of the variable angle between the quadrangle's true north and the grid north of the Universal Transverse Mercator (UTM) projection coordinate system. The DEM data for 7.5-minute units correspond to the USGS 7.5-minute topographic quadrangle map series for all of the United States and its territories, except Alaska.

The 15-minute DEM (large-scale) data correspond to the USGS 15-minute topographic quadrangle map series of Alaska. The unit size changes with the latitude. The 15-minute DEM data are referenced horizontally to NAD27. The elevations along profiles are spaced 2 arc-seconds of latitude by 3 arc-seconds of longitude. The first and last data points along a profile are at the integer degrees of latitude.

3.2.1.3 Soils

The U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), has three soil geographic databases of varying scales. The data include physical and chemical soil properties for approximately 18,000 soil types. Each database has three categories: soil properties (particle size, bulk density, available water capacity, organic matter, salinity, and soil recreation), locational properties (flooding, water table depth, bedrock depth, and soil subsidence), and use and management properties (sanitary facilities, building site development, recreational development, rangeland potential, construction material, crops, woodland suitability, and wildlife habitat suitability).

The most detailed level of information is provided by the Soil Survey Geographic data (SSURGO), which is available in 7.5-minute topographic quadrangle units (1:24,000) and is distributed as coverages for soil survey areas, usually containing over ten quadrangle units. State Soil Geographic data (STATSGO) is a coarser database designed for regional, multistate, river basin, state, and multicounty resource planning, monitoring, and management. The STATSGO database is at 1:250,000 scale (1- by 2-degree quadrangle) and is distributed as statewide coverages. See Table 3-2 listings 8 and 11 for data access information. National Soil Geographic data (NATSGO) is a database which is suitable for national or regional resources assessment and planning. With a scale of 1:5,000,000, the NATSGO database has information about the major land resource areas.

3.2.1.4 Hydrography

Hydrography is available from several federal sources at a 1:24,000 scale and may be available in greater detail from state and local government agencies. The USGS digital line graphs (DLGs) are readily available and provide information on 5 main types of data categories: boundaries, public land survey, transportation (including pipelines and power lines), hydrography (streams and water bodies) and hypsography (elevation contours). The DLG data can be converted into other formats compatible with GIS software. For more information on how to place orders or obtain additional information regarding technical details and pricing schedules, see Table 3-2 listing 6 for Internet contact information.

The EPA Reach File system has a series of hydrologic databases that uniquely identify and interconnect stream segments (reaches) for the nation. RF3-Alpha is the latest and most detailed version of the reach file system, containing more reaches than the previous versions, RF1 and RF2. Stream segments have unique reach codes for determining the upstream and downstream reaches and identifying the stream name for each reach. River Reach data can be obtained from the STORET User Assistance Group in the EPA Office of Water. See Table 3-2 listing 4 for more information.

3.2.1.5 Land Use and Land Cover

Land use and land cover data are available from several federal sources. In many cases, the federal data will be either out-of-date or not detailed enough. More detailed (large-scale) land use data may also be obtained from county assessor maps, which are available at various scales (e.g., 1:200, 1:2,400, 1:4,800). County assessor maps may provide better detail for inventorying contamination sources in urban areas. The various departments of highways and transportation can provide maps for city streets and other local and regional road maps.

3.2.2 Inventory Potential Sources of Contamination

Potential sources of contamination, also known as sanitary defects, are conditions that may result in contamination of a water supply. These may be point and nonpoint source pollutants, connections to unsafe water supplies, raw water bypasses in treatment plants, improperly designed or installed plumbing fixtures, or water and sewer pipes leaking into the same ditch. All known and potential sources of contamination should be included in the GIS database. Pollutants may be classified into categories depending on the likelihood of their introduction into the water supply and the level and significance of contamination that can result from them.

A contaminant inventory can include records of operation, discharge, disposal, construction, and other permitted activities, as well as zoning and health records obtained from local government agencies. All relevant information should be gathered while focusing the search for contamination sources at sites of particular concern. These include, but are not limited to (EPA, 1991a):

1. Discharge sites: septic tanks, irrigation pipes
2. Storage, treatment, or disposal sites: landfills, underground tanks, mine tailings
3. Substance transporting sites: pipelines
4. Activities that result in discharges: highway construction, fertilizer application
5. Natural sources impacted by anthropogenic activities

Further information on contaminant inventory activities is provided in the EPA *Guide for Conducting Contamination Source Inventories for Public Drinking Water Supply Protection Programs* (EPA, 1991a). Some of these data, such as Toxic Chemical Release Inventory (TRI) data (see Table 3-2 listing 1), can be obtained from the EPA. Other data may need to be obtained through field surveys.

3.2.2.1 Point Source Data

Point sources of contamination include wastewater treatment plants, industrial discharges, barnyards, feedlots, storage tanks (surface and underground), combined

sewer overflows, septic tanks, sewer lines, and transportation networks. Documents describing the location and quantity for most of these sources can be obtained from several agencies including sewer districts, divisions of health, water supply systems, and state water programs, such as sanitary surveys and WHP programs.

The EPA has searchable online information about several subjects related to environmental pollution. See http://www.epa.gov/enviro/html/ef_overview.html to access information about hazardous waste data, toxic release inventory, safe drinking water information, and water discharge permits among others. The information also includes records of water supply systems and their contaminant level violations.

3.2.2.2 Nonpoint Source Data

Nonpoint source (NPS) pollution comprises the largest portion of water quality problems in the United States. NPS pollution occurs when precipitation or irrigation water running over the land or infiltrating through the ground carries pollutants and deposits them into rivers, lakes, coastal waters, or groundwater. The leading contributors of NPS pollution are resource extractions (mining), agriculture, urban runoff, and municipal point sources (EPA, 1996). Forestry activities such as logging and road construction also cause considerable contamination in source water.

Resource extraction activities that can result in NPS pollution include mining (surface, subsurface, placer, dredge), petroleum activities, mill and mine tailings, acid mine drainage, and abandoned and inactive mining. Agricultural practices that cause NPS pollution include grazing, plowing, pesticide spraying, irrigation, fertilizing, planting, and harvesting. Pollutants that result from agricultural activities are sediments, nutrients, pathogens, pesticides, and salts. Agricultural practices can also cause damage to stream channels and habitat.

Contaminated urban runoff comes from industrial and nonindustrial permitted activities, dry weather flows, highways, roads, and bridges. Pollutants from urban sites include sediments from development; oil, grease, toxic chemicals, and road salts from roads, parking lots, and automobiles; nutrients and pesticides from turf management and gardening; and viruses and bacteria from human and animal activities.

Forestry activities that cause pollution include removal of streamside vegetation, road construction and use, timber harvesting, and mechanical preparation for tree planting. Construction of roads and their use constitute the primary source of total sediments from forestry operations. Harvesting trees near streams affects water quality and stream bank stability.

3.3 Analyze the Data

After the GIS database has been built, the data can be analyzed to assess the risk associated with potential sources of contamination, delineate protection areas, and develop display products.

3.3.1 Contamination Source Risk Analysis

Classify the contaminant data into risk groups depending on the threat of contamination they pose to the source water. Appendix E shows a method for prioritizing and weighing the level of risk from various forms of contamination (EPA, 1991b). Similar approaches may be adopted for surface water sources. The tasks in this phase may reveal the need for a new inquiry or a more thorough data gathering effort with respect to particular sites or contaminants. For more information, see *Managing Groundwater Contamination Sources in Wellhead Protection Areas: A Priority Setting Approach* (EPA, 1991b).

Susceptibility analysis identifies the location, frequency, and significance of potential contaminants in the source water protection area and determines the likelihood the PWS will be contaminated by these sources. Water quality models may be used for estimating contamination levels and determining the significance of selected contaminants in the protection area or in the watershed.

3.3.2 Proximity Analysis and Delineation of Protection Areas

After potential sources of contamination are identified, their proximity to the water supply intakes can be mapped. A set of maps at various scales can be produced from the GIS database illustrating the proximity of potential pollutants to the water supply system. With data documenting geographic locations of actual and potential contaminants, a source water protection area can be delineated.

Surface water sources used for drinking water supplies may be protected by delineating a protection area around or upstream from the source intake. Three approaches for delineating a protection area for surface water systems are topographic area, buffer distance, and stream-flow time of travel (TOT) (EPA, 1997b). For systems using groundwater sources, approaches for delineating a WHP area are based on fixed-radius, hydrogeologic/geomorphic characteristics, and modeling, which includes analytical, semi-analytical, numerical flow and solute transport models (EPA, 1993). The appropriate method for a particular system is chosen as a balance between ease of use, level of detail needed, and available resources.

The PWS systems using a combination of groundwater and surface water sources may consider conjunctive delineation of source water protection areas. Conjunctive delineation is the integrated delineation of the zone of groundwater contribution and the area of surface water contribution to a PWS. Further information on this subject can be

found in *Delineation of Source Water Protection Areas, a Discussion for Managers; Part 1: A Conjunctive Approach for Groundwater and Surface Water* (EPA, 1997c).

3.3.2.1 Topographic Area

Topographic area is defined as the watershed for the surface water feature. Watersheds are delineated by drawing a line along the highest elevation around the surface water feature. In this case, the study area itself is the source water protection area.

3.3.2.2 Buffer Zone

A buffer zone may be delineated for the purpose of protecting drinking water intake and is typically dependent on the hydrogeology, topography, and stream hydrology. A protection buffer for a source surface water intake is an upstream strip of vegetated land along the shore of the stream or lake. Buffer widths vary from 15 to 60 meters (approximately 50 to 200 ft) depending on topographic, land use, political, and legal factors (EPA, 1997b). Buffer zones reduce water quality impacts from runoff, increase wildlife habitat and improve stream-bank integrity.

Systems with groundwater sources may use a fixed-radius protection area (buffer) around source wells depending on aquifer properties. The radius could be fixed arbitrarily or based on TOT (EPA, 1993).

3.3.2.3 Time of Travel

Water supply systems tapping rivers that are designated for commercial transportation or for industrial and municipal wastewater discharge may use TOT for source water intake protection. The time it takes a pollutant introduced into an upstream section of a river to travel to a source water intake is estimated using the stream-flow TOT. The contamination level of the pollutant at the intake can be evaluated using various water quality models. The TOT method provides tools for predicting impacts from spills or discharges at sections upstream of a drinking water intake, thereby enhancing protection strategies for emergency spills.

A TOT is also used for delineating protection areas for groundwater-based systems by estimating contaminant transport into drinking water wells. Groundwater flow is significantly slower than that of surface water (e.g., years versus hours or days, respectively), allowing more response time for controlling or remediating spills and other plumes. The EPA (1993) provides comparisons of TOT-based methods used for delineating WHP areas.

3.3.2.4 Modeling

Surface runoff and groundwater models can be used for delineating a source water protection area. Analytical, semi-analytical, and numerical flow and solute transport

models can estimate the potential water quality impacts from one or more pollution sources upstream of a drinking water intake. With knowledge of land uses (e.g., agricultural, industrial, residential), soil properties, and precipitation rates in an area, potential contaminant loadings from runoff or infiltration can be estimated. Modeling provides analytical tools for assessing water quality impacts resulting from land use changes, and may be used to identify effective water quality protection strategies. Some models need site-specific data which may, in turn, require field surveys.

3.3.2.5 Stream Network Analysis: Water Quality Study

Stream network analysis provides tools for studying how contaminants are transported in streams. Distributions of contaminant concentrations along a stream can be studied using the physical and chemical properties of the contaminant as well as the hydraulics of the stream. Most GIS software packages, such as ARC/INFO's network analysis, have capability for modeling linear processes. More complex analyses can be performed by linking appropriate water quality models in ARC/INFO (e.g., Grayman et al., 1993).

3.3.3 Generate Display Products

Maps are graphic representations of geographic information, and, as such, provide powerful visual communication of ideas. The Surface Water Assessment Program requires strong public participation in all processes involving development of methods for, and implementation of, source water assessment. State agencies proposing or conducting a SWAP may use sets of maps for displaying the geographic extent of the SWAP program. For example, maps for public presentation can show stream segments with highlighted buffer areas and marked with potential pollution sites. A GIS provides the capability for generating such maps at various scales with selected sets of themes.

Table 3-2. Federal Spatial Data Set Sources

1. **Agency:** U. S. Environmental Protection Agency (EPA)
Web Page: http://www.epa.gov/enviro/html/nsdi/spatial_extent.html
Description: The EPA Envirofacts Warehouse - Geospatial Data Clearinghouse site provides access to the metadata (descriptive) records for numerous national, EPA regional, state, and county data sets. Some of the files are available using file transfer protocol (ftp) from the EPA FTP site address listed in the Access column.

Data Type	Coverage	Format	Access	Cost
National Priority List (NPL) site boundaries	U.S.	ARC/INFO export	ftp://ftp.epa.gov/pub/spdata/npl.e00	None
EPA Regulated Facilities point locations	U.S.	ARC/INFO export, Gzip compressed	ftp://ftp.epa.gov/pub/spdata/ef Both efmmyy.e00.gz and efmmyy.e01.gz files must be downloaded, Gzip uncompressed, and imported	None
1994 Fish consumption advisories	Conterminous U.S.	ARC/INFO export, Gzip compressed	ftp://ftp.epa.gov/pub/spdata/fish_adv.e00.gz	None
Hydrologic Unit Boundaries (watersheds)	Conterminous U.S.	ARC/INFO	email request to nsdi@epamail.epa.gov	None
EPA River Reach File Version 1.0 (RF1)	Conterminous U.S.	ARC/INFO	email request to nsdi@epamail.epa.gov	None
Toxic Chemical Release Inventory (TRI) facilities and data	U.S.	dBase	http://www.epa.gov/opptintr/tri/access.htm	None
1:250,000-scale quads of GIRAS Landuse/Landcover data (edgematched by EPA; based on aerial photographs taken in the late 1970s and early 1980s and has not been updated)	Conterminous U.S.	ARC/INFO export, Gzip compressed	ftp://ftp.epa.gov/pub/spdata/EPAGIRAS Read the README file	None

2. **Agency:** U. S. Environmental Protection Agency
Web Page: <http://www.epa.gov/OWOW/watershed/landcover/lulcmap.html>
Description: This EPA Office of Water site contains a land cover digital data directory for the United States. The data directory is organized by state and by national and multistate coverages. This site does not provide direct access to the data sets but provides information to the user on contacts and obtaining the data.

Data Type	Coverage	Format	Access	Cost
1:250,000-scale quads of GIRAS Landuse/Landcover data (edgematched by EPA; old data)	Conterminous U.S.	ARC/INFO export, Gzip compressed	ftp://ftp.epa.gov/pub/spdata/EPAGIRAS Read the README file for determining which files to download	None
1:250,000- and 1:100,000-scale quads of USGS GIRAS Landuse/Landcover data	Conterminous U.S. and Hawaii	GIRAS, CTG	http://edcwww.cr.usgs.gov/glis/hyper/guide/1_250_lulc for anonymous ftp instructions	None
AVHRR biweekly composite Land Cover, 1-km resolution	Conterminous U.S.	Raster	http://edcwww.cr.usgs.gov/dsprod/prod.html#satellite Order CD-ROMs from EROS Data Center (605)594-6142	Pre-1996, \$32 per file; post-1996, \$50 per file
Gap Analysis data	Partial U.S. by state	ARC/INFO export (varies by state)	http://www.gap.uidaho.edu/gap/Projects/States/	Varies by state
Multi-Resolution Land Characteristics (MRLC) Consortium Thematic Mapper-based Land Cover (30-meter resolution)	U.S.	ARC/INFO export, Gzip compressed	For availability: http://www.epa.gov/mrlc/Databases.html To obtain contact: Jim Wickham, USEPA, wickham.j@epamail.epa.gov	Non-EPA customers may have to purchase

3. **Agency:** U. S. Environmental Protection Agency
Web Page: <http://earth1.epa.gov/oppe/spatial.html>
Description: This EPA Office of Policy, Planning and Evaluation site contains access to GIS spatial data sites at the federal, state, and local levels. Some links provide direct access to downloadable data; in other

cases, the links provide access to the Agency's Web site where you must navigate to find the data. Very good comprehensive site but some links are out-of-date.

4. **Agency:** U. S. Environmental Protection Agency
Web Page: <http://www.epa.gov/OWOW/NPS/rf/rfindex.html>
Description: This EPA Office of Water site contains information on the EPA river reach files. To obtain Reach File data, documentation, and technical support call the STORET User Assistance Group at (800)424-9067 in the EPA Office of Water.

5. **Agency:** U.S. Geological Survey
Web Page: <http://nhd.fgdc.gov/>
Description: U.S. Geological Survey site containing information on the development and availability of a National Hydrography Data set that combines the best of the USGS Digital Line Graphs (DLG) hydrography files and the EPA Reach File Version 3.0 (RF3). Check out <http://nhd.fgdc.gov/nhdpgs/statmaps.htm> to see the latest production status.

6. **Agency:** U.S. Geological Survey
Web Page: <http://edcwww.cr.usgs.gov/doc/edchome/ndcldb/ndcldb.html>
Description: U.S. Geological Survey site containing FTP file access to Digital Elevation Models (DEM), Digital Line Graphs (DLGs), and Land Use and Land Cover (LULC).

Data Type	Coverage	Format	Access	Cost
1:250,000-scale and 7.5-minute DEMs	U.S.	DEM	http://edcwww.cr.usgs.gov/doc/edchome/ndcldb/ndcldb.html	None
1:2,000,000-scale, 1:100,000-scale, and 1:24,000-scale DLGs	U.S.	DLG, SDTS	http://edcwww.cr.usgs.gov/doc/edchome/ndcldb/ndcldb.html	None
1:250,000-scale, 1:100,000-scale GIRAS Landuse/Landcover data	U.S.	GIRAS	http://edcwww.cr.usgs.gov/doc/edchome/ndcldb/ndcldb.html	None

7. **Agency:** U.S. Geological Survey
Web Page: <http://mcmcweb.er.usgs.gov/>
Description: U.S. Geological Survey site for the Mid-Continent Mapping Center in Rolla, Missouri, containing information on Digital Raster Graphics (DRG) as well as other products.

Data Type	Coverage	Format	Access	Cost
1:250,000-scale, 1:100,000-scale, and 1:24,000-scale DRGs	U.S.	Tagged Interlaced File Format (TIFF), GeoTIFF	http://mcmcweb.er.usgs.gov/drg/avail.html This site also lists some state sites that have DRGs available on-line for free. Order CDs on-line at http://edcwww.cr.usgs.gov/webglis/	\$32 for one CD or \$42 for two CD sets (plus a \$3.50 handling charge per order)

8. **Agency:** U.S. Geological Survey
Web Page: <http://water.usgs.gov/public/GIS/background.html>
Description: U.S. Geological Survey Water Resources site containing metadata and FTP file access to numerous national coverages commonly used in water resources studies. Some pertinent data set from the site are listed below.

Data Type	Coverage	Format	Access	Cost
Locations of NASQAN benchmark stations	Conterminous U.S.	ARC/INFO export, Gzip compressed	http://water.usgs.gov/lookup/getspatial?benchmark	None
Climate Divisions from the National Climatic Data Center	Conterminous U.S.	ARC/INFO export, Gzip compressed	http://water.usgs.gov/lookup/getspatial?climate_div	None
1:100,000-scale county boundaries	Conterminous U.S.	ARC/INFO export, Gzip compressed	http://water.usgs.gov/lookup/getspatial?county100	None
1:2,000,000-scale Hydrologic Cataloging Unit boundaries	Conterminous U.S.	ARC/INFO export, Gzip compressed	http://water.usgs.gov/lookup/getspatial?huc2m	None
1:250,000 Soils data (STATSGO)	Conterminous U.S.	ARC/INFO export, Gzip compressed	http://water.usgs.gov/lookup/getspatial?ussoils	None

9. **Agency:** U.S. Geological Survey
Web Page: <http://edcwww.cr.usgs.gov/webglis/>
Description: The U.S. Geological Survey Global Land Information System (GLIS) site provides descriptions and prices for geospatial data available from the USGS. Most of the data listed at this site is available for a price on CD-ROM, usually \$32 per CD plus handling. Be sure to check for the data on other sites listed in this table where data can be downloaded for free before ordering data from this site.
10. **Agency:** U.S. Fish and Wildlife Service
Web Page: <http://www.nwi.fws.gov/nwi.htm>
Description: The U.S. Fish and Wildlife Service National Wetland Inventory (NWI) site provides access to NWI data.

Data Type	Coverage	Format	Access	Cost
National Wetlands Inventory data, 1:24,000-scale	Partial U.S.	ARC/INFO export	ftp://www.nwi.fws.gov/arcdata/ Go into 1:250,000-scale quad directory to access 1:24,000 quad data	None

11. **Agency:** U.S. Department of Agriculture
Web Page: http://www.ftw.nrcs.usda.gov/nsdi_node.html
Description: U.S. Department of Agriculture (USDA) National Resources Conservation Service site containing FTP access to soils and other USDA data.

Data Type	Coverage	Format	Access	Cost
STATSGO Soils data, 1:250,000 scale by state	U.S.	ARC/INFO, DLG-3, GRASS	http://www.ftw.nrcs.usda.gov/stat_data.html	None
SSURGO Soils data (scales 1:12,000 - 1:63,360) by county	Partial U.S.	ARC/INFO, DLG-3, GRASS	http://www.ftw.nrcs.usda.gov/ssur_data.html	None

12. **Agency:** U.S. Bureau of the Census
Web Page: <http://www.census.gov/ftp/pub/mp/www/rom/msrom12i.html>
Description: The U.S. Census Bureau site provides brief descriptions of the TIGER/Line files, 1997 version. The data is available for the entire U.S. on 6 CD-ROMs for \$1,500 or \$250/CD-ROM for different sections of the country. Data is in TIGER/Line format. Contact Census customer services to order (301)457-4100.

Chapter 4

Description of Software Support Tools

There are numerous software support tools available for use in assessing source waters. These tools operate within specific operating and software system environments. This chapter contains information about these tools to assist users in deciding which ones may be suitable for their application. The information presented here is not an endorsement of any of these products. New products and improvements to existing products are continuously being introduced; therefore, users should conduct their own investigation of software tools to ensure they are getting the latest information.

Specifically, this chapter contains descriptions of various supporting software modules and hydrologic models. The selections are considered some of the more promising and potentially useful that were encountered during this GIS evaluation. It should be noted that there are hundreds of available hydrologic models described in the scientific literature, but many of these will probably not be suitable for use in a source water assessment. Principal purveyors of other downloadable software and hydrologic models not described in this chapter include the EPA Center for Exposure Assessment Modeling (<http://ftp.epa.gov/epa-ceam/wwwhtml/softwdos.htm>), the USGS Water Resources Division (<http://water.usgs.gov/software/>), and the U.S. Army Corps of Engineers' Hydrologic Engineering Center (<http://www.hec.usace.army.mil/>).

4.1 Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

The EPA Office of Science and Technology (OST) developed the BASINS to software promote the assessment and integration of point and nonpoint sources of pollution for watershed and water quality management. Full documentation of BASINS Version 2.0 is available in detail at <http://www.epa.gov/ostwater/BASINS/>. A brief description of BASINS is provided in the following subsections.

4.1.1 Applications

BASINS is a multipurpose environmental analysis system designed to be used by regional, state, and local agencies as well as organizations such as utilities to support environmental and ecological studies within multiple or single watersheds. For the purpose of source water assessments, the functionality of BASINS was evaluated as a tool for performing watershed and water quality based studies for a hypothetical source water protection area for both surface and groundwater systems.

The watershed and water quality features of BASINS bring key data and analytical components into one software system. Within BASINS, analysts can access national environmental information, apply assessment and planning tools, and run a variety of nonpoint loading and water quality models.

The BASINS software is comprised of a suite of interrelated components for performing the various aspects of environmental analysis. The components include: (1) nationally derived databases; (2) assessment tools that address large- and small-scale characterization needs; (3) functionality to organize and evaluate data, including user defined watershed delineation, import, land use reclassification, elevation reclassification, and look-up tables; (4) watershed characterization reports on selected watersheds; (5) water quality models (TOXIRoute and QUAL2E); and (6) the nonpoint source model (NPSM) and postprocessor, which provide integrated assessment of watershed loading and transport.

A geographic information system (ArcView 3.0a, from ESRI) provides the integrated framework for operating BASINS. This combination of framework, information, and tools provides the user with all the strengths of each package to analyze and display landscape relationships and information through the use of maps, tables, or graphics.

In addition, the combination of ArcView and BASINS software packages provides a cost-effective method of constructing a simple yet robust GIS base for source water evaluation.

4.1.2 Constraints/Advantages

BASINS is a free public-domain software package. Currently, EPA is continuing to develop enhancements for BASINS. This effort includes plans for additional data, models, and improvements to general functionality.

As with all new software packages it takes time to familiarize an inexperienced user with the software idiosyncrasies. To assist the user, EPA provides a comprehensive BASINS User's Manual. The User's Manual guides the user through the initial BASINS installation and set-up section through sections that address data, tools, utilities, outputs, and models. Each section is organized with an easy to follow tutorial with accompanying examples and graphics. The EPA provides phone contacts and e-mail addresses for assistance and technical support for users of BASINS. Users are encouraged to access the EPA OST home page (<http://www.epa.gov/ostwater/BASINS>) for information on new updates, answers to frequently asked questions, user tips, and additional information.

The prepackaged data sets in BASINS allow a user to get baseline data for source water assessment from one source. The availability of all required data from one source allows a user to be up and running very quickly without having to search for data sets from a variety of sources.

The BASINS data sets are available via the Internet or packaged as a set of 10 CDs, each corresponding to one of the 10 EPA regions. The core data sets available from the Internet are bundled into individual USGS HUC watersheds and are downloaded by each HUC watershed. There is a front end map browser at the BASINS web site which helps identify the watershed(s) of interest. The data sets include: (1) base cartographic data such as HUC boundaries, major roads, populated places, urbanized areas, and EPA region, state, and county boundaries; (2) environmental background data for soils, stream networks, elevation models, and land use and land cover; (3) environmental monitoring data for water quality monitoring stations, bacteria monitoring stations, National Sediment Inventory, listing of fish and wildlife advisories, gage sites, weather stations, and Drinking Water Supply sites; and (4) point source/loading data for Permit Compliance System sites, Industrial Facilities Discharge sites, Toxic Release Inventory sites, Superfund National Priority List sites, and Resource Conservation and Recovery Act information system sites.

Two additional data sets are available. The dem file includes digital elevation model data to represent terrain relief and the rf3 (Reach File) is a data base of surface water features that identifies all streams, lakes, reservoirs, coastlines, and estuaries (divided into segments called "reaches") in the United States. The rf3 file is a more detailed and complete reach file than the rf1 file provided in the core data set.

Since BASINS is designed to work with ArcView software, the data sets are in ArcView shape file format. However, this format does not limit the user to using only ArcView GIS to display or work with BASINS data. Most GIS platforms have built-in translator programs that will reformat ArcView shape files into the resident GIS, allowing users to employ BASINS data with their chosen GIS platform.

Some utilities might wish to perform analyses at a variety of scales in order to meet several objectives at once. BASINS incorporates tools that operate on both large and small watersheds. Adding locally developed, high-resolution data layers expands the local-scale evaluation capabilities.

The most limiting factor of BASINS is that ArcView 3.0a must be purchased and loaded prior to loading BASINS. Because ArcView is used as the framework for BASINS, any limitations of ArcView are inherited throughout BASINS. At this time, the most current version of ArcView (ArcView 3.1) only works with BASINS by using

program modifications prepared by EPA. Up-to-date modifications are available from the BASINS technical support personnel.

The user must read Section 4, Installation, of the BASINS User's Manual very carefully. Directions to extract BASINS data and Build a "Project File" should be followed exactly as documented. Section 4 can be a little confusing the first time through it. All the data sets in BASINS are unprojected (in decimal degrees, e.g., 34.4500, 114.6250). During the data extraction process BASINS allows you to project the data sets into any ArcView supported projection. Although the BASINS documentation does not stress the importance of general projection principles, the user should give this step serious thought before projecting all the data sets into a particular projection. The user should evaluate the projection parameters of any additional or local data set they would be adding into BASINS. A significant amount of time may be required for general database maintenance to change the projection of all the data sets.

Another constraint in the use of BASINS is that, at this time, there are no groundwater models supplied within the BASINS framework.

4.1.3 Results/Products

Examples of various BASINS output products are shown in the three case studies in Appendices A, B, and C.

4.1.4 Source and Cost

The BASINS software and data are available free of charge from the EPA at <http://www.epa.gov/ostwater/BASINS/>. The ESRI ArcView 3.0a software must be available prior to loading BASINS. Current cost structure of ArcView 3.0a is available by contacting ESRI at (909) 793-2853 or at <http://www.esri.com>.

4.1.5 Operational Requirements

Data Requirements

BASINS is prepackaged with a large amount of available data, and other data sets can be readily added to the BASINS framework.

System Requirements

BASINS 2.0 is a customized ArcView GIS application that has, at a minimum, similar hardware and software requirements to those of the PC-based ArcView 3.0a system. The minimum requirements are: ArcView 3.0a (with ArcView Dialog Designer), a 133-MHz Pentium processor, 30 Mb for BASINS software, 120 Mb for a single 8-digit watershed data set, 32 Mb of RAM plus 32 Mb of permanent virtual memory swap space, a compact disc reader (if BASINS software and data sets are

loaded via CD), a color monitor, and Windows 95 or NT (QUAL2E does not work correctly under Windows-NT).

Experience with ArcView, relational data bases, and hydrologic modeling will be helpful for the user.

4.2 BASINS Stream Water Quality Model - QUAL2E

QUAL2E is a stream quality model that can be executed from BASINS. A brief description of the model is provided in the following subsections.

4.2.1 Applications

QUAL2E is a one-dimensional steady-state water quality model that allows users to simulate the fate and transport of water quality constituents in selected stream reaches under specified flow conditions. QUAL2E uses complex algorithms to simulate nutrients, biochemical oxygen demand, temperature, algae, and conservative and nonconservative substances. The model accepts point source discharges and is suitable for specific flow conditions.

4.2.2 Constraints/Advantages

QUAL2E is operated through a graphical user interface in BASINS. Stream reaches must be connected for the model to function properly. At this time, QUAL2E does not run on Windows-NT.

4.2.3 Results/Products

Results from QUAL2E were not specifically evaluated because the model could not be run on Windows-NT. The primary product expected from this model is fate and transport information useful for assessing water quality in a HUC watershed.

4.2.4 Source and Cost

QUAL2E is a freely available public-domain model that is packaged with the downloadable BASINS software.

4.2.5 Operational Requirements

Operational requirements for QUAL2E are the same as those for BASINS, except that QUAL2E will not presently run on Windows-NT. Experience with ArcView, relational data bases, and hydrologic modeling will be helpful for the user.

4.3 BASINS Stream Water Quality Model - TOXIRoute

The BASINS Stream Water Quality model called TOXIRoute can be executed from BASINS. A brief description of TOXIRoute is provided in the following subsections.

4.3.1 Applications

The TOXIRoute model performs simple assessments of pollutant concentrations in streams. TOXIRoute uses a simple first-order decay solution to simulate the transport of selected pollutants in streams and rivers. This model provides an initial approach for examining concentrations of discharged pollutants in receiving waters. TOXIRoute does not explicitly consider nutrient or chemical reactions or transformations. In cases where algae growth or other significant chemical processes are a concern, this simplified model might be inappropriate. This model assumes steady-state conditions, where the system has reached equilibrium.

4.3.2 Constraints/Advantages

This model might have limitations in cases where wet weather processes, such as nonpoint source runoff, predominate.

4.3.3 Results/Products

The primary product expected from this model is a simulation of selected pollutants transported through streams or rivers.

4.3.4 Source and Cost

TOXIRoute is a freely available public-domain model that is packaged with the downloadable BASINS software.

4.3.5 Operational Requirements

Operational requirements for TOXIRoute are the same as those for BASINS. Experience with ArcView, relational data bases, and hydrologic modeling will be helpful for the user.

4.4 BASINS Nonpoint Source Model (NPSM)

The BASINS Nonpoint Source Model (NPSM) is a planning-level watershed model integrating both point and nonpoint sources. A brief description of NPSM is provided in the following subsections.

4.4.1 Applications

The NPSM is capable of simulating nonpoint source runoff and associated pollutant loadings, accounting for point source discharges, and performing flow and water quality routing through stream reaches and well-mixed reservoirs. The NPSM uses most of the simulation capabilities of the Hydrologic Simulation Program - FORTRAN (HMPF). For a detailed description of HMPF refer to the documentation available at the BASINS web page.

The NPSM can be used to simulate a single watershed (BASINS provided or user-delineated watersheds) or a system of multiple hydrologically connected watersheds. NPSM can be applied to support various water quality modeling studies such as evaluation of current water quality status, simulation of the impact of future land use changes on water quality, point and nonpoint strategies, and helping to develop watershed controls necessary to meet specific water quality goals.

4.4.2 Constraints/Advantages

The NPSM can be run directly from BASINS, although it establishes a new NPSM graphical user interface, or as a stand-alone program. NPSM outputs cannot be viewed in BASINS. NPSM will only operate on the Reach File, version 1, stream networks. It will not operate on the Reach File, version 3, stream networks.

4.4.3 Results/Products

The primary product expected from NPSM is spatially integrated watershed information regarding nutrient loading at various scales.

4.4.4 Source and Cost

The NPSM is a freely available public-domain model that is packaged with the downloadable BASINS software.

4.4.5 Operational Requirements

Data requirements for NPSM require that meteorological data sets be downloaded from the BASINS web site. All other data is provided in BASINS. System requirements are the same as for BASINS. Experience with ArcView, relational data bases, and hydrologic modeling will be helpful for the user.

4.5 Riverine Emergency Management Model (REMM)

The Riverine Emergency Management Model (REMM) was originally developed for hydrologic modeling in the upper Mississippi River in Minnesota. A brief description of REMM is provided in the following subsections.

4.5.1 Applications

With respect to SWAP, the REMM model is a pollutant fate-and-transport model best suited for evaluating time of travel (TOT) and spill response on river systems.

4.5.2 Constraints/Advantages

The REMM model may be applied to areas other than the Upper Mississippi River Basin if sufficient input data on river flow, channel shape, and pollutant chemistry are available. The model was designed to be run by a hydraulic engineer or other professional with an equivalent understanding of the input data requirements.

4.5.3 Results/Products

The REMM model can provide site-specific information regarding the fate and transport of a specific pollutant in a river system.

4.5.4 Source and Cost

REMM is public-domain software and is freely available for download from Richard Pomerleau, P.E., at the U.S. Army Corps of Engineers office in St. Paul, Minnesota (e-mail: webmaster@mvp-wc.usace.army.mil or phone: 651-290-5640).

4.5.5 Operational Requirements

Detailed site-specific data on stream discharge, flow, routing, cross-sectional geometry, and pollutant chemical properties are required to run REMM. The data must be input using a record/card format as described in the REMM Technical Manual that comes with the model. In terms of system requirements, according to the latest documentation in the REMM Technical Manual, the model can be run on DOS or any Windows platform of 3.x or greater. Experience in hydraulic engineering and hydrologic modeling is strongly recommended.

4.6 Watershed Modeling System (WMS) Model

The Watershed Modeling System (WMS) was developed by the Environmental Modeling Research Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station. A brief description of the WMS model is provided in the following subsections.

4.6.1 Applications

With respect to SWAP, the WMS model is designed for comprehensive hydrologic analysis. The WMS model merges information obtained from terrain models and GIS with industry-standard hydrologic analysis models such as HEC-1 and TR-20. Terrain models can obtain geometric attributes such as area, slope and runoff distances. Many display options are provided to aid in modeling and understanding the drainage characteristics of terrain surfaces.

4.6.2 Constraints/Advantages

The WMS model is designed for seamless file transfer to and from ArcView. The distinguishing difference between WMS and other applications designed for setting up hydrologic models is its ability to take advantage of digital terrain data for hydrologic data development. WMS uses three primary data sources for model development: GIS thematic data layers, digital elevation models (DEMs), and triangulated irregular networks (TINs). Supported models include the HEC-1 flood hydrograph program, the TR-20 interface for rainfall-runoff modeling, the CASC2D finite difference model, the NFF flood discharge model, and the Rational Method approach. The WMS is designed

to be run by a hydraulic engineer or other professional with an equivalent understanding of hydrologic modeling.

4.6.3 Results/Products

WMS can provide site-specific information regarding the fate and transport of a specific pollutant in a river system.

4.6.4 Source and Cost

The WMS is proprietary software and is available via the Engineering Computer Graphics Laboratory at Brigham Young University in Provo, Utah (<http://www.ecgl.byu.edu>). The software cost ranges from \$500 to \$2,600 depending on the desired modules. Government discounts may be available upon request.

4.6.5 Operational Requirements

The WMS can be run on Windows and UNIX Xwindows platforms. Experience with ArcView is helpful, and some experience in hydraulic engineering and hydrologic modeling is recommended.

4.7 Underground Storage Tank (UST)-Access Software

The UST-Access software was developed using the Microsoft Access 2.0 relational data base management system. A brief description of the UST-Access software is provided in the following subsections.

4.7.1 Applications

With respect to SWAP, the UST-Access software is probably best suited for evaluating leaking underground storage tanks (LUST) for their potential effects on surface water or groundwater systems.

4.7.2 Constraints/Advantages

The UST-Access is a Windows-based program that utilizes structured query language (SQL) to extract information about a site. The software was designed to be run by a user with a fundamental understanding of data base management. At this time, UST-Access will not run on Access95 or later versions.

4.7.3 Results/Products

UST-Access can provide very detailed site-specific information regarding underground storage tanks across the United States.

4.7.4 Source and Cost

All UST-Access installation files are stored as self-executable archive files on the Cleanup Information (CLU-IN) Bulletin Board System of the EPA Office of Solid Waste

and Emergency Response.

4.7.5 Operational Requirements

All necessary data files are available via the CLU-IN site. According to documentation in the UST-Access User's Manual (Version 2.30), the data management system can be run on a 33 MHz 80386 (or higher) PC with 8-Mb of RAM as a minimum using a Windows platform of 3.x or later. A minimum of one copy of Microsoft Access 2.0 should reside on the user's PC or system administrator local access network (LAN). There are no other special administration requirements. Experience with relational databases will be helpful for the user.

4.8 Spatially Referenced Regressions on Watersheds (SPARROW) Model

The Spatially Referenced Regressions on Watersheds (SPARROW) model is an extension from the Hydrologic Simulation Program - Fortran (HMPF) modeling framework. A brief description of the SPARROW model is provided in the following subsections.

4.8.1 Applications

With respect to SWAP, the SPARROW model is probably best suited for relating water quality in a watershed to sources of nutrient loading within that watershed. Spatially referenced regression modeling is a statistical technique that uses geographic information to provide nutrient-load predictions that are more spatially robust than those provided by other large-scale watershed models.

Applications of SPARROW and HMPF include the estimation of nutrient loads, evaluation of land use change scenarios, and identification of potential management practices. HMPF is presently the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions.

4.8.2 Constraints/Advantages

Because the regression models are linked to spatial information, predictions and subsequent analytical results from SPARROW can be illustrated through detailed maps that provide information about nutrient loading at multiple scales.

4.8.3 Results/Products

Together with HMPF, SPARROW can provide detailed, spatially integrated watershed information regarding nutrient loading at multiple spatial scales.

4.8.4 Source and Cost

The HMPF and SPARROW models are public-domain software freely available through USGS (<http://www.usgs.gov>) for the cost of pressing a CD (about \$35). Soon, the models may be available for direct download by prospective users (<http://water.usgs.gov/software/>).

4.8.5 Operational Requirements

There are no special data requirements beyond those needed to run the HMPF model. Presumably, HMPF and SPARROW can be run on a 33-MHz 80386 (or higher) PC with 8-Mb of RAM at a minimum using a standard DOS platform. There are many versions of the HMPF model in use and each may have slightly different requirements. Experience with relational data bases and hydrologic modeling will be helpful for the user.

4.9 Hydrology Extension for the ArcView Spatial Analyst Software

A brief description of the new Hydrology Extension for ArcView's Spatial Analyst 1.1 software is provided in the following subsections.

4.9.1 Applications

With respect to SWAP, the Hydrology Extension is probably best suited for creating input data for hydrologic models. With this extension, users can create watersheds and stream networks from a DEM, calculate physical and geometric properties of watersheds, and aggregate these properties into an attribute table that can be attached to a grid or shapefile.

Models that are readily linked to the Hydrology Extension include the COE's Hydrologic Modeling System (HMS) and River Analysis System (RAS) models, the BYU Watershed Modeling System (WMS), and USGS TR-20 runoff model.

4.9.2 Constraints/Advantages

This software extension was developed to share information between ArcView Spatial Analyst and the WMS model. The file format and description for this extension can be used to develop other similar GIS/model interfaces.

4.9.3 Results/Products

Used as part of ArcView Spatial Analyst 1.1, the Hydrology Extension can provide detailed, spatially integrated watershed information for hydrologic modeling at multiple spatial scales.

4.9.4 Source and Cost

ArcView Spatial Analyst 1.1 is proprietary software distributed by ESRI (<http://www.esri.com>). Price varies widely depending on the user's affiliation such as with government or industry.

4.9.5 Operational Requirements

There are no special data requirements beyond those needed to run the desired hydrologic models. The ArcView modules can be run on either a Windows-based PC or Unix platform. Personnel experience with ArcView, relational data bases, and hydrologic modeling will be helpful for the user.

4.10 MassGIS Watershed Tools for the ArcView Spatial Analyst Software

The State of Massachusetts, Division of Watershed Management, GIS Division (MassGIS) has developed new GIS watershed analysis tools for use with the ArcView Spatial Analyst. A brief description of these software tools is provided in the following subsections.

4.10.1 Applications

MassGIS is presently demonstrating a new set of tools that will perform automatic watershed delineation from any point on a stream, summation of land uses for contributing areas, upstream and downstream searches for specific sites on streams, and integration of documents and graphics into a GIS project. Although the tools have been constructed primarily for use in Massachusetts, presumably they will work for other states as well.

With respect to SWAP, the watershed tools are probably best suited for delineating subwatersheds for specific water monitoring points and for developing an inventory of available data for these delineated areas.

4.10.2 Constraints/Advantages

These software tools were developed to work with ArcView Spatial Analyst in a PC Windows environment

4.10.3 Results/Products

Used in ArcView Spatial Analyst, the watershed tools can provide detailed, spatially integrated watershed information for hydrologic modeling at multiple spatial scales.

4.10.4 Source and Cost

ArcView Spatial Analyst is proprietary software distributed by ESRI (internet: www.esri.com). Price varies widely depending on the user's affiliation with government

or industry. The MassGIS watershed tools are public-domain software; the contact person is J. Rader of MassGIS (john.rader@state.ma.us; phone: 617-727-5227 ext. 306).

4.10.5 Operational Requirements

Data requirements will vary according to the user. At this time the application is designed to work with data provided by the State of Massachusetts. Other applications will require some customization and linkage with outside data sets. The tools are designed to run with ArcView Spatial Analyst on a Windows-based PC platform. Personnel experience with ArcView, relational data bases, and hydrologic modeling will be helpful but not necessary.

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Appendices

- A. Case Study A: Procedure for Conducting a Source Water Assessment Plan GIS Evaluation for a Watershed System in Falmouth, Kentucky.
- B. Case Study B: Procedure for Conducting a Source Water Assessment Plan GIS Evaluation for a Groundwater System in Lebanon, Ohio.
- C. Case Study C: Procedure for Conducting a Source Water Assessment Plan GIS Evaluation for a Reservoir/Watershed System in Wilmington, Ohio.
- D. State Source Water Protection Contact List.
- E. Priority Setting and Risk Weighing Guide for Contaminants in Wellhead Protection Areas.

Appendix A

Case Study A: Conducting a SWAP GIS Evaluation for the Licking River Watershed Above Falmouth, Kentucky

The following narrative describes the stepwise procedure employed by the Lockheed Martin Environmental Systems GIS staff in Las Vegas, Nevada, to create a GIS assessment of a hypothetical source-water protection area. It is assumed this surface water intake serves a riverside community in Kentucky. Generally, the overall assessment process involves delineation of protection area, resource characterization, source inventory, susceptibility analysis, and identifying management objectives (<http://www.epa.ohio.gov/ddagw/pdu/swapflow.html>). This case study addresses the first three of these five steps. It is assumed that with the information gained from this study, further site-specific SWAP evaluations can focus on the latter two steps.

Identifying Extent of SWAP Watershed Protection Area

The first step was to perform an Internet search for information regarding previous source-water protection area plans that may have previously been prepared by various state-level groups to address SWAP compliance. Using a personal computer (PC) and a Web connection with a search engine, a helpful Internet website was found at <http://www.epa.gov/OGWDW/source/contacts.html> which contained examples of SWAP draft documents and also a list of individuals to contact in various states. At the time of this search there was no guidance report available for the State of Kentucky. However, after examining draft source-water evaluation reports for several other states (e.g, Ohio, Arizona, Illinois, Rhode Island), we concluded that the gross protection area for our case study would be the Licking River watershed area that is geographically upstream of the public water supply (PWS) intake for Falmouth, Kentucky.

Collecting General Watershed Information from the Internet

Next, we logged onto the EPA “Surf Your Watershed” (SYW) website at <http://www.epa.gov/surf2>. This site is a good repository for general information on a particular geographic area of interest, be it a region, state, county, watershed, or other delineation. Clicking on the *Locate Your Watershed* icon took us to <http://www.epa.gov/surf2/locate>, where box entries enabled us to locate watersheds by geographic unit. The portion of the Licking River watershed above Falmouth, Kentucky, is wholly contained within hydrologic unit code (HUC) 05100101, so we selected *8-digit USGS hydrologic cataloging code* in the first box, entered *05100101* in the second box,

then pressed *Submit*, which migrated us to a several-page watershed summary screen at <http://www.epa.gov/surf2/hucs/05100101>, as shown in Figure A-1. Clicking on specific underlined links, such as those for *Rivers and Streams* or *Nonpoint Source Projects*, migrated us to screens containing watershed information like those shown in Figures A-2 and A-3. Data on stream flow and water and land uses were also available for perusing.

For the purposes of this assessment, the most useful watershed-level information presently available from the SYW site was accessible via underlined links found under the *Environmental Information* heading. As shown in Figures A-4, A-5, and A-6, site data for industrial facilities regulated by EPA are automatically tapped through linkages with the EPA's "Envirofacts" interactive database query tool which includes information on toxic releases, hazardous wastes, and Superfund sites, respectively. Detailed information for an individual facility within the HUC watershed, as shown in Figure A-7, can be generated by clicking on the underlined link (in any of these three figures) labeled with the facility ID number. In this way, an historical list can be compiled of all potential contaminants that have been released at some time somewhere within the watershed. This is the "first cut" of a SWAP watershed evaluation using freely available GIS resources. It should be noted that access via SYW is the preferred method of querying Envirofacts data, although the data may not always be immediately served through SYW because of frequent EPA routine maintenance on the server databases. At this time, direct queries of Envirofacts cannot be made on a watershed or subwatershed basis, although queries may be formulated to access data by zip code, city, county, state, or EPA region by migrating to http://www.epa.gov/enviro/html/rcris/rcris_query_java.html.

An expedient way to generate a cursory GIS graphical representation of federal facilities within the Licking River Watershed was found through the "Xinfo" links; in this case, the link to "BasinInfo" at <http://www.epa.gov/region10/www/gisapps/basinmethod.html>. From any given facility information page, the *Map this Facility* button was pressed, then the *Map with SiteInfo* button was pressed, and then the underlined link to BasinInfo was selected. The underlined link to *Select a basin to map by its 8-character basin code* was selected, allowing us to work through the specifications outlined in several subsequent screens, as shown in Figure A-8. Then, a request was made of EPA's Xinfo map server, as shown in Figure A-9, which provided (via electronic mail within 15 minutes of submission) a very detailed graphics file and accompanying text file containing the locations and types of federally regulated facilities within the 05100101 HUC watershed, as shown in Figure A-10. Note that the output graphic files may appear somewhat crude if the area of interest is large, i.e., greater than county size. In any event, the Xinfo output files can be viewed using PC-standard software such as Paint, Adobe Acrobat (downloadable free from the Internet), or Notepad. We have found no better way to obtain an initial GIS-based snapshot of potential

contaminant point sources within a watershed, using only a PC and freely accessible Internet GIS resources.

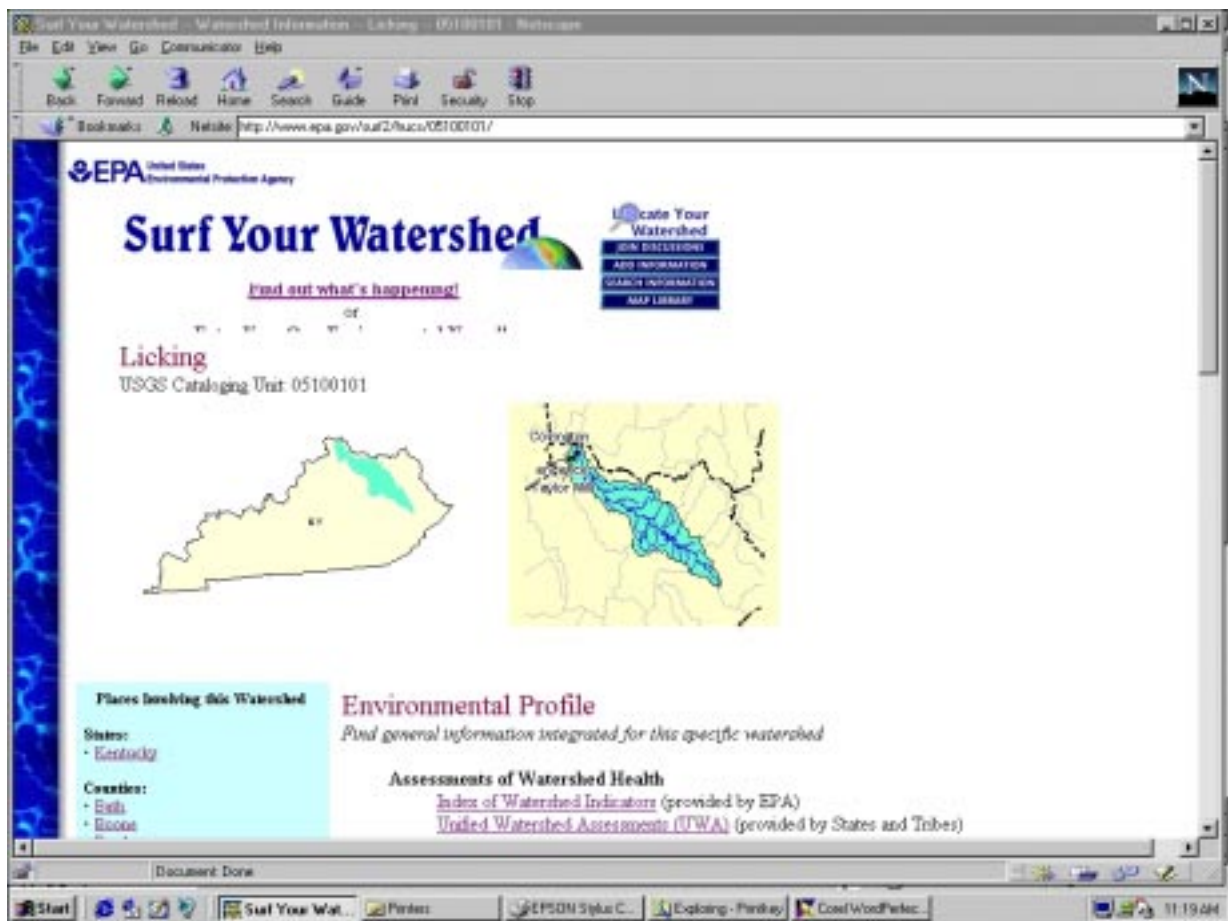


Figure A-1. EPA Surf Your Watershed World Wide Web screen for a watershed summary of the Licking River Basin in Kentucky (Screen 1 of 3).



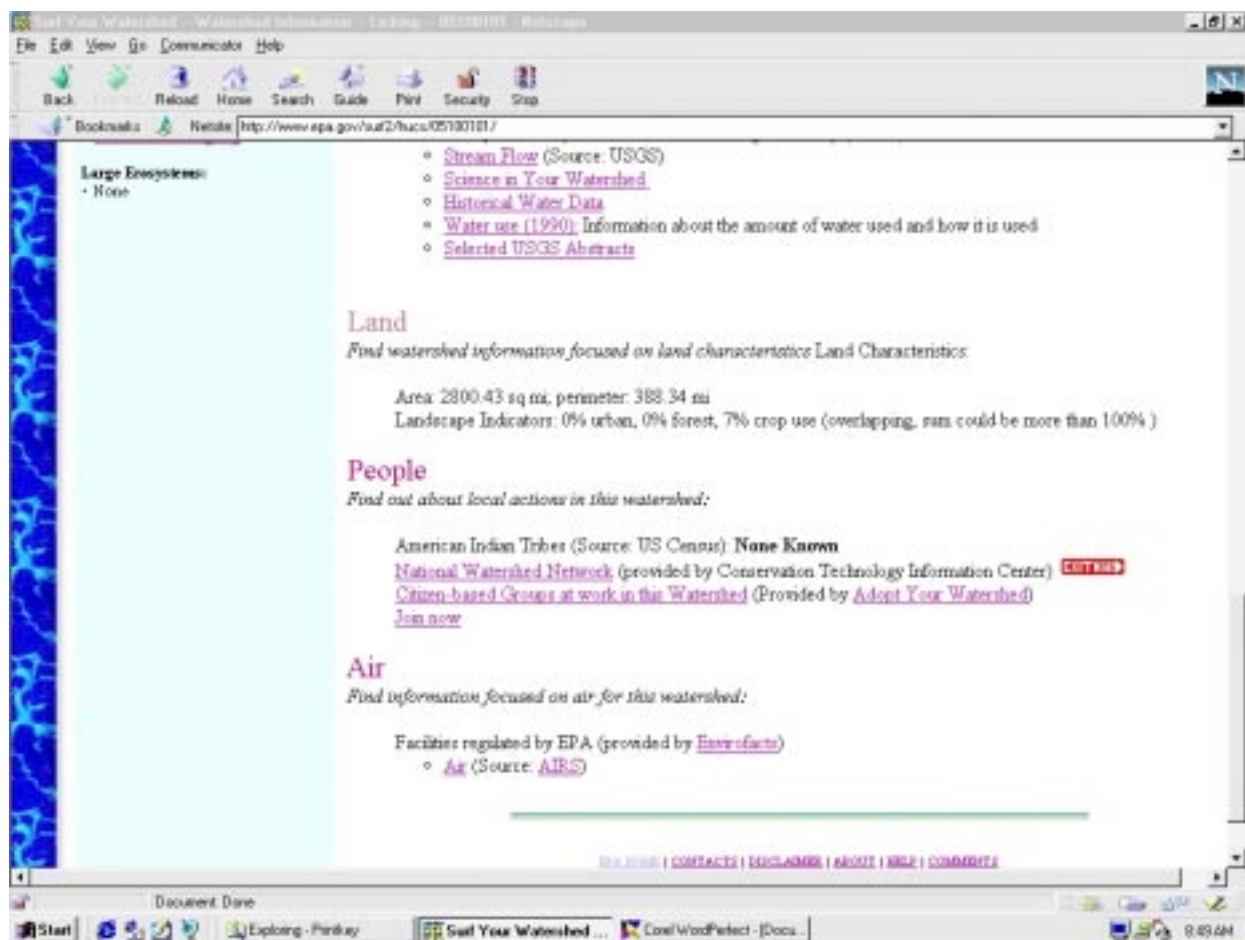


Figure A-1. EPA Surf Your Watershed World Wide Web screen for a watershed summary of the Licking River Basin in Kentucky (Screen 3 of 3).



Figure A-2. List of Rivers and Streams for the Licking River Basin.



Figure A-3. List of Nonpoint Source Projects for the Licking River Basin.

United States
Environmental Protection Agency

Surf Your Watershed

Locate Your Watershed
ADD INFORMATION
SEARCH INFORMATION
MAP LIBRARY

TRIS Facilities for:
Licking
USGS Cataloging Unit: 05100101

Facility ID	Facility Name	Facility Address
KYD083828962	ADVANCED INSULATION CONCEPTS, INC	8055 Production Ave. Florence, KY 41042
KYD066051913	BP CHEMICALS/SILMAR RESINS	3535 Latonia Ave Covington, KY 41015
KYD985077312	CAMCO CHEMICAL CO	8150 Holton Dr Florence, KY 41042
KYD985077460	CHESTER LABS INC	3208 Dixie Hwy Richinger, KY 41018
KYD068946854	DESAVO LIME CO	Springdale Rd. Bte. 4 Box 372a Maysville, KY 41056
KYD985100668	DESAVO LIME CO BLACK RIVER DIV	Hwy 8 Butler, KY 41006
KYD985093400	ESCO CORP	3792 Lake Park Dr Covington, KY 41017
KYD985093400	ESCO CORP	4301 Boron Ave

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Figure A-4. List of TRI Facilities for the Licking River Basin.

RCRIS Facilities in USGS Cataloging Unit 05100101 - Netscape

File Edit View Go Communicator Help

Back Reload Home Search Guide Print Security Stop

Location: <http://www.epa.gov/8866/uxended/ova/surfao?uc=05100101&dp=01&name=Licking>

EPA United States Environmental Protection Agency

Surf Your Watershed

Locate Your Watershed

JOIN EXISTING
ADD INFORMATION
SEARCH INFORMATION
MAP LIBRARY

RCRIS Facilities for:
Licking
USGS Cataloging Unit: 05100101

Facility ID	Facility Name	Facility Address
KYD981803885	A 1 ELECTRIC MOTOR SVC INC	1461 Dune Hwy Park Hills, KY 41015
KYD985075293	A F BRIDINGER & SONS	502 W 12th St Covington, KY 41011
KY0000128702	A T & T	Hwy 17 & 27 S Butler, KY 41006
KYD985116003	AFCO MFG INC	1549 Kellogg St Covington, KY 41012
KYD981020795	AFFORDABLE TRANSMISSION SERVIC	3912 Dune Hwy Erlanger, KY 41018
KY0000382333	AMERICAN DYES & COATINGS CORP	7880 Foundation Dr Florence, KY 41042
KYD024127250	ANGELOS CAMPBELL COUNTY CHEV/GEO INC	1028 Monmouth St Newport, KY 41071
KYD98442548	ANTHONY COF INDUSTRIES INC	20 W 43 St

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Figure A-5. List of RCRIS Facilities for the Licking River Basin.

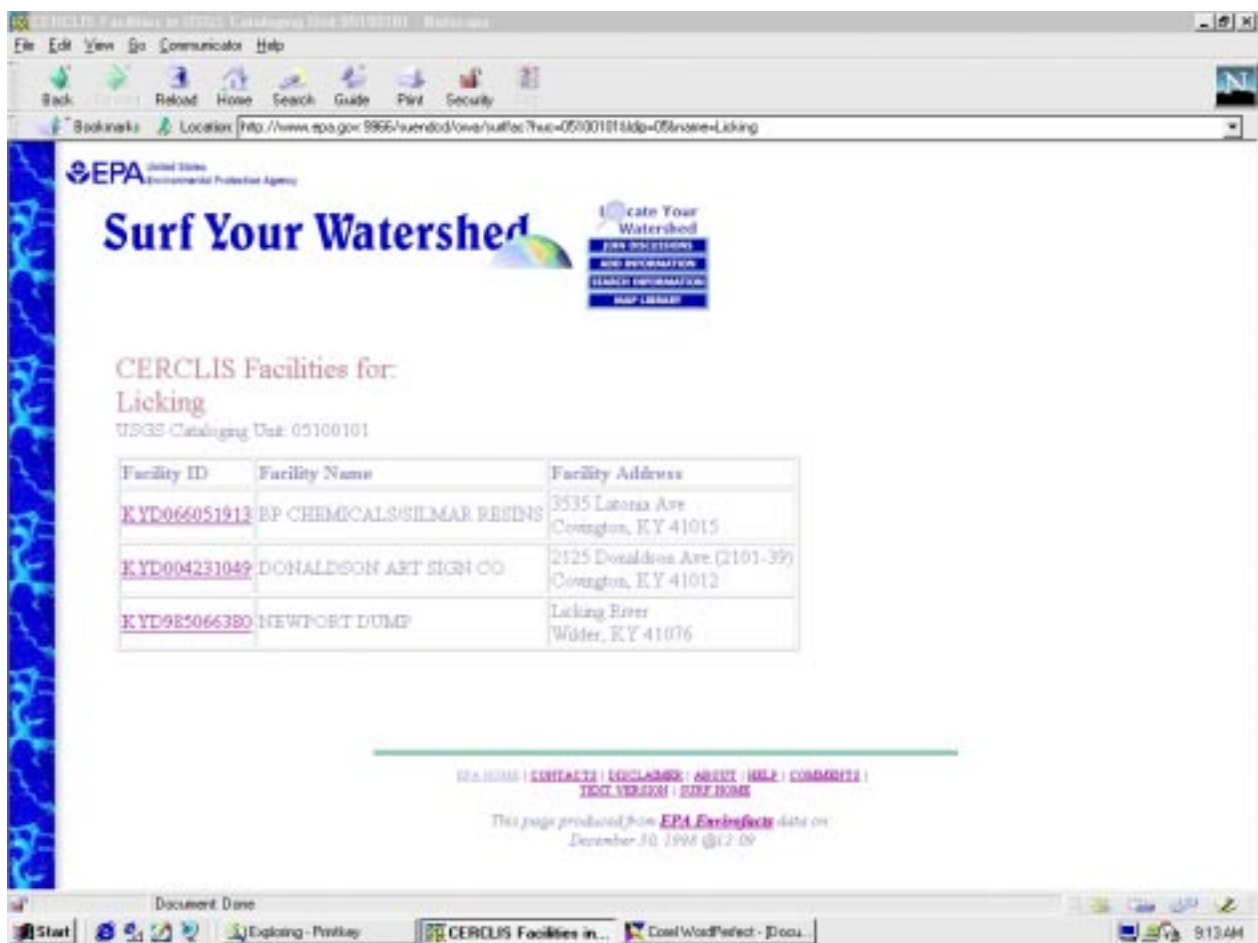


Figure A-6. List of CERCLIS Superfund Facilities for the Licking River Basin.



Figure A-7. Detailed TRI information for an individual facility within the Licking River Basin (Screen 1 of 3).

ENVIRONMENTAL REPORT - Worksheet

File Edit View Go Communicator Help

Back Reload Home Search Guide Print Security

Location: http://www.epa.gov/9966/envidoc/ows/multi2_get_facType_id=CYD981854227&sys_code=00

SIC CODE SIC DESCRIPTION
2491 WOOD PRESERVING

Chemicals Transferred to other Sites

<u>CHEMICAL NAME</u>	<u>CAS NUMBER</u>	<u>DOCUMENT</u>	<u>RELEASE AMOUNTS LBS/YR</u>	<u>RELEASE BASIS CODE</u>	<u>TREATMENT TYPE</u>	<u>TRANSFER SITE NAME</u>	<u>TRANSFER SITE CITY</u>
ARSENIC COMPOUNDS	N020	1395095083693K.Y	250	MONITORING DATA	SOLIDIFICATIONSTABILIZATION	EVOTECH MANAGEMENT SERVICES	BELLEVILLE
CHROMIUM COMPOUNDS	N090	1395095320646K.Y	250	MONITORING DATA	SOLIDIFICATIONSTABILIZATION	ENVOTECH MANAGEMENT SERVICES	BELLEVILLE
COPPER COMPOUNDS	N100	1395095083717K.Y	250	MONITORING DATA	SOLIDIFICATIONSTABILIZATION	EVOTECH MANAGEMENT SERVICES	BELLEVILLE

Chemicals Released to Air
There was no data of this type reported for this facility.

Chemicals Released via Underground Injection
There was no data of this type reported for this facility.

Chemicals Released to the Land Surface
There was no data of this type reported for this facility.

Document: Done

Start BASINS 2.0 Corel WordPerfect - \$... Exploring - Flickr ENVIROFACTS R... 8:04 PM

Figure A-7. Detailed TRI information for an individual facility within the Licking River Basin (Screen 2 of 3).

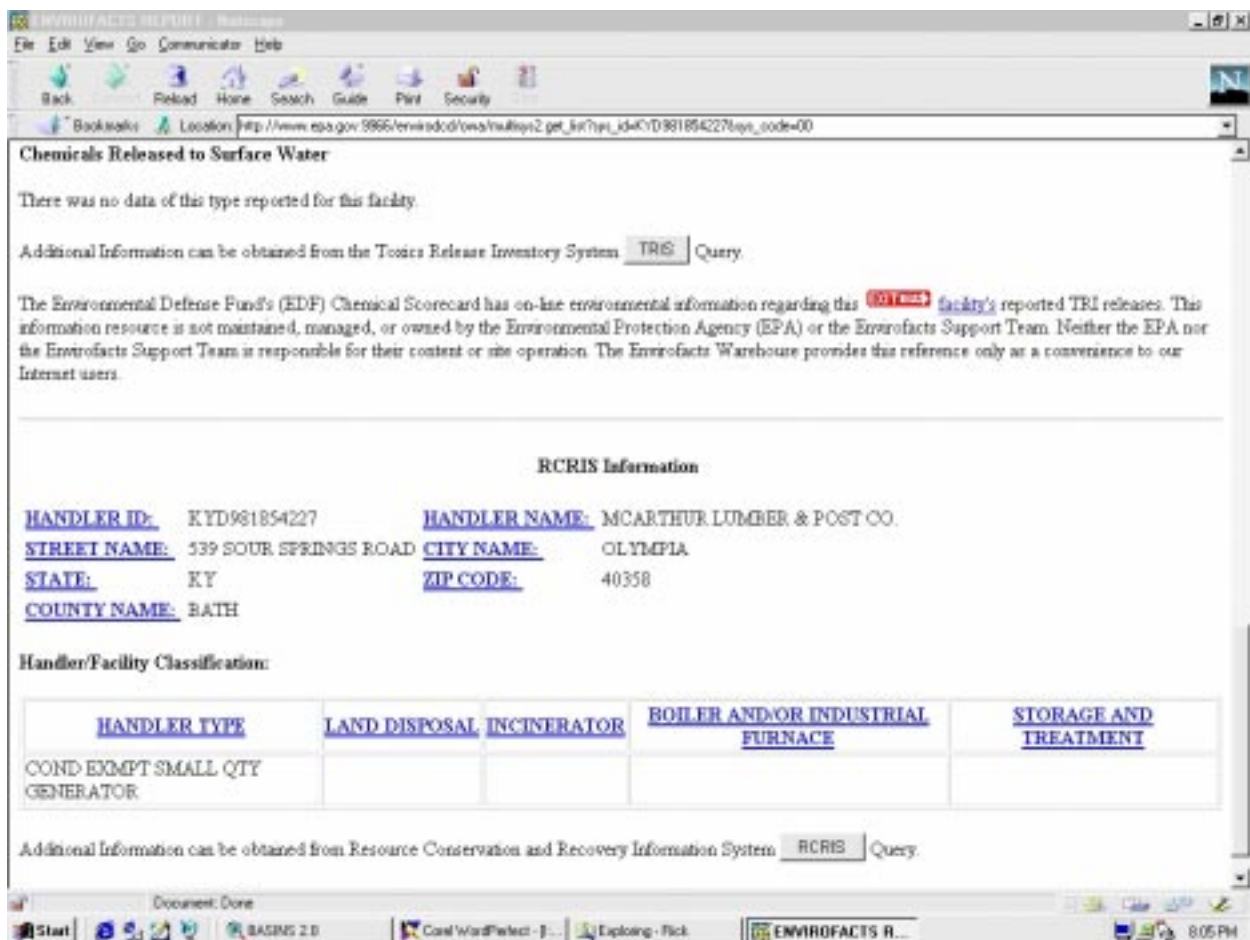


Figure A-7. Detailed TRI information for an individual facility within the Licking River Basin (Screen 3 of 3).

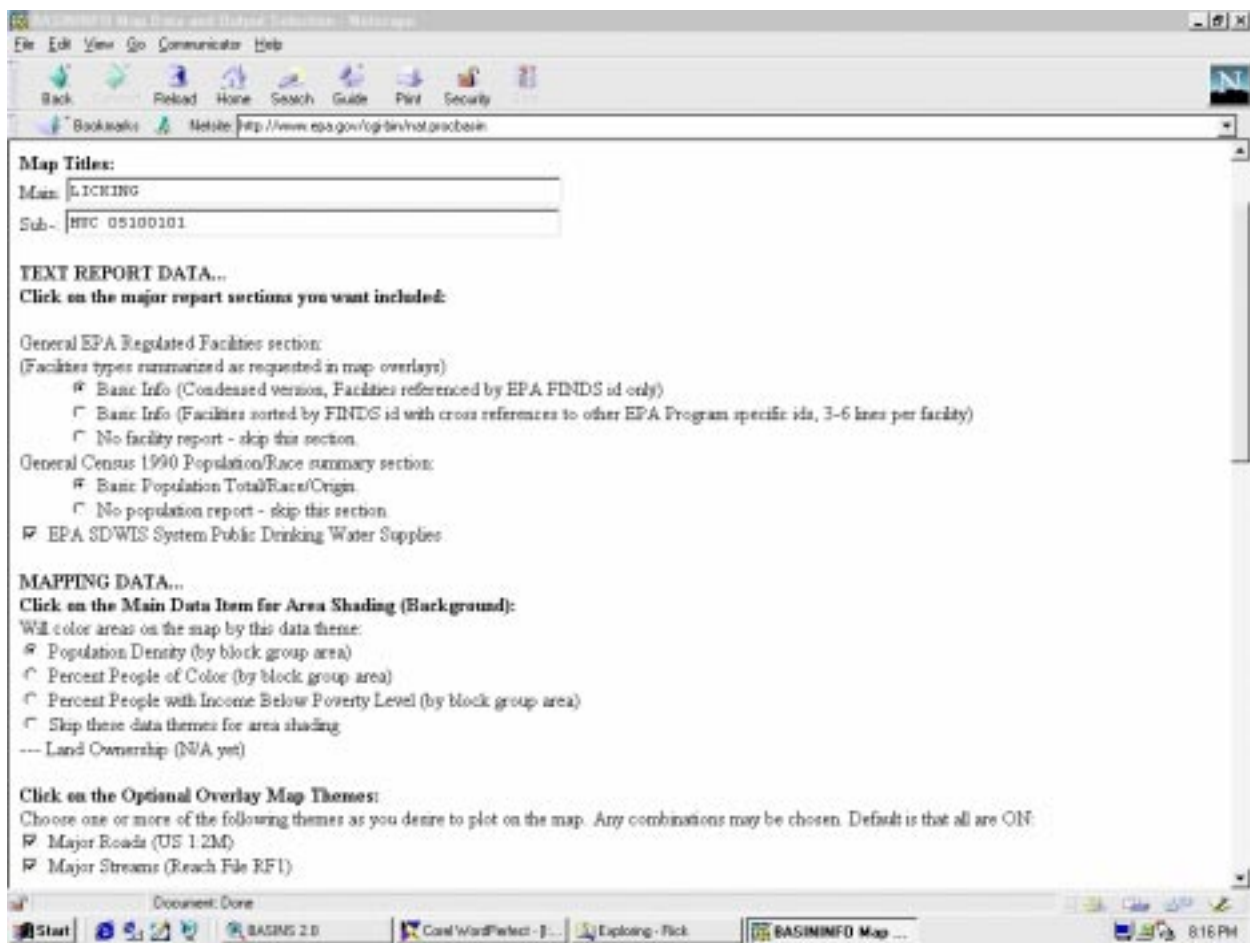


Figure A-8. Map information available from BasinInfo through the EPA Xinfo Map Server (Screen 1 of 2).



Figure A-8. Map information available from BasinInfo through the EPA Xinfo Map Server (Screen 2 of 2).



Figure A-9. Response to a map request from the EPA Xinfo Map Server.

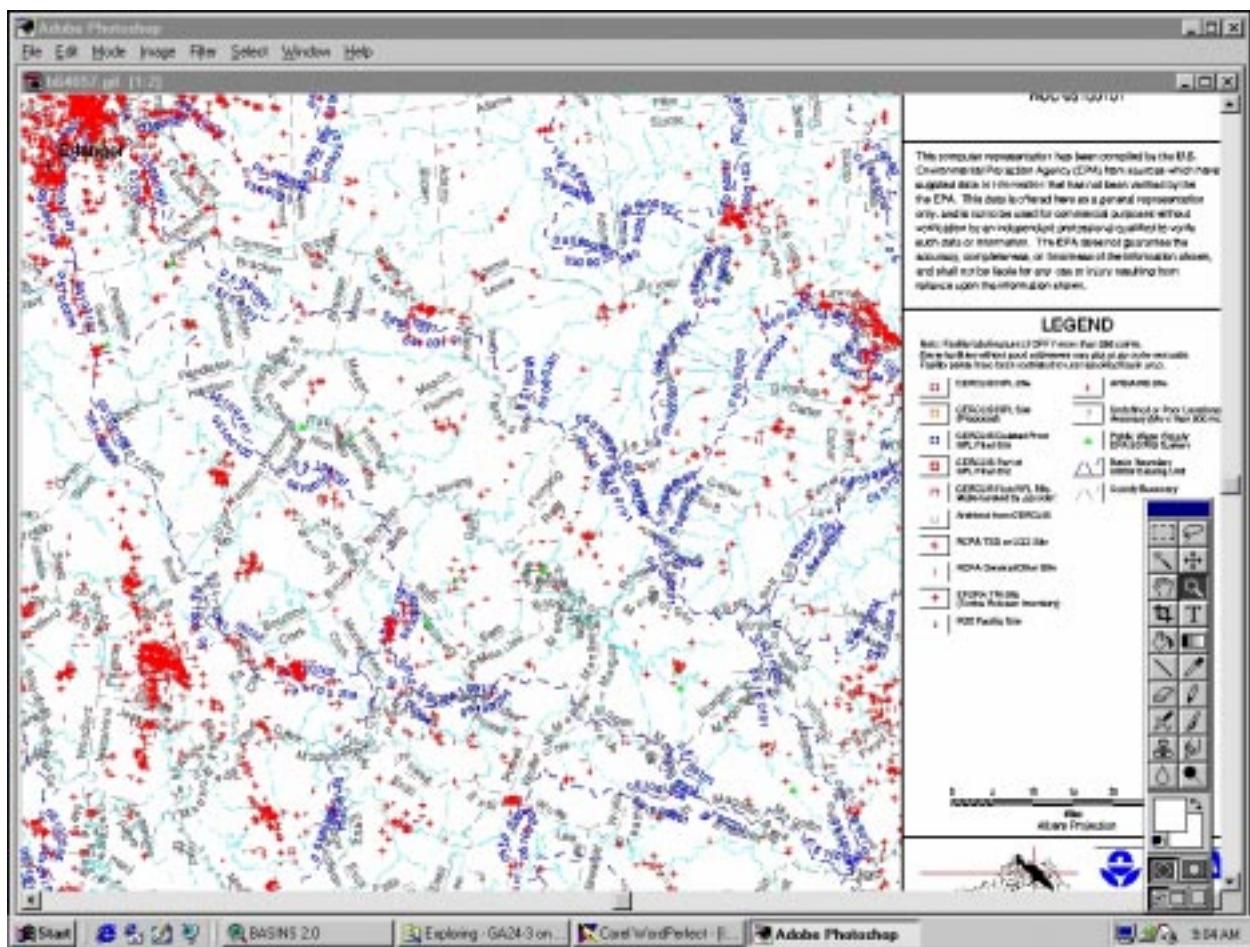


Figure A-10. Map containing the locations and types of federally regulated facilities within the Licking River Basin, produced by the EPA Xinfo Map Server.

Returning to the SYW screen for the Licking River Watershed, selecting the underlined link *EnviroMapper for Watersheds* migrated us to the EPA “EnviroMapper” interactive mapping tool. A generalized map of HUC watershed 05100101 was automatically displayed, with the option of selecting RF1 streams, STORET water quality stations, roads, and other geographic features within the view frame. As many as 20 generalized data layers associated with the Index of Watershed Indicators (IWI) are available for viewing within the frame. These data layers provide broad categorical descriptions of environmental themes such as *Chemicals in Source Water* or *Potential Pesticide Runoff from Farms*, which can be used for a very cursory qualitative evaluation or for creating a general perspective of watershed condition. When done viewing, close the EnviroMapper screen and reactivate the previous SYW screen, or enter a carriage return within the “netsite URL” box. EnviroMapper can also be accessed directly (outside of SYW) via <http://www.epa.gov/enviro/html/mod/EnviroMapper/index.html>).

It is important to understand that EnviroMapper offers up its data themes as a function of map scale. For example, when evaluating contamination sources at the scale of a small community such as Falmouth, many types of site-level data themes (including geographic features and potential contaminant-producing facilities) enter the view frame, as shown in Figure A-11. When zooming out to the larger Licking River Watershed map extent, many of these features and facilities disappear from the frame and cannot be queried at that particular map scale, as shown in Figure A-12. Hence, the best way to construct a query for a large area appears to be via SYW as described previously.

Collecting Specific Watershed Information

One cost-effective method of constructing a simple-yet-robust GIS framework for source-water evaluation is through a combination of the ArcView and BASINS software packages. Although there are other proprietary software packages similar to ArcView that perform comparably, the BASINS 2.0 public-domain software was designed by EPA to run specifically on ArcView 3.0a. BASINS is downloadable free of charge from the Internet. Following is a stepwise discussion of our experimentation with the ArcView/BASINS tools.

ArcView 3.0a proprietary software was purchased from ESRI and installed on a PC driven by WinNT, Win95, or Win98 (see Chapter 2). The BASINS 2.0 public-domain software was downloaded from <http://www.epa.gov/OST/BASINS> and the setup.exe program was run to install it on the PC (see BASINS 2.0 User's Manual, Section 4.1). ArcView Dialog Designer free software was subsequently downloaded from the ESRI website at <http://www.esri.com/base/products/arcview/avsoftware.html>.

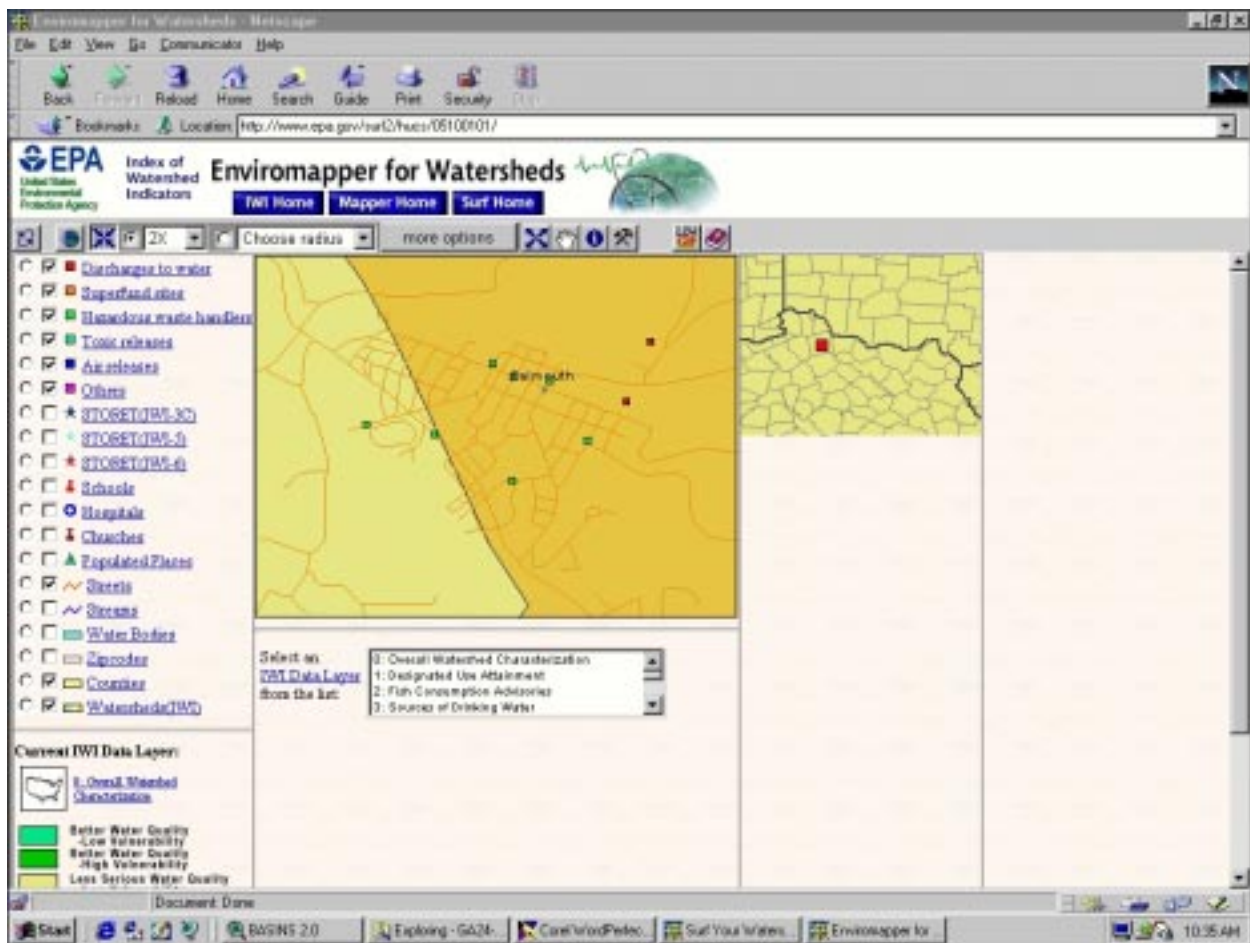


Figure A-11. Types of site-level thematic data shown in the EnviroMapper frame at a large (local) map scale.

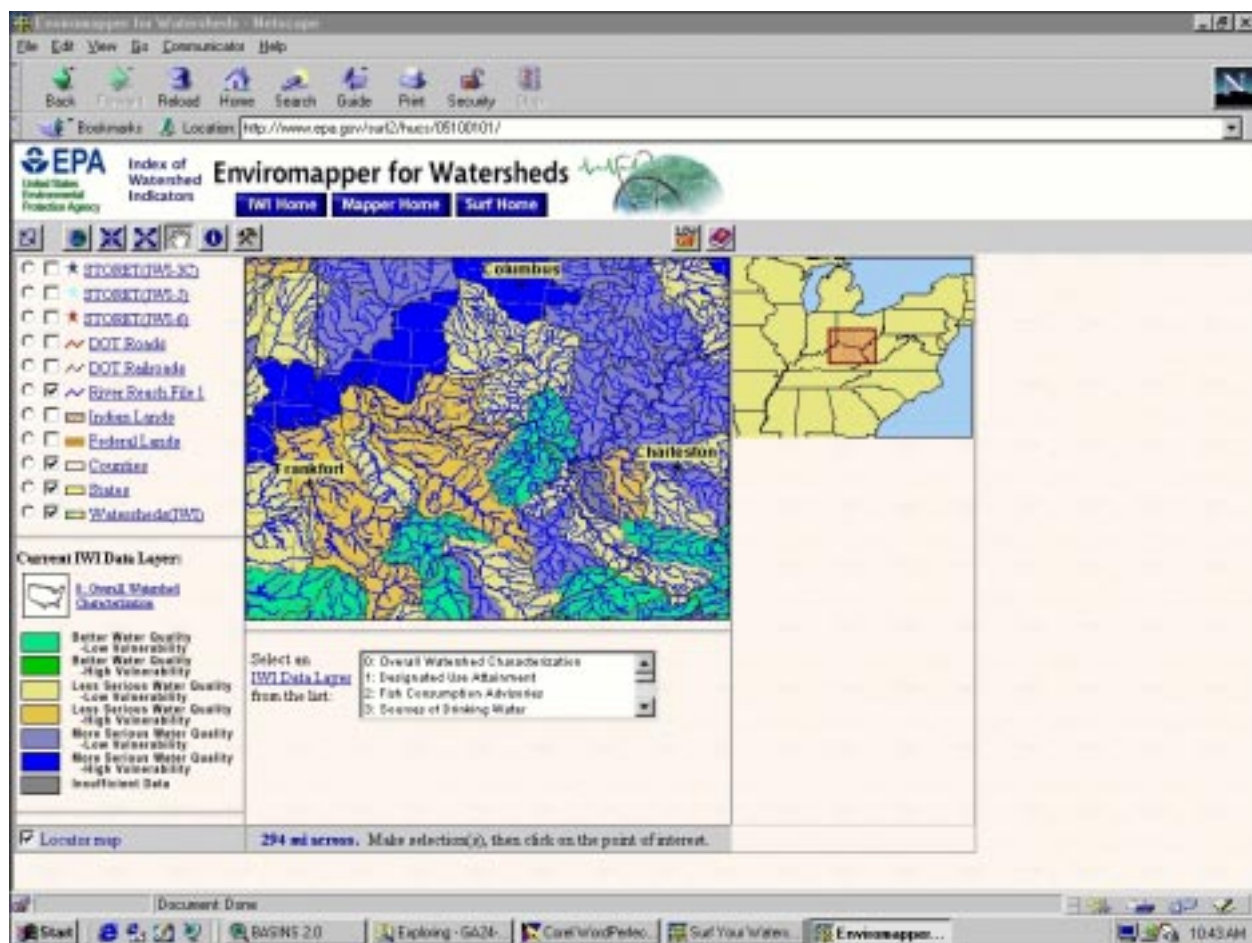


Figure A-12. Types of thematic data shown in the EnviroMapper frame at a small (regional) map scale.

From the BASINS website (see above), we downloaded the core, dem, and rf3 self-executable zip-archive (.exe) data packets for the Licking River HUC 05100101 into the `basins\data` subdirectory, and then extracted their component files into the `basins\data\05100101` subdirectory (see BASINS 2.0 User's Manual, Section 4.2). Next, we clicked on the Start button in Windows and, under *Programs*, selected *Basins*, and then *Data Extraction*. Each .exe file was selected sequentially for extraction, first for the core data, then for the dem and the rf3. The projection parameters for Licking River watershed were set to UTM Zone 17 for the sake of this case study. In order to be used within BASINS, the dem and rf3 shapefiles were imported so they could be visualized and accessed in the watershed view (see BASINS 2.0 User's Manual, Section 7.2).

Watershed Delineator, a digitizing tool within BASINS, was used to define the subwatershed portion of the Licking River above Falmouth, Kentucky (see BASINS 2.0 User's Manual, Section 7.1). The 05100101 HUC watershed boundary was used as the base (edit) coverage, and background coverages of the RF3 streams overlain on the DEM physiography were used to aid in the delineation. Using topographic cues and the stream network as guides, a single line was digitized with the mouse that distinguished the unneeded portion of HUC 05100101 watershed from the needed portion that was to be considered for the Falmouth case study, as shown in Figure A-13. The new watershed boundary was saved as a new shapefile in the `basins\data\05100101\delineatedwatersheds` subdirectory and was subsequently imported into the view (see BASINS 2.0 User's Manual, Section 7.2). A graphic showing the new watershed boundary with the counties, cities, and other regional features was created, as shown in Figure A-14. Then, with the new watershed boundary activated, the available data themes were individually brought up in the view to observe and document their distribution, as shown in Figure A-15.

Using the BASINS Report menu, a land use distribution report was generated for the new watershed. The outputs from this operation included a graphics plot and table describing the types and component acreages of various land uses within the watershed, as shown in Figure A-16. Other options within the Report menu include evaluations for point sources, water quality, air emissions, soil characteristics, or watershed topography. Unfortunately, information on point sources can only be derived one parameter at a time and for one year at a time, while information on water quality can be generated across all years of record but for one parameter at a time. Another limitation is that newly derived reports will overwrite any previously generated reports, making it difficult to gather component tables that would be needed to build a multiple-parameter watershed database via the Report tools.

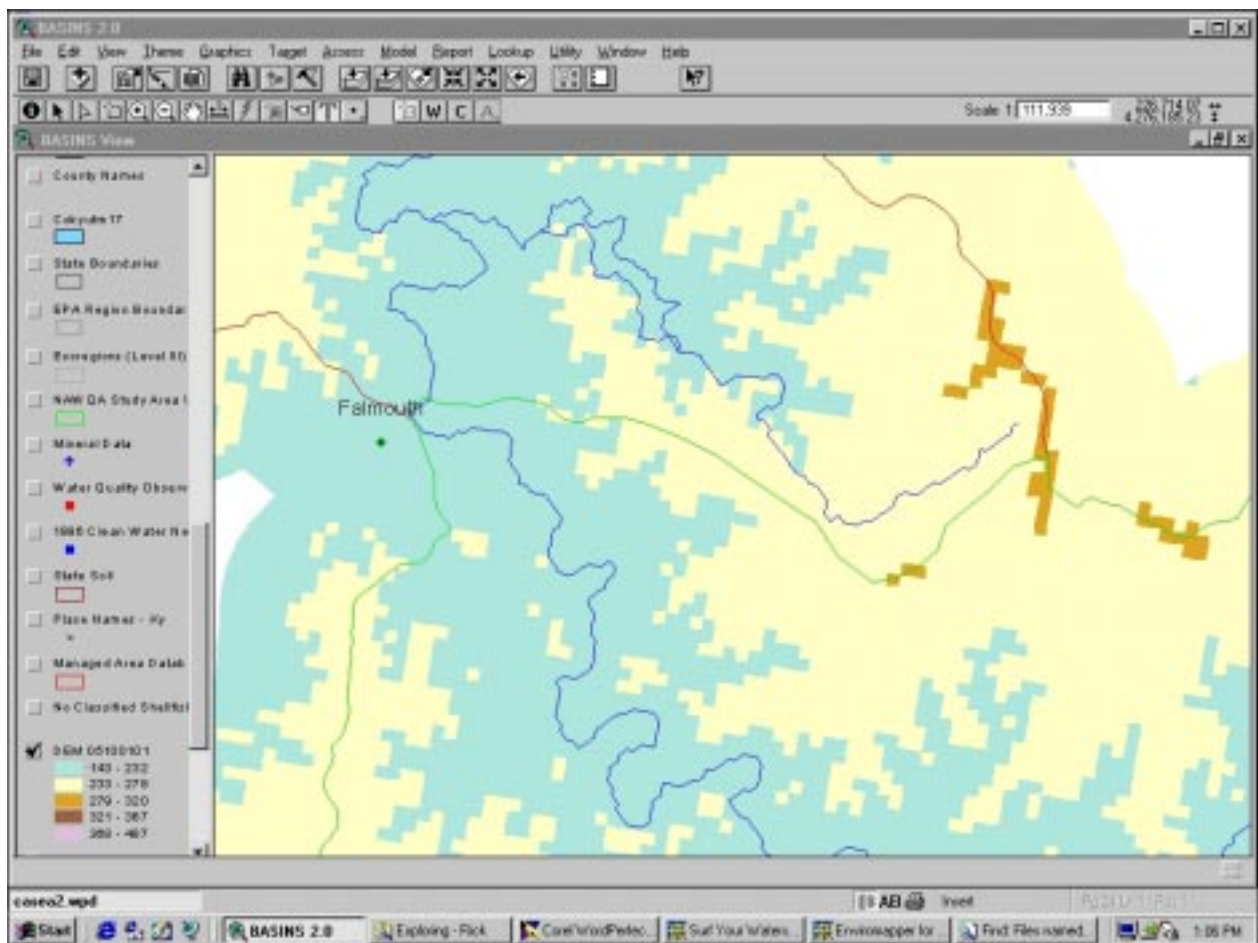


Figure A-13. Use of topography and streams to differentiate the upstream watershed for Falmouth (green line) from the removed portion (red line).

Licking River Watershed - Case Study A



Figure A-14. Upstream watershed boundary for Falmouth showing counties, cities, and other regional features.

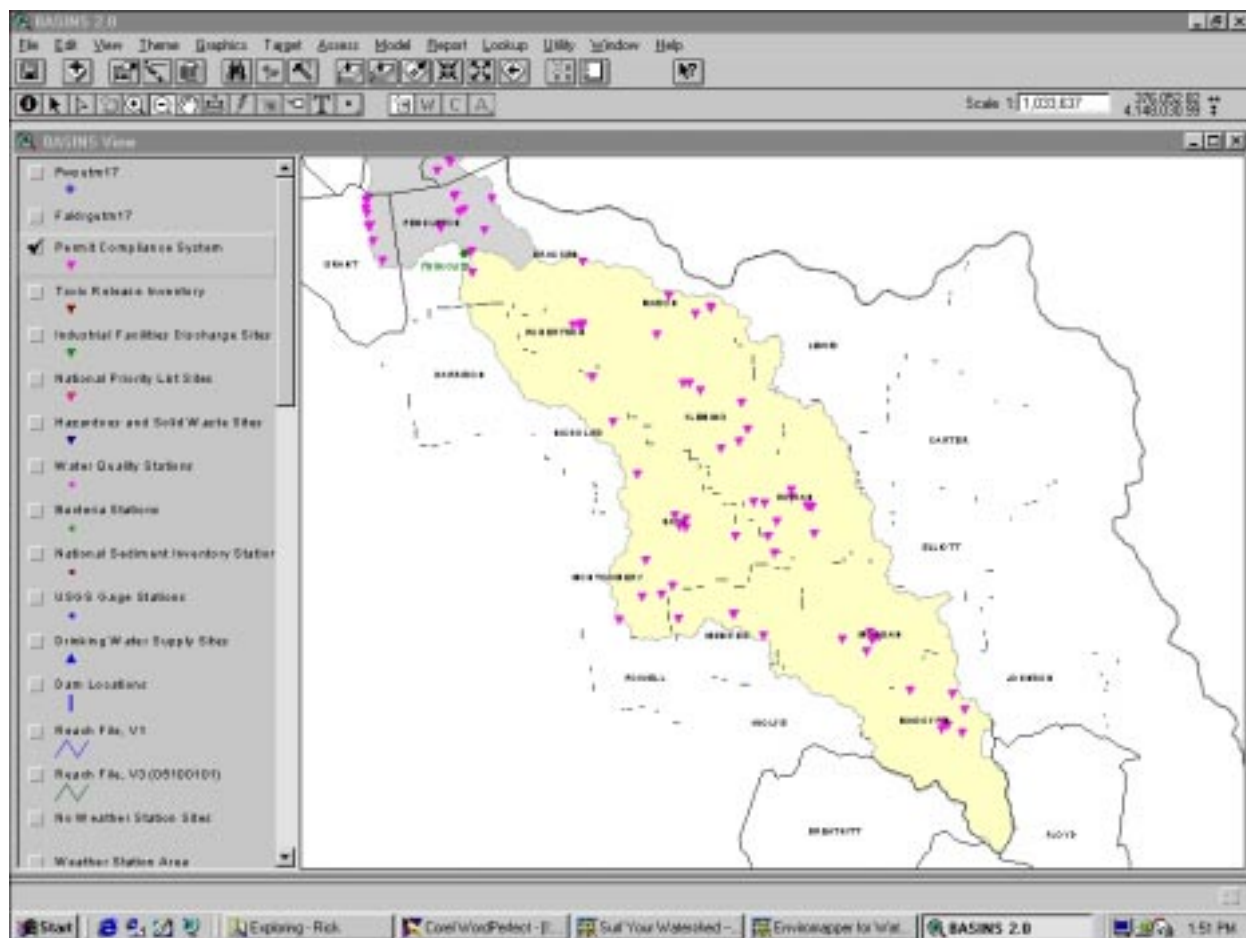


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 1 of 10: Permit Compliance System sites).

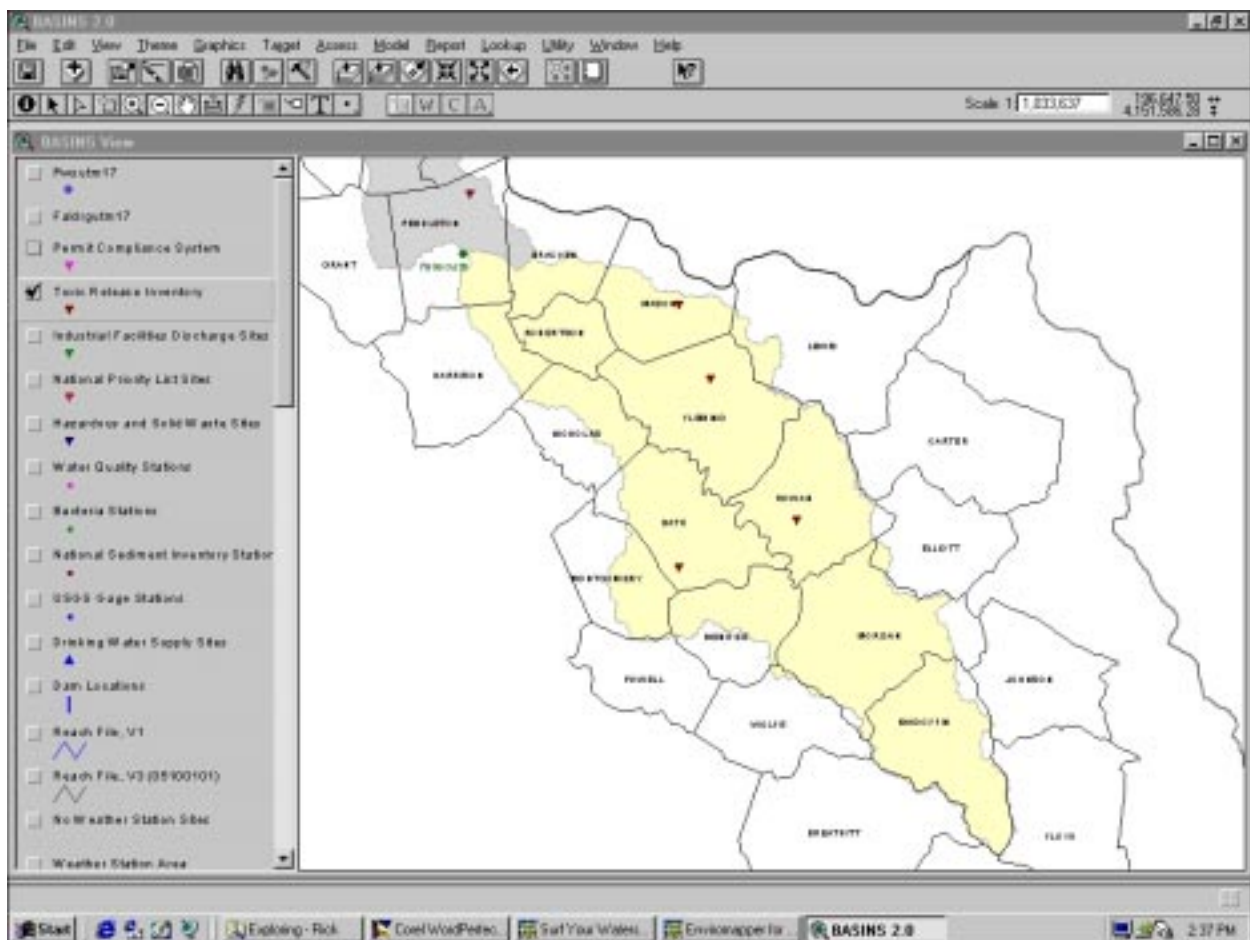


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 2 of 10: Toxic Release Inventory sites).

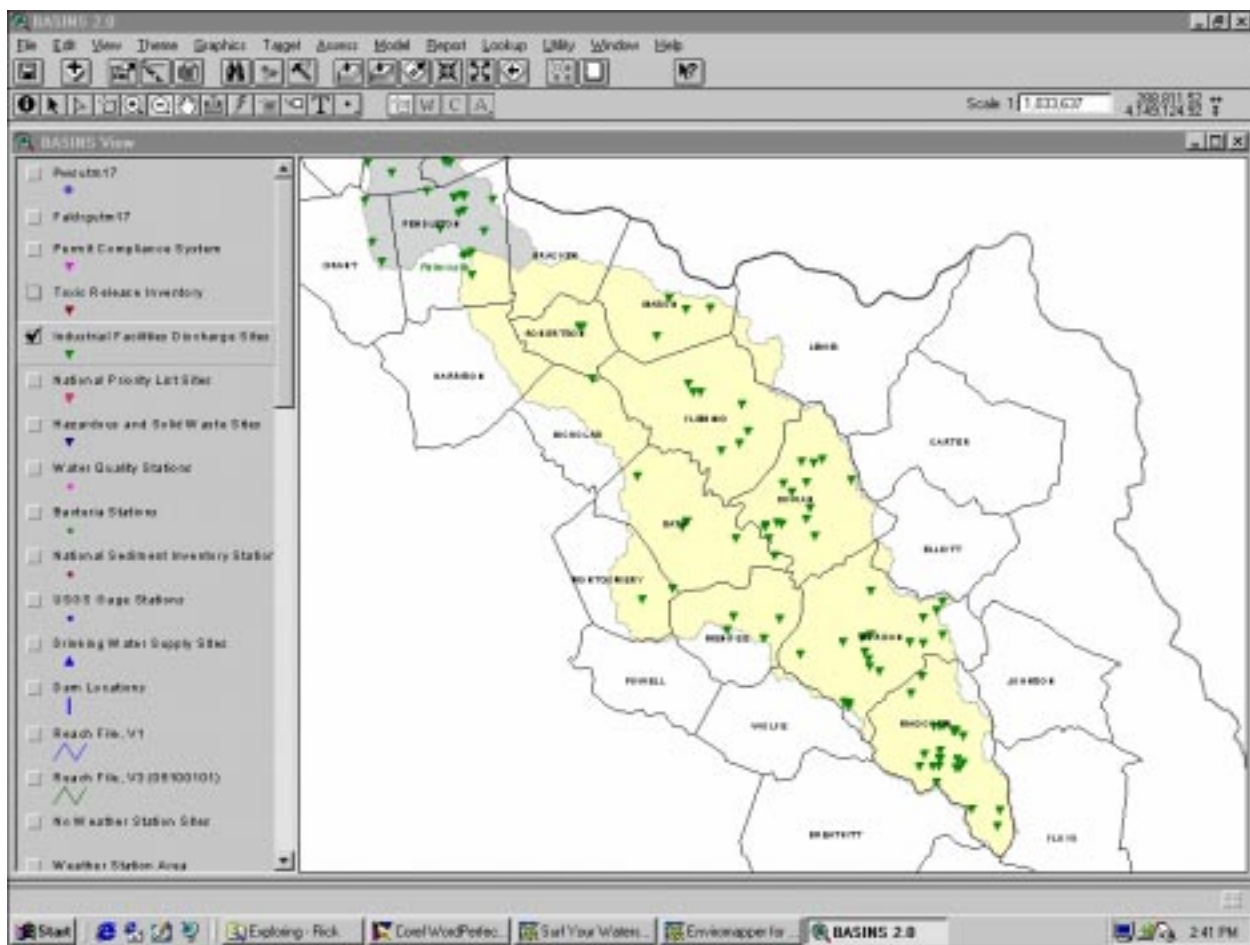


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 3 of 10: Industrial Facilities Discharge sites).

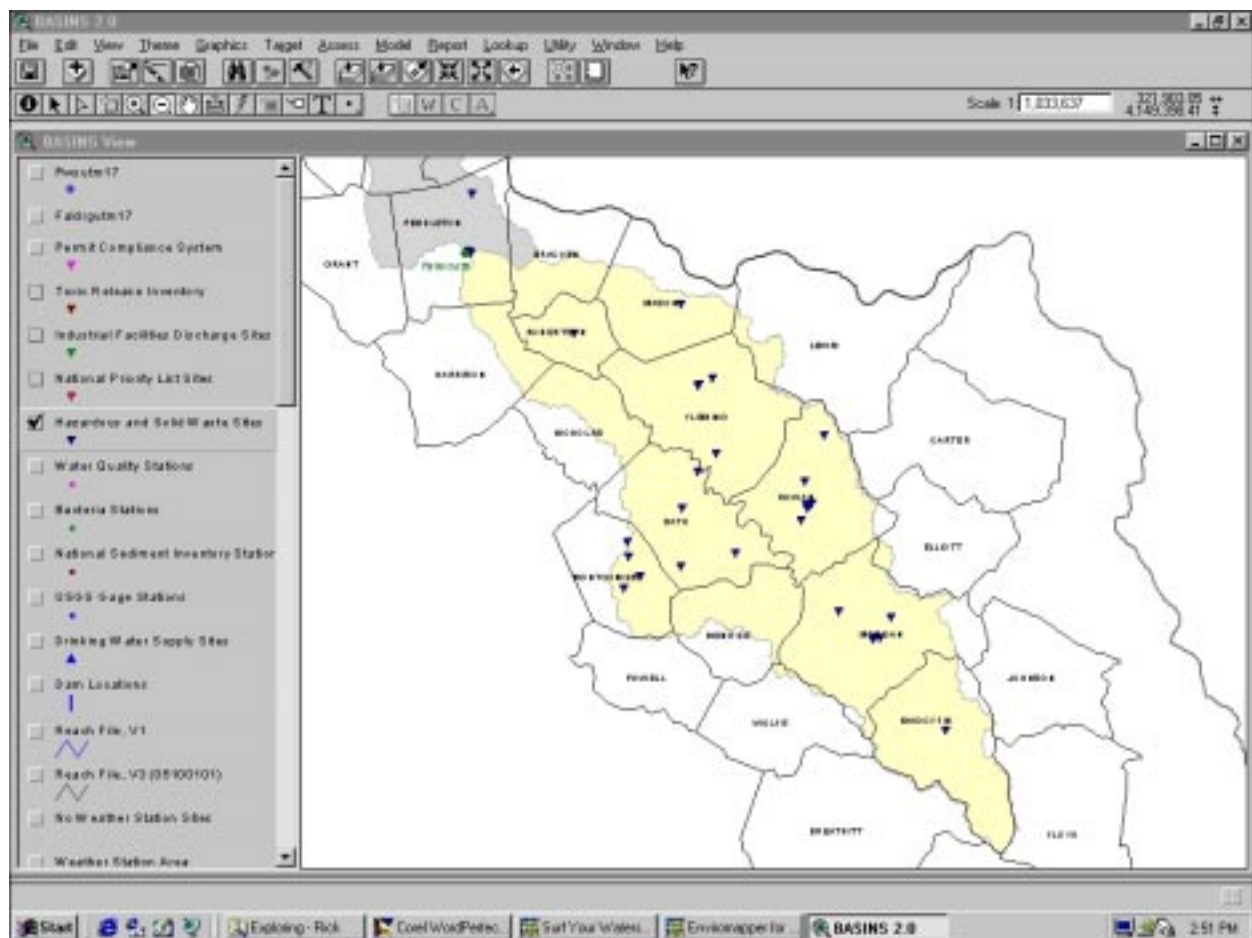


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 4 of 10: State of Kentucky Hazardous and Solid Waste sites).

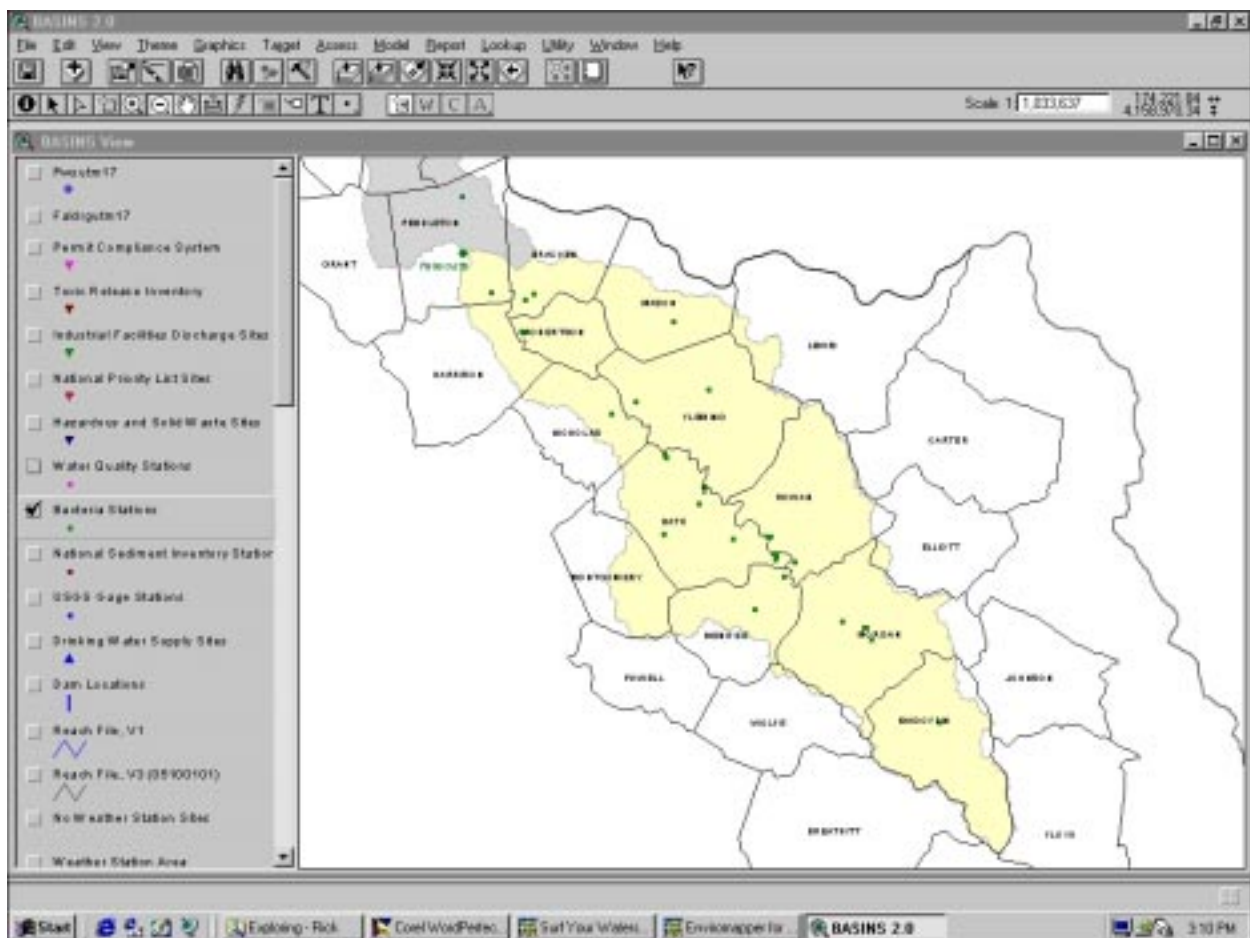


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 6 of 10: Bacteria monitoring stations).

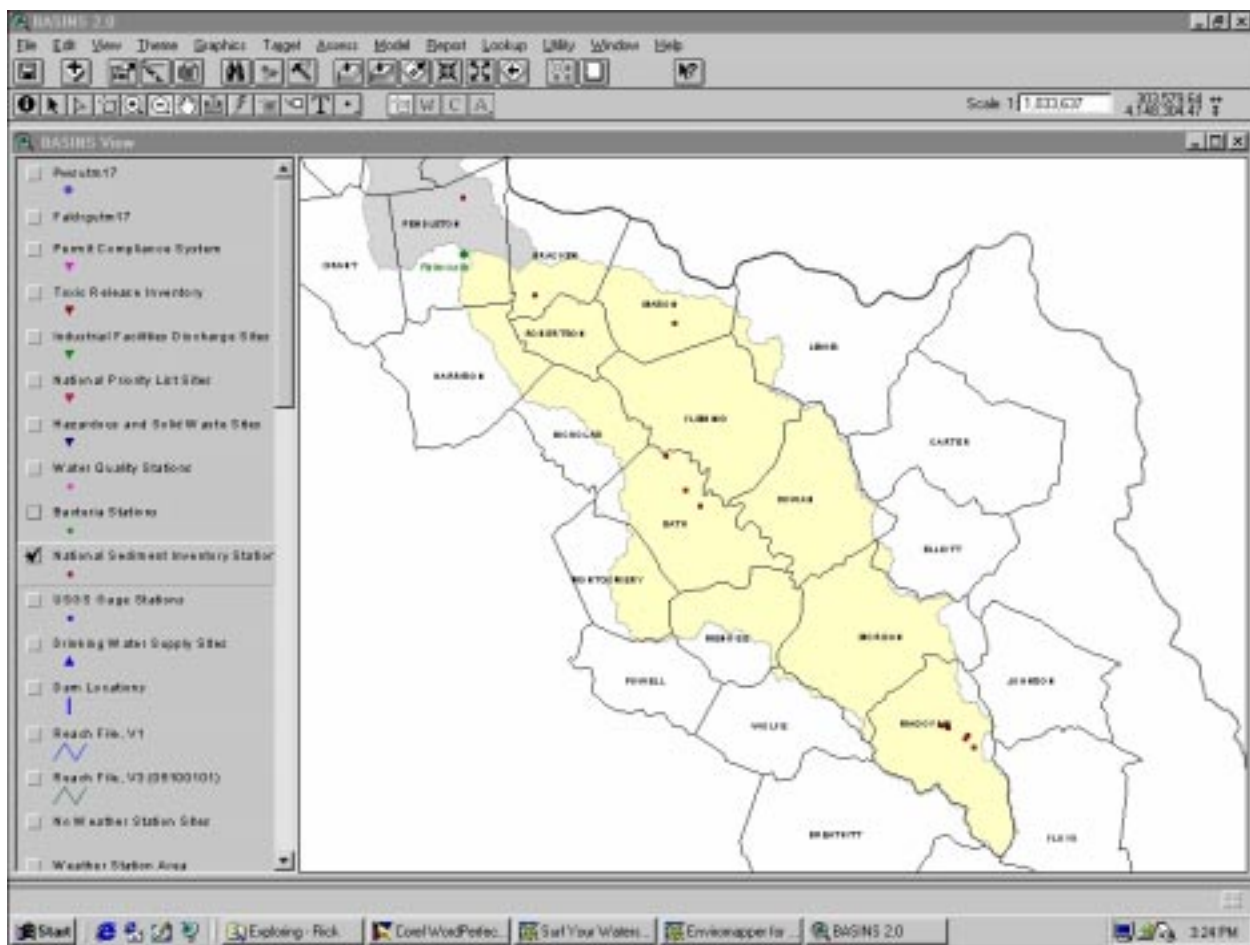


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 7 of 10: National Sediment Inventory monitoring stations).

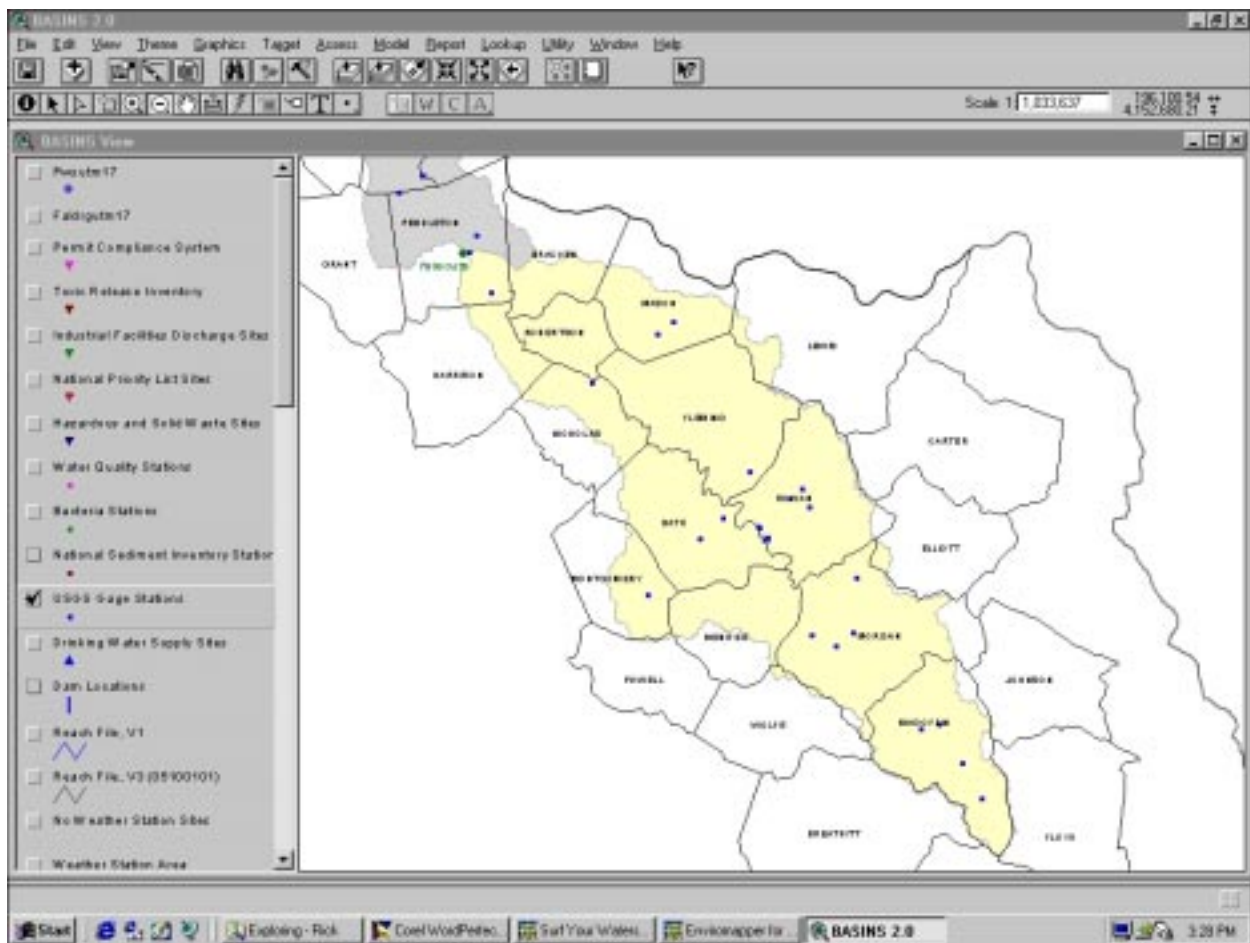


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 8 of 10: USGS stream gage monitoring stations).

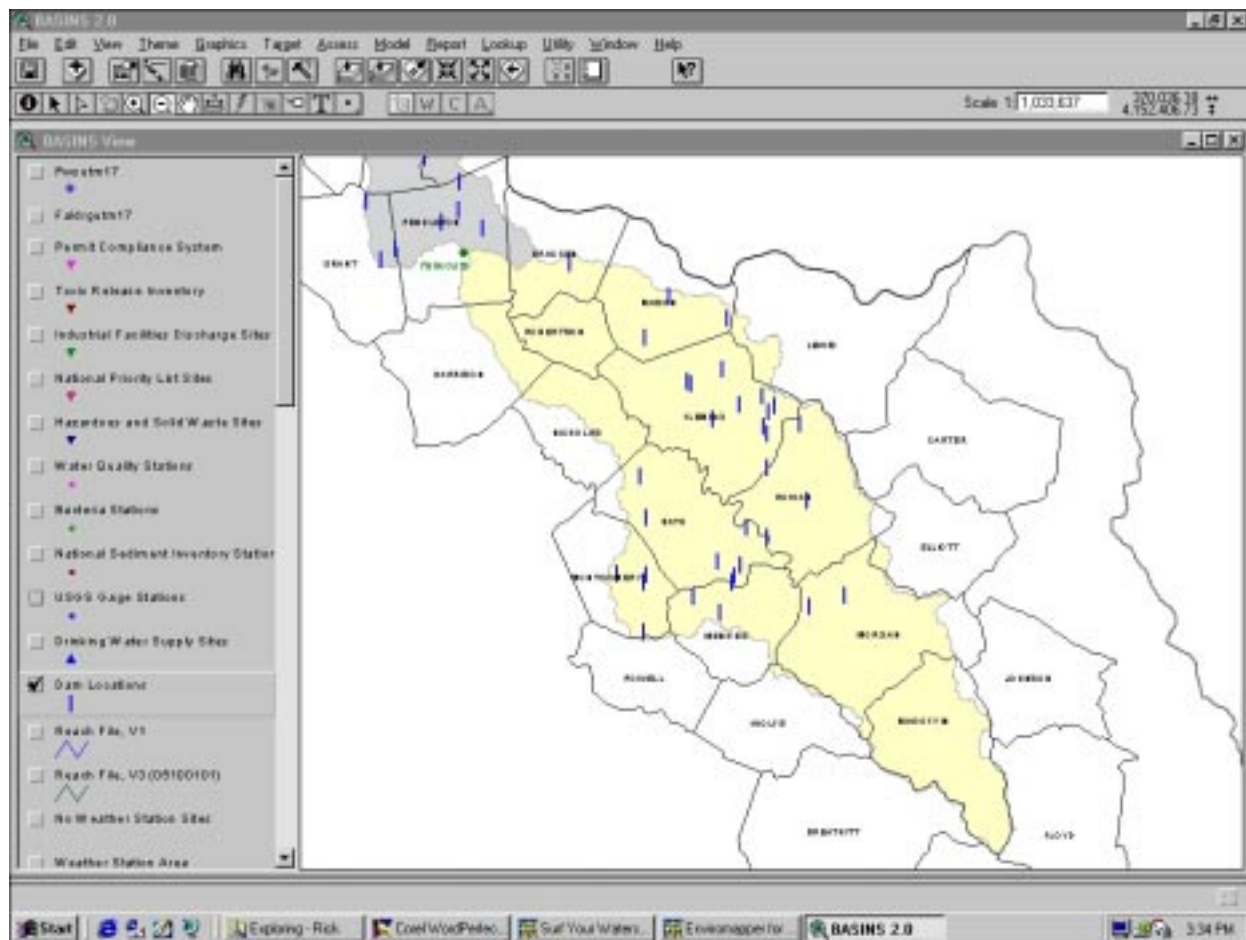


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 9 of 10: Dam sites).

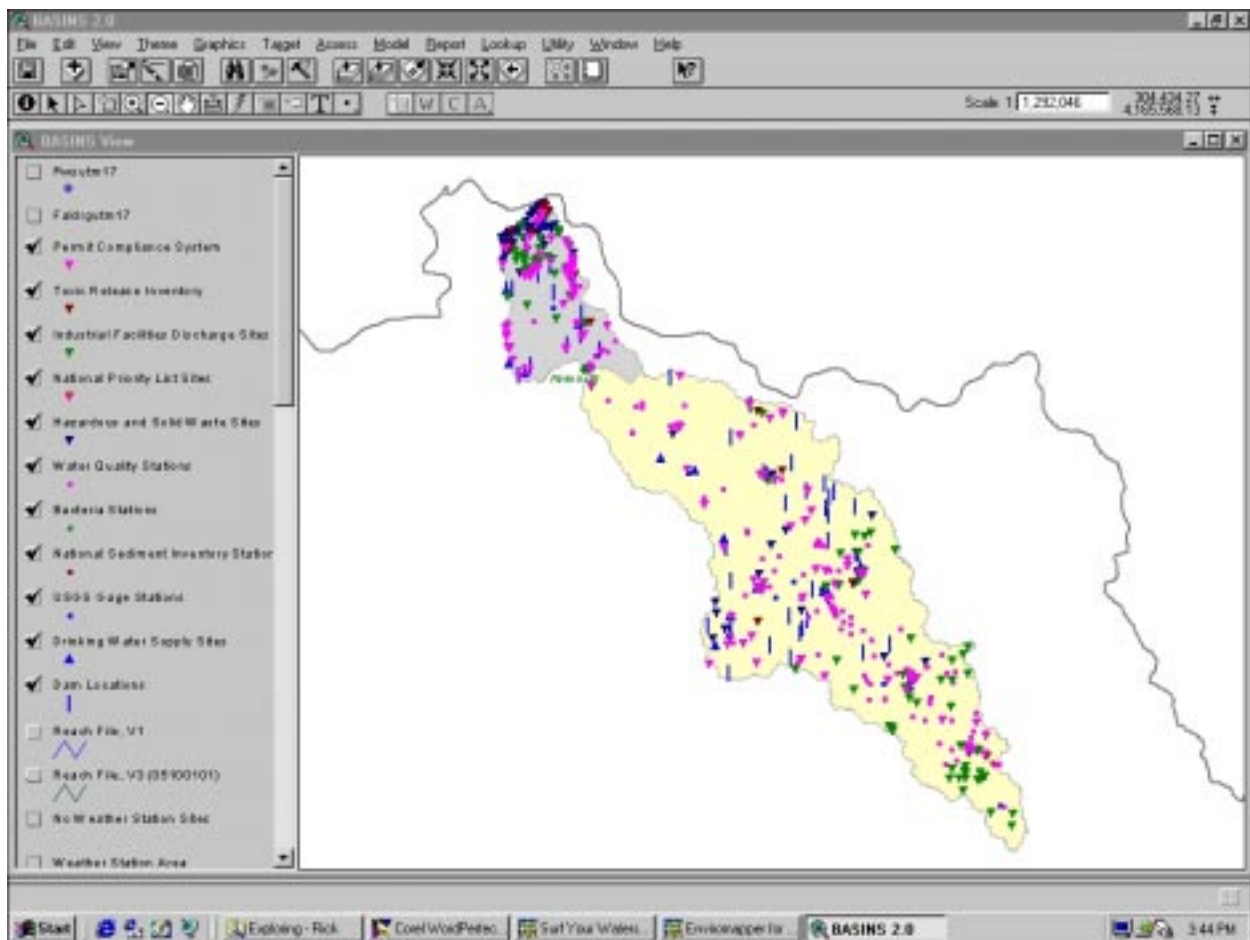


Figure A-15. Thematic data for various point locations in the Licking River Basin (Screen 10 of 10: All available point-location facilities and monitoring sites).

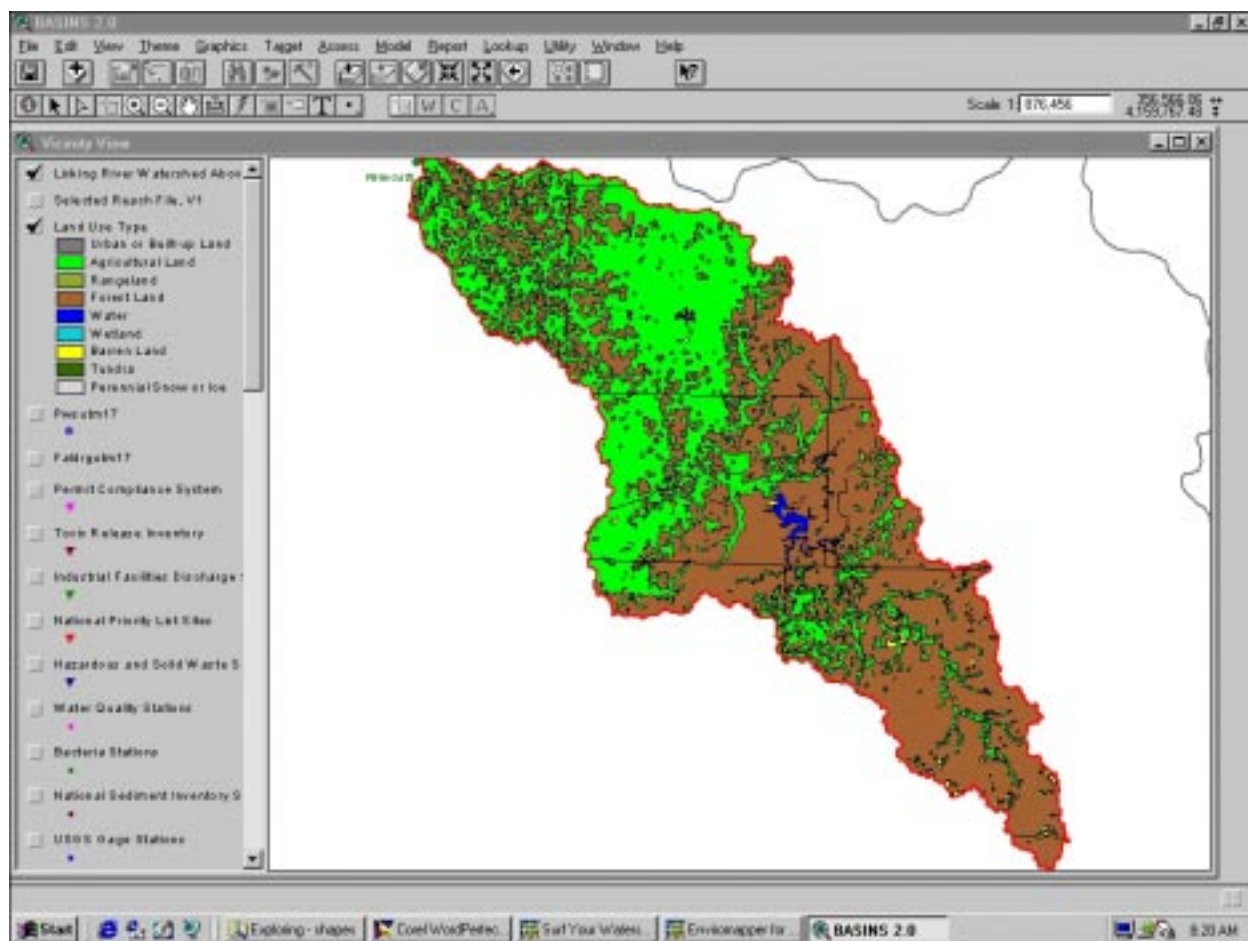


Figure A-16. Map and supporting table of land use distribution in the Licking River Watershed above Falmouth, Kentucky (Screen 1 of 2).

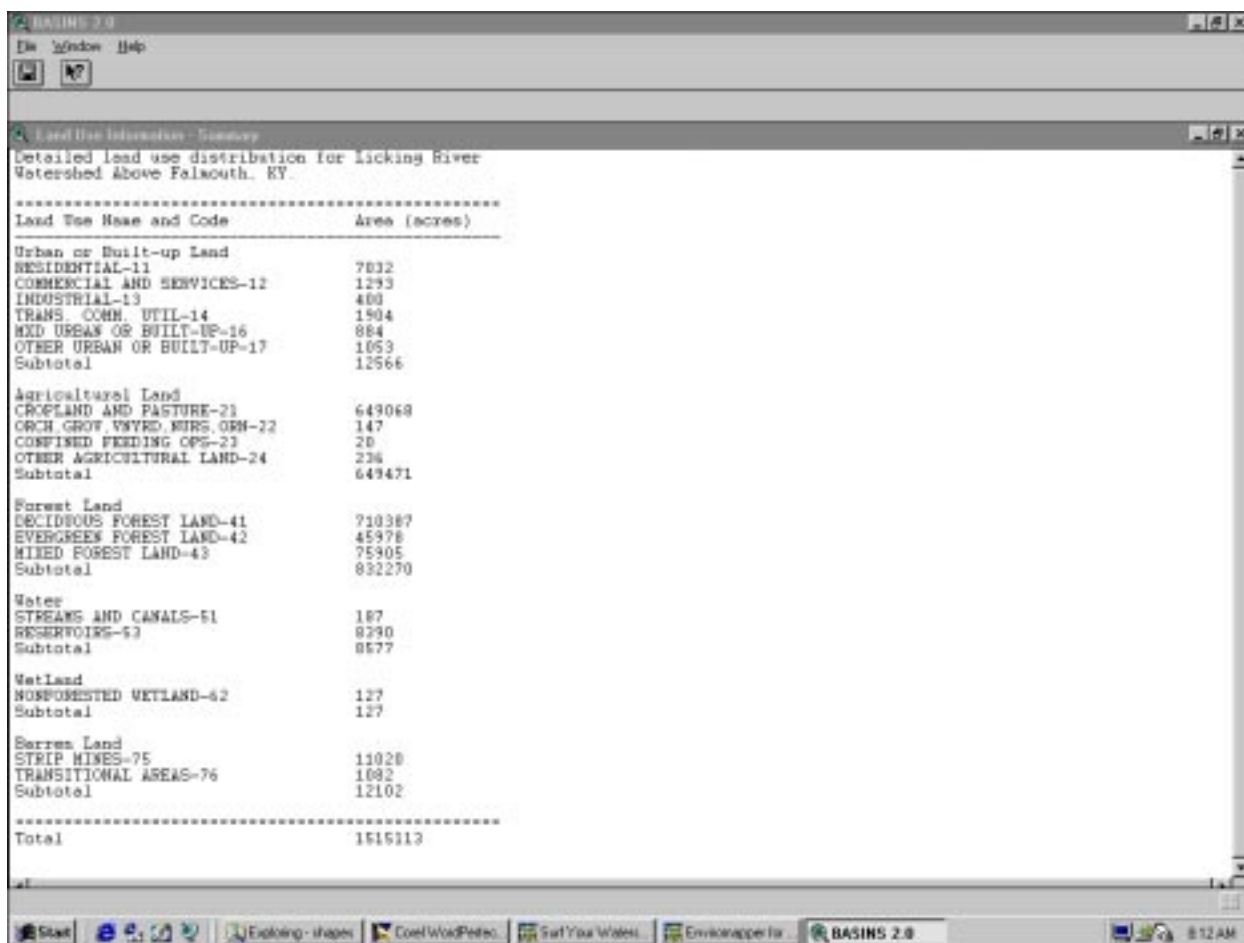


Figure A-16. Map and supporting table of land use distribution in the Licking River Watershed above Falmouth, Kentucky (Screen 2 of 2).

It also became apparent that BASINS was not optimized for performing simple queries on irregularly defined subwatershed areas smaller than a HUC watershed but larger than a municipality or metropolitan urban area. Hence, the other BASINS tools such as Target and Assess were not as useful as they might have been. Because this situation is relevant to the Falmouth subwatershed study, we looked at alternatives within BASINS or ArcView that would allow us to extract the specific water quality and potential contaminant release information we were seeking. Two techniques appear to be suited to this endeavor: data mining and theme table linkage/join/export, both described below.

Data mining was used to gather station-level statistical summaries of water quality data for multiple parameters over a long period of record (1970 to the present, depending on location). The mining process builds dynamic links between the spatial map extent and relational data attribute tables. The water quality theme was activated and the Data Mining icon was pressed, allowing a box to be dragged (using the mouse) to encapsulate the entire subwatershed. A series of tables then filled the screen with water quality attribute tables and lists of tables and parameters, as shown in Figure A-17. By clicking on any parameter in the parameter table, a relational linkage is made with the other tables via highlighting of the appropriate records. Similarly, clicking on a particular water quality station will highlight all related records. This is an especially good way to view the data interactively, but might not be the best approach if the desired endpoint of the evaluation is a subset database of all possible water quality records for the area of interest. It should be noted that only water quality, bacteria, and permitted facility data sets are supported by data mining in BASINS at this time.

Theme table linkage/join/export is arguably the best available method within BASINS for producing all-encompassing views of available data for any particular theme. This approach requires that the inherent relational database linkages be defined properly (see ArcView manual for description of link procedure). The approach was tested for the Falmouth subwatershed using the TRI database. The TRI theme was activated on the view, the *Select Feature* icon was pressed, a box was drawn around the watershed with the left button of the mouse, and the *Open Theme Table* icon was pressed. After reactivating the *BASINS View* screen, the Theme menu was opened to choose the *Select by Theme* option, followed by the *Are Completely Within* option, and then the *Licking River Watershed Above Falmouth* option, which creates a new subset of TRI locations for capturing the water release data. The order of the latter two entries should be reversed if the desired options are not visible.

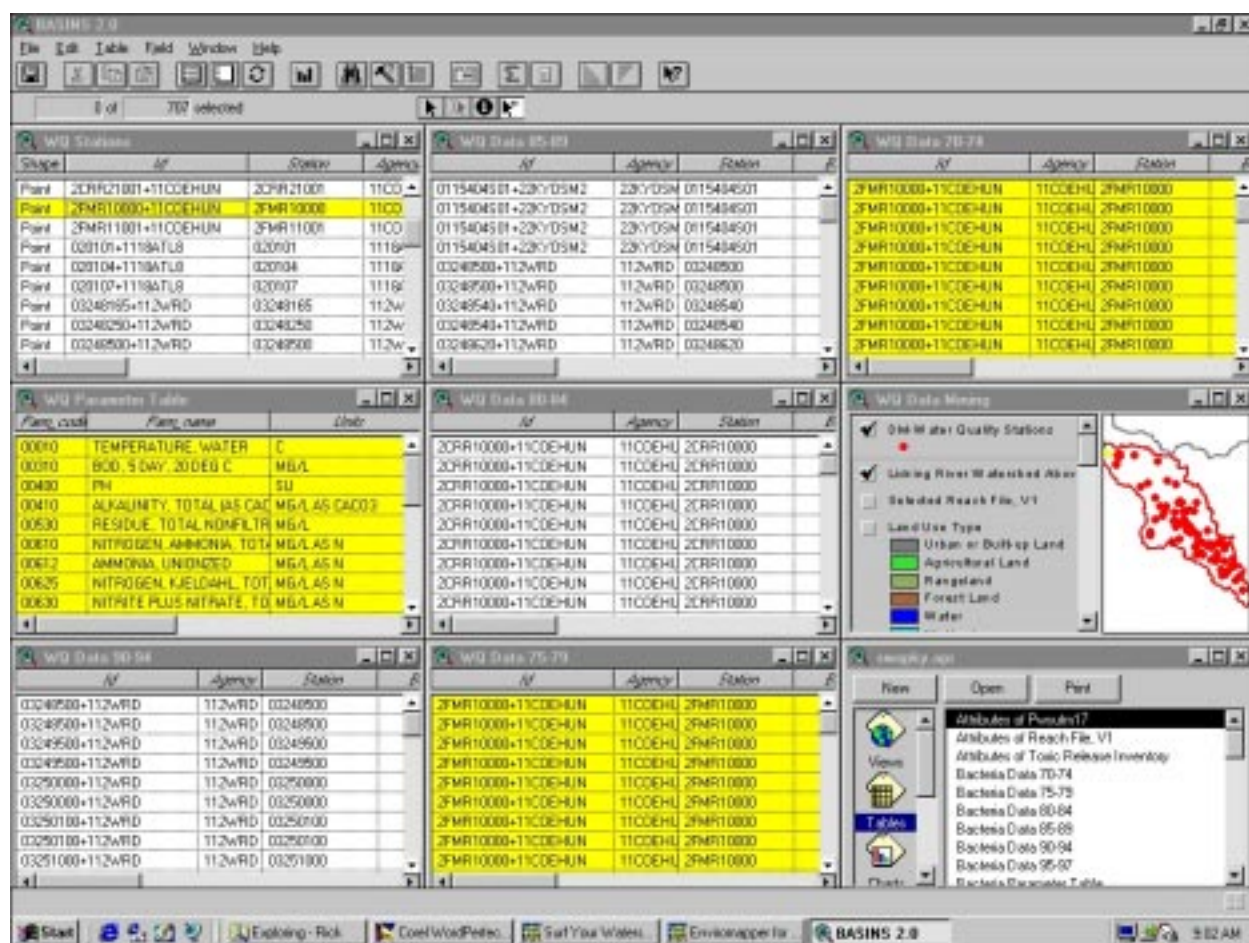
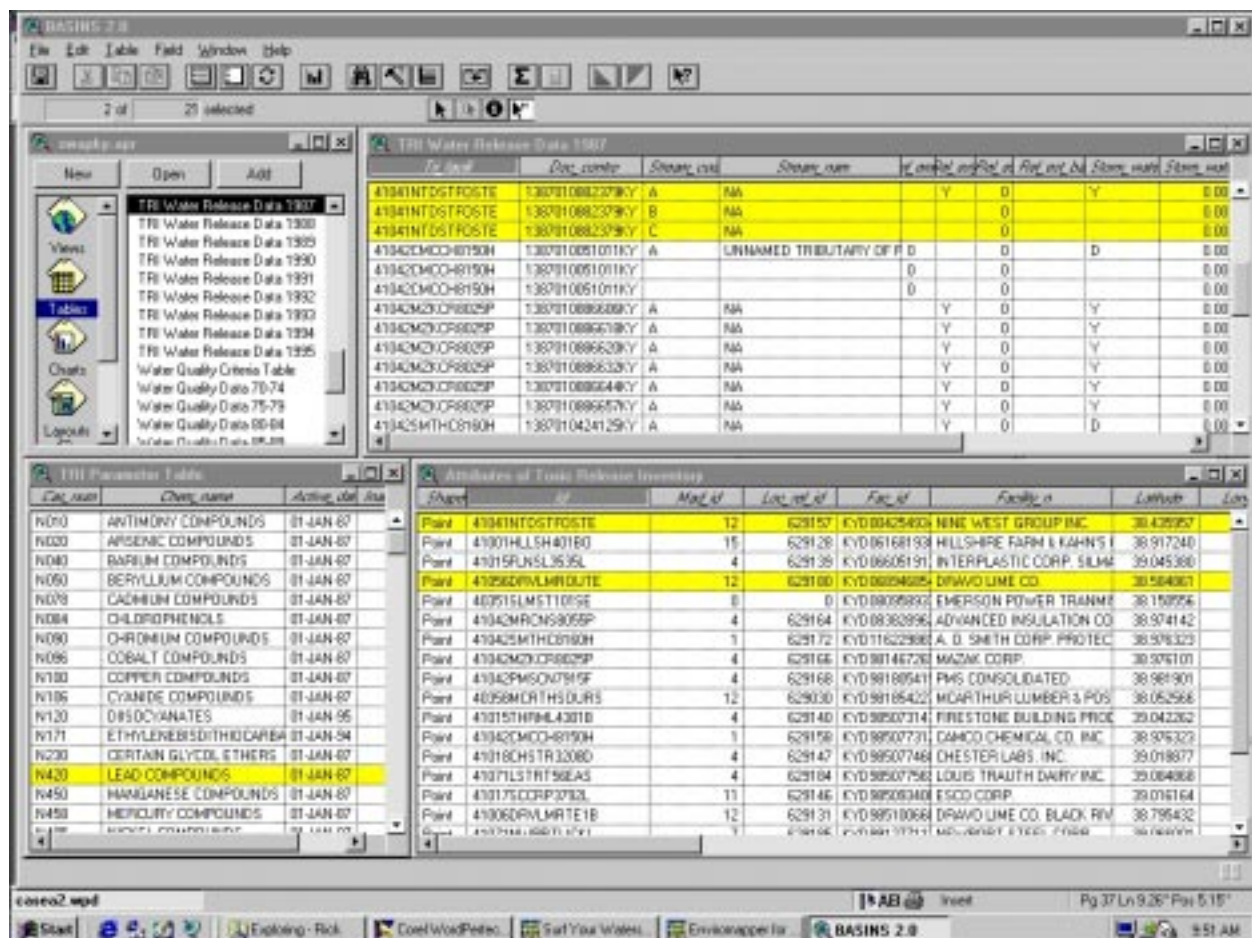


Figure A-17. Use of Data Mining in BASINS to view water quality parameters and attributes for the Licking River Watershed above Falmouth, KY.



Next, we clicked on the *Tables* icon within the Project window which brought up a list of available .dbf data files to query. Tables for *Attributes of TRI*, *TRI Parameter Table*, and *TRI Water Release Data* for the years 1987 through 1995 were activated in separate windows by double-clicking on the appropriate table within the list.

A relational link was established by activating the TRI 1987 data window and highlighting the *Tri_facili* item, then activating the *Attributes of TRI* window and highlighting the matching *Id* item, selecting the Table menu, and then choosing *Link*. This operation highlighted all 1987 TRI water records associated with the four TRI sites that were identified as being within the subwatershed, as shown in Figure A-18. Then, the TRI 1987 data window was activated and, with the appropriate records highlighted, the File menu was activated where the Export option was chosen followed by the *Delimited File* option, and the output file was given a connotative name of *Tri_fal87.txt*. This comma-delimited file was imported into Microsoft Excel (or any other standard spreadsheet software) for viewing, printing, and manipulation. The entire procedure was then repeated for each TRI year table. Note that the TRI parameter table should also be exported so the user can later correlate a contaminant's identification number with its descriptive name.

From the aforementioned outputs it was possible to develop an exhaustive list of all possible TRI contaminants that might have impacted the watershed during that period of record. This is the very crux of a thorough SWAP watershed evaluation, i.e., to determine all potential substances that might endanger a public water intake, even if there are upstream safeguards such as dams that could theoretically slow or impede downstream contamination. This approach could be applied to all of the different national contaminant and water monitoring data sets and also to imported data sets prepared by state or local entities (e.g., LUST/RUST, PWS, sanitary surveys, other hazardous waste).

Modeling Options

As described in the body of this report there are innumerable public-domain hydrologic models available to the user. The BASINS Model menu allows direct access to three built-in hydrologic models: the Non-point Source Model (NPSM), TOXIRoute, and QUAL2E. NPSM simulates the fate and transport of water quality constituents in surface water bodies, whereas TOXIRoute and QUAL2E are simple, one-dimensional steady-state models useful where input data is limited.

The Non-point Source Model is a bit of a misnomer in that it also allows point-source inputs for PCS sites; it operates on a year-by-year modeling basis. The NPSM is capable of simulating nonpoint source runoff and associated pollutant loadings, accounting for point source discharges, and performing flow and water quality routing through connected stream reaches and well-mixed reservoirs (see BASINS 2.0 User's Manual, Section 10). This model is potentially useful for SWAP evaluation of a watershed system such as the Licking River.

TOXIRoute calculates final and average concentrations of general water quality constituents based on dilution and first-order-decay algorithms (see BASINS 2.0 User's Manual, Section 9.2). Examples of information that can be generated from TOXIRoute are shown in Figure A-19. This model is also potentially useful for SWAP evaluation of watershed systems.

QUAL2E can simulate nutrient loading, oxygen demand, temperature, and algae, among other substances (see BASINS 2.0 User's Manual, Section 9.1). This will probably be the least useful of the three models for SWAP applications. At the time of this evaluation, QUAL2E would not run on WinNT-driven PCs because of formatting incompatibilities within the model.

```

LEAD, DISSOLVED (AS PB)
"caseq", "name", "length", "Flow", "avg. conc", "final conc", "child final conc"
05100101001, "LICKING R", 40394.535, 121.898, 0.000, 0.000, 0.000
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05100101006, "LICKING R", 8368.589, 117.275, 0.000, 0.000, 0.000
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05100101008, "LICKING R", 11426.342, 74.824, 0.000, 0.000, 0.000
05100101009, "BEAVER CR", 24622.963, 2.155, 0.000, 0.000, 0.000
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05100101011, "LICKING R", 26554.176, 65.643, 0.000, 0.000, 0.000
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```

Figure A-19. Comma-demited ASCII output file, an example of the kind of information that can be generated from the TOXIRoute model in BASINS.

Appendix B

Case Study B: Conducting a Source Water Assessment Plan GIS Evaluation for a Ground Water System in Lebanon, Ohio

The following narrative describes the stepwise procedure employed by the LMES GIS Staff in Las Vegas, Nevada, to assess a hypothetical source-water protection area for a ground water system. Due to the ever increasing use of the Internet by federal, state, and local agencies, Source Water Assessment Program (SWAP) source material and GIS data are becoming more available and easier to use. The amount and quality of GIS data and other source materials available on the Internet are continually increasing and improving. Thus, the Internet resources investigated during this case study should not be considered all inclusive. The SWAP report discusses in detail many of the concepts and data sources used in the following sections.

Available SWAP Information

An initial starting point to build a SWAP GIS evaluation is to search the Internet for available information regarding existing source water protection area plans that has been prepared for SWAP compliance by various state groups. The USEPA Office of Water has put together an Internet website of state source water protection contacts (<http://www.epa.gov/OGWDW/source/contacts.html>). One contact is the SWAP program for Ohio under the direction of the Division of Drinking and Ground Waters within the Ohio Environmental Protection Agency (<http://www.epa.ohio.gov/ddagw/pdu/swap.html>). The Ohio SWAP site outlines the goals and current activities underway for the program. It is also a good place to look for relevant GIS data within the state.

Identifying Available Internet Background Data, Site, and Mapping Information

There are several Internet web sites that provide background, site, and mapping information on a particular geographic area of interest. The EPA and USGS web sites provide a wide variety of ground water information and interactive mapping capabilities for a specific area of interest. The USGS web site (<http://water.usgs.gov>) maintains various web pages with ground water reports, modeling, mapping, and state information. For this demonstration we used the interactive mapping tools at the EPA "Surf Your Watershed" web site (<http://www.epa.gov/surf2/>) because it has broader access to data that would help to delineate a source water protection area. This site is a

repository for general information on a particular geographic area, be it a region, state, county, watershed, or other delineation. After accessing the EPA site, we clicked on the *Locate Your Watershed* icon which took us to the “Locate Your Watershed” page. Then we entered Ohio in the *QuickNAV* box which brought up a list of Ohio geographic features. We clicked the *Little Miami Watershed* (USGS hydrologic unit code, HUC 05090202). This took us to the “Environmental Profile” page which provides links to general environmental information and web sites for the Little Miami Watershed.

In the “Environmental Profile” page we then migrated to the EPA “Enviromapper” interactive mapping tool by selecting the underlined link *Enviromapper for Watersheds* (Figure B-1) (Note: Enviromapper can also be accessed independently via (<http://maps.epa.gov/enviro/html/mod/enviromapper/index.html>)). After zooming to the vicinity of Lebanon the following options were turned on: Discharges to water, Superfund sites, Hazardous waste handlers, Toxic releases, Air releases, Storet points, Streets, and Streams (Figure B-2). As many as 20 generalized data layers associated with the Index of Watershed Indicators (IWI) are available for viewing within the frame. These data layers provide broad categorical descriptions of themes such as *Chemicals in Ground Waters*, which are useful primarily for qualitative evaluations or for creating a general perspective of your ground water site.

At this point we can physically identify any feature displayed in the map frame. For example, depress the radio button next to the *Toxic Releases* feature, click on the *i* button, and click on a toxic release site. The name of the TRI site of interest will be displayed on the right side of the frame. For example we clicked on a TRI site South of Lebanon (Figure B-3). We then clicked on the name of the TRI site and a new report window opened with data from the EPA Envirofacts database (Figures B-4a through B-4d). The Envirofacts database provides information such as name, address, chemicals transferred to other sites, and chemicals released to air, via underground injection, land surfaces, and surface water for the facility you selected.

Now that we have identified the Toxic Release site of interest, we can create a hard copy of the map by clicking on the *Map this facility* button. We have two options at this point, *Map with Query Mapper* (maps facility and the surrounding landuse/landcover or demographic information) and *Map with SiteInfo* (maps all facilities and produces a cumulative report on demographic and safe drinking water information). Either option will allow you to set up your map with radius circles, text report data, optional themes, and output formats. The map request is then generated and an e-mail message is returned to you when the map is completed. By clicking on the direct URL path in the e-mail, the map is ready for download. An example of the map generated around the Lucas Sumitomo Brakes TRI site is shown in Figure B-5.

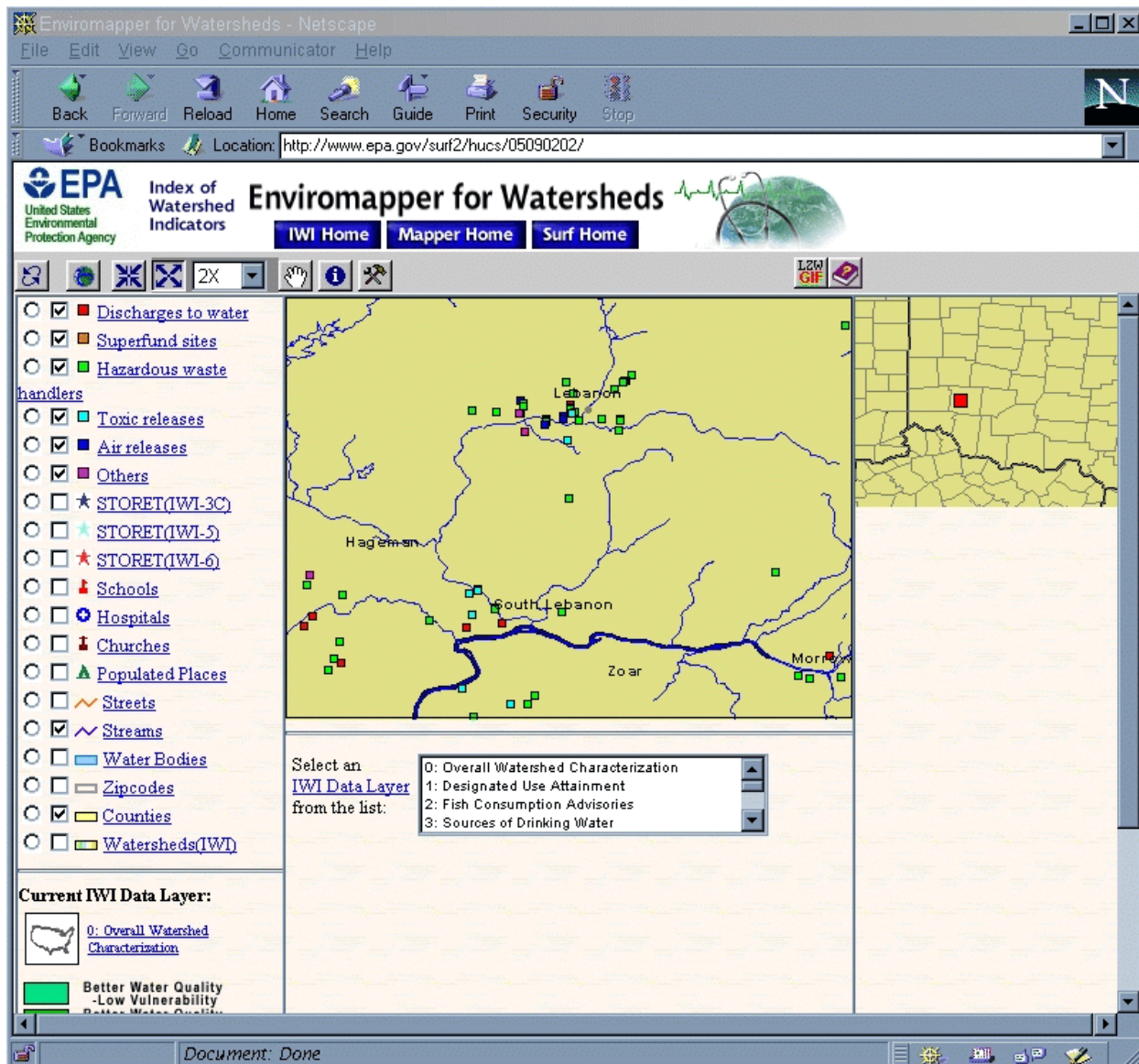


Figure B-2. EPA Enviromapper for Watersheds screen showing data available for the area around Lebanon, Ohio from options checked.

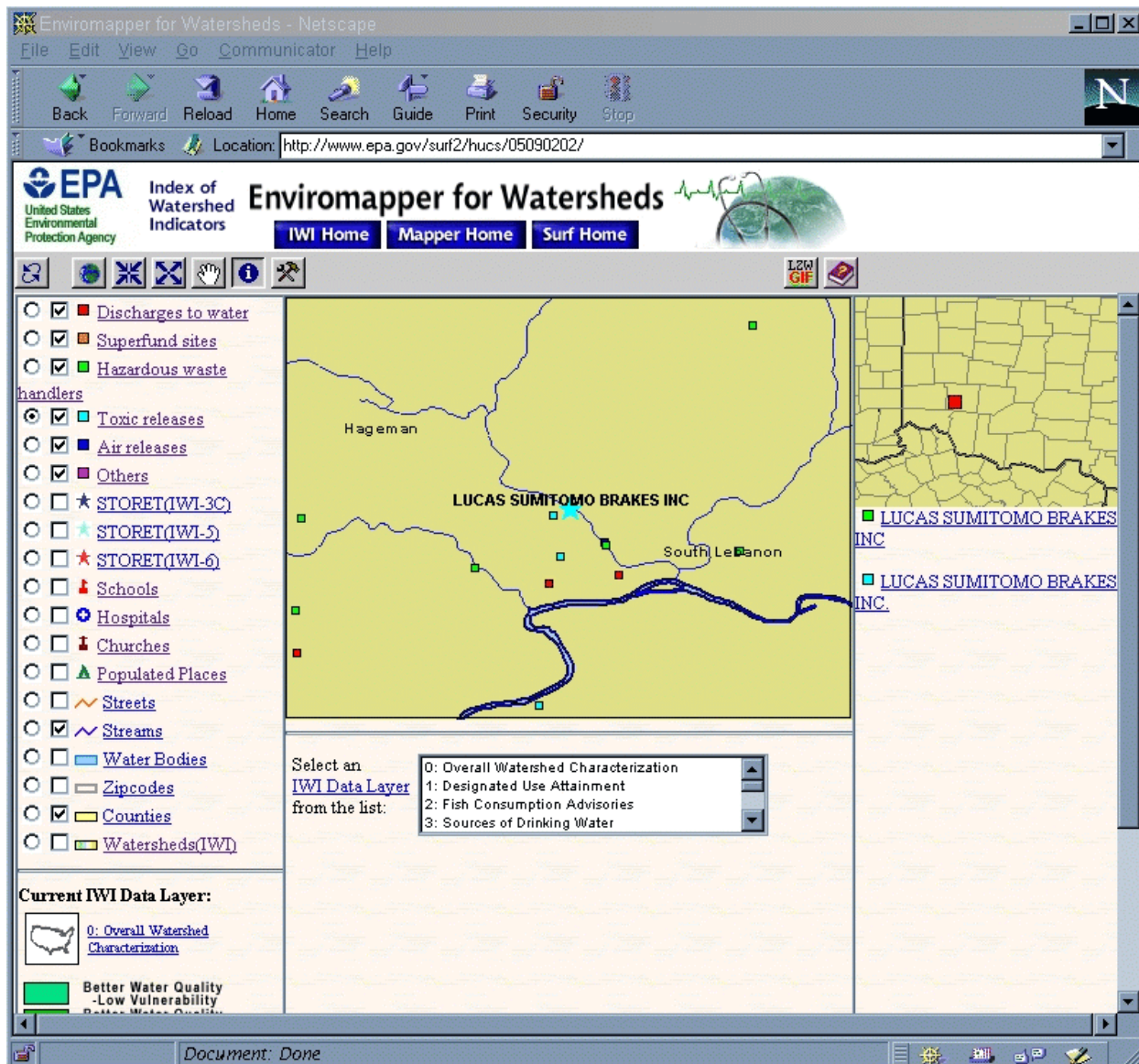


Figure B-3. The EPA Enviromapper screen showing a toxic release inventory (TRI) site south of Lebanon, Ohio.

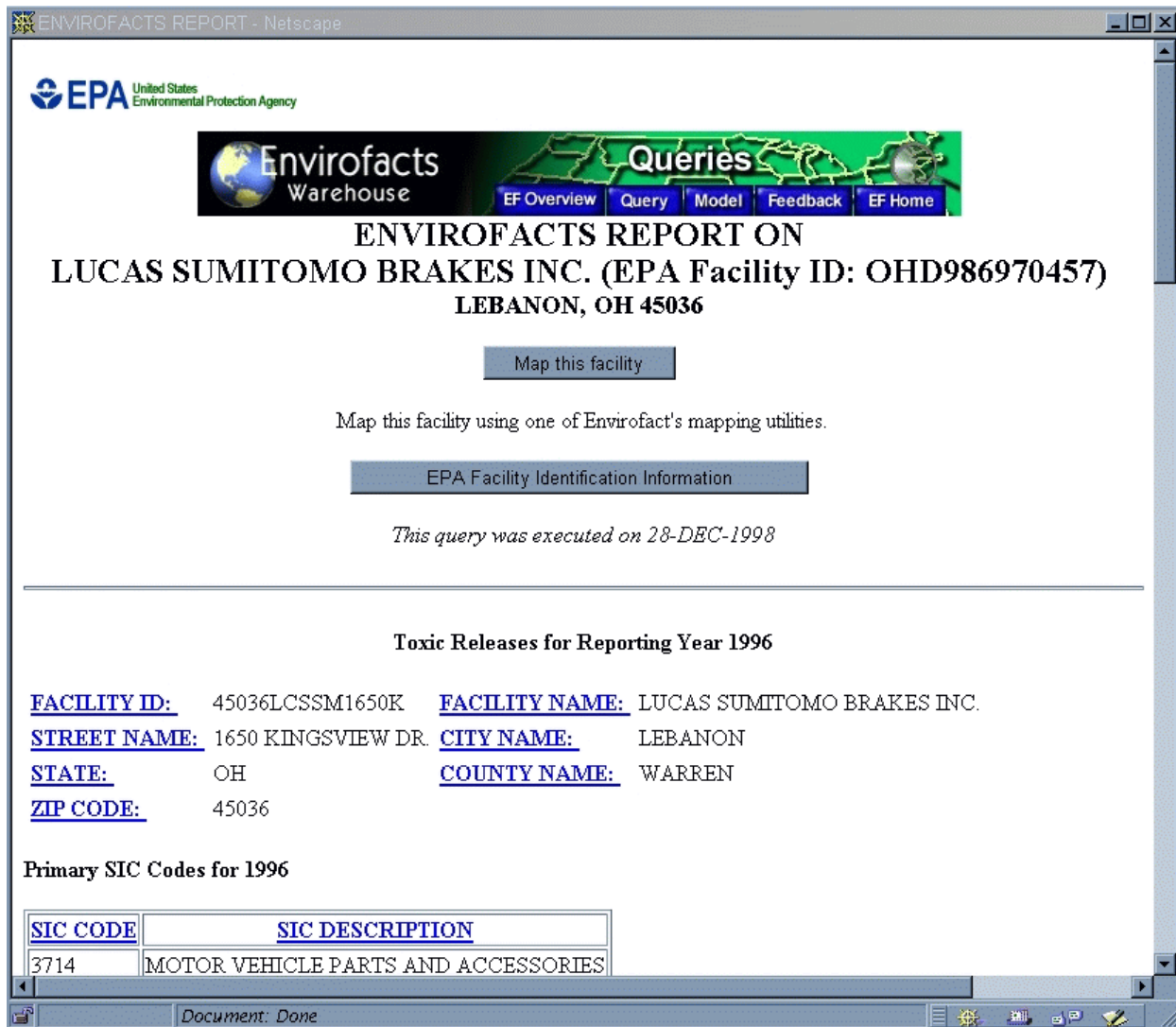


Figure B-4a. Web page showing data on a TRI site from the EPA Envirofacts data base.

Chemicals Released to the Land Surface

There was no data of this type reported for this facility.

Chemicals Released to Surface Water

There was no data of this type reported for this facility.

Additional Information can be obtained from the Toxics Release Inventory System [TRIS](#) [Query](#)

The Environmental Defense Fund's (EDF) Chemical Scorecard has on-line environmental information regarding this [LUCAS](#) facility's reported TRI releases. This information resource is not maintained, managed, or owned by the Environmental Protection Agency (EPA) or the Envirofacts Support Team. Neither the EPA nor the Envirofacts Support Team is responsible for their content or site operation. The Envirofacts Warehouse provides this reference only as a convenience to our Internet users.

AIRS / AFS Information

<u>PLANT NAME:</u>	LUCAS SUMITOMO BRAKES	<u>COMPLIANCE SYSTEM PLANT ID:</u>	00017
<u>AFS PLANT ID:</u>		<u>NATIONAL EMISSIONS DATA</u>	
<u>STREET NAME:</u>	1650 KINGSVIEW DRIVE	<u>SYSTEM PLANT ID:</u>	
<u>CITY NAME:</u>	LEBANON	<u>LATITUDE:</u>	0
<u>STATE:</u>	OH	<u>LONGITUDE:</u>	0
<u>ZIP CODE:</u>	45036	<u>DUNS NUMBER:</u>	
<u>COUNTY NAME:</u>	WARREN	<u>PRINCIPAL PRODUCT:</u>	
<u>EMERGENCY</u>		<u>INVENTORY YEAR:</u>	
<u>CONTROL:</u>		<u>CLASS CODE:</u>	UNKNOWN POLLUTANT CLASSIFICATION
<u>COMPLIANCE STATUS:</u>	UNKNOWN COMPLIANCE STATUS		

The current AIRS/AFS database does not have any pollutant data for this facility.

Figure B-4c. Web page showing data on a TRI site from the EPA Envirofacts data base.

[COUNTY NAME:](#) WARREN [INVENTORY YEAR:](#)
[EMERGENCY CONTROL:](#) [CLASS CODE:](#) UNKNOWN POLLUTANT CLASSIFICATION
[COMPLIANCE STATUS:](#) UNKNOWN COMPLIANCE STATUS

The current AIRS/AFS database does not have any pollutant data for this facility.
 Additional information can be obtained from the Air Facility Subsystem ([AIRS](#)) Query Form.

RCRIS Information

[HANDLER ID:](#) OHD986970457 [HANDLER NAME:](#) LUCAS SUMITOMO BRAKES INC
[STREET NAME:](#) 1650 KINGSVIEW DR [CITY NAME:](#) LEBANON
[STATE:](#) OH [ZIP CODE:](#) 45036
[COUNTY NAME:](#) WARREN

Standard Industrial Classification:

SIC CODE	SIC DESCRIPTION
3714	

Handler/Facility Classification:

HANDLER TYPE	LAND DISPOSAL	INCINERATOR	BOILER AND/OR INDUSTRIAL FURNACE	STORAGE AND TREATMENT
LARGE QTY GENERATOR				

Additional Information can be obtained from Resource Conservation and Recovery Information System [RCRIS](#) Query.

Figure B-4d. Web page showing data on a TRI site from the EPA Envirofacts data base.

Determine Extent of the Ground Water Protection Area

The first step in determining the extent of the ground water protection area is to delineate the area around the public water supply well field (or a portion of the area) that contributes ground water to the wells. After examining draft source water evaluation reports for several states (e.g., Ohio, Arizona, Rhode Island), we concluded that the extent of ground water protection area is based on aquifer-by-aquifer hydrogeologic parameters. These parameters include geology, aquifer type or sensitivity, porosity, flow direction, gradient, soil type, time-of-travel calculations, and distance to pollution sources. This information provides a hydrogeologic database that can be used to help determine the recharge area or protection area around public water system wells. We conclude that state or local experts would be called in at this point to assist with the delineation process.

One approach to begin the delineation process of a ground water protection area is to check out state programs such as the Wellhead Protection Program (WHPP) which have delineated at least an initial Wellhead Protection Area around public water supply intakes. Under WHPP the supplier or the municipality must inventory the Wellhead Protection Area for potential sources of contamination and develop a plan to protect ground water. Ohio's Wellhead Protection Program web site is located at (<http://www.epa.ohio.gov/ddagw/pdu/wellhead.html>) and is a good starting point for background information on different WHPP state activities. A state GIS database that might be of interest at this level is the Ground Water Potential Pollution Maps (DRASTIC) that are currently being converted into digital form by the Ohio Department of Natural Resources (see http://www.epa.ohio.gov/ddagw/pdu/gis_covs.html).

For visual purposes throughout the rest of this GIS evaluation we will display data within a minimum 2-mile radius around the public water supply well for Lebanon.

Collecting Specific Ground Water Information - Federal Data

As noted earlier, there are several Internet mapping tools available from EPA and USGS that at a minimum provide geographic perspective of an area of interest as well as federal regulated sites (TRI, PCS, and NPL). These mapping tools are fast and powerful which allows a user to get up and running with nothing more than a PC and an Internet connection. The EPA and USGS mapping tools do have their limits. If you want to customize the data or output, add new state or local data, or run hydrologic models, you must move to a more robust GIS.

It appears the most cost-effective method of constructing a simple-yet-robust GIS base for source water evaluation is through a combination of the ArcView and BASINS software packages. Although there are other proprietary software packages similar to ArcView that perform comparably, the public-domain BASINS 2.0 software was designed by EPA to run specifically on ArcView 3.0a; it is downloadable free of charge from the Internet. Following is a discussion of our investigation with the ArcView/BASINS tools.

ArcView 3.0a proprietary software was purchased from ESRI and can be installed on a PC driven by WinNT, Win95, or Win98. For this demonstration we used ArcView/BASINS driven by WinNT. The BASINS 2.0 public-domain software was downloaded from (www.epa.gov/OST/BASINS) and the setup.exe program was run to install it on the PC (see BASINS 2.0 User's Manual, Section 4.1). The BASINS data sets (core, dem, and rf3) are bundled into USGS HUC watersheds data packets and are downloaded by HUC watershed. There is a front end map browser at the BASINS web site which helps identify the watershed(s) of interest.

From the BASINS website, we downloaded the core, dem, and rf3 self-executable zip-archive (.exe) data packets for the Little Miami Watershed (HUC 05090202) into the basins\data subdirectory and then extracted their component files into the basins\data\05090202 subdirectory (see BASINS 2.0 User's Manual, Section 4.2). Next, we clicked on the Start button in Windows and, under Programs, selected Basins, and then Data Extraction. Each .exe file was selected sequentially for extraction, first for the core data, then for the dem, and then rf3. The projection parameters for Little Miami Watershed were set to UTM Zone 17 for the sake of this case study. In order to be used within BASINS, the dem and rf3 shapefiles were imported so they could be visualized and accessed in the watershed view (see BASINS 2.0 User's Manual, Section 7.2).

Two maps were generated using ArcView/BASINS. These maps were generated to illustrate the initial mapping capabilities of ArcView/BASINS and to compare the basic data sets between BASINS and the "Enviromapper" map (Figure B-5). Figure B-6 shows a locational map of the Little Miami Watershed with county boundaries and major streams. We generated a map (Figure B-7) showing the Little Miami Watershed federal data in approximate scale to the "Enviromapper" map, Figure B-5. Comparing Figure B-5 to B-7, we see that the BASINS Drinking Water Supply sites are missing in the 2-mile radius while the "Enviromapper" map identifies a PWS site as "Lebanon, City of Plant 2" in the same area. The PWS data set in BASINS seems to be incomplete with respect to the "Enviromapper" PWS sites. To verify missing or incomplete PWS data from the BASINS Little Miami data set, we identified and added the Ohio Public Water Supply location data into BASINS (see below).

Identifying and Collecting Specific Ground Water Information - State Data

We depart from the prepackaged data sets provided from BASINS and would like to incorporate specific Ohio state-generated GIS data. This section discusses ways to add state and locally generated data into the GIS. As a test of availability and to demonstrate adding state data to the GIS, we chose to examine four state data sets: Ohio Public Water Supply locations, Little Miami Aquifer boundary, Master Sites List, and Registered Underground Storage Tanks.

Little Miami Watershed, Ohio

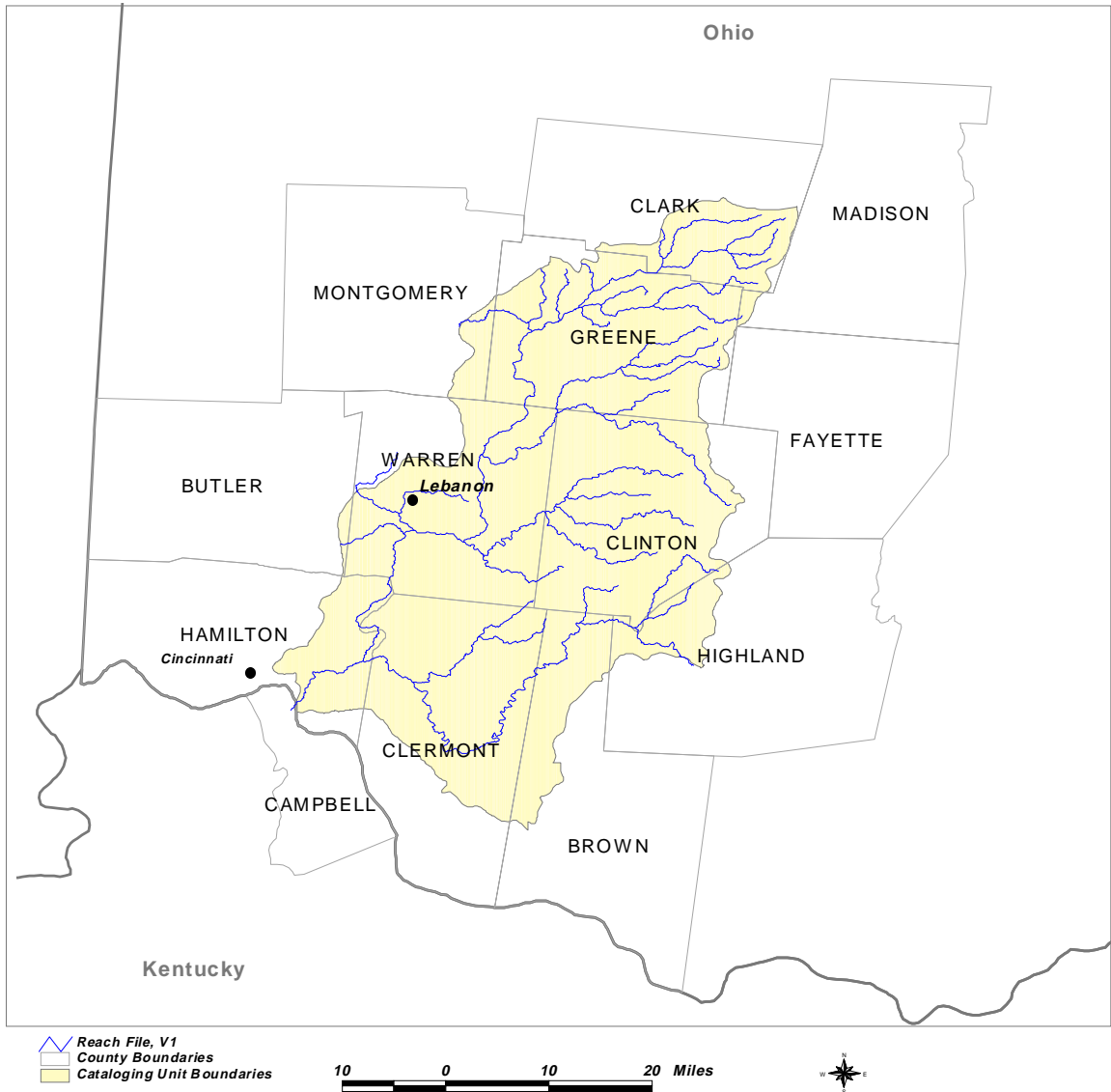


Figure B-6. Map showing the location of the Little Miami Watershed with county boundaries and major streams.

Federally Regulated Sites - Lebanon, Ohio

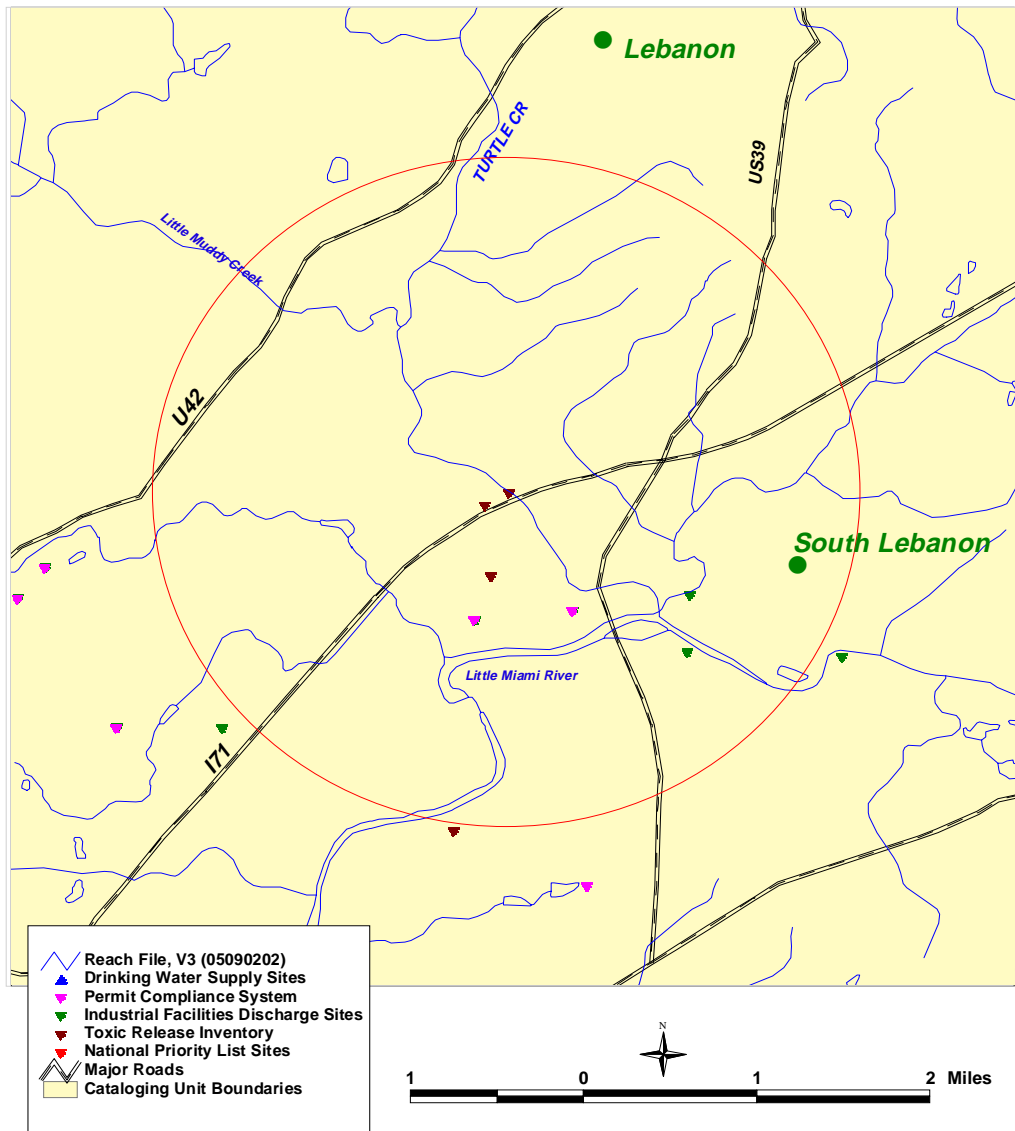


Figure B-7. Map showing the federally regulated sites and a 2-mile radius south of Lebanon, Ohio.

Many state agencies in Ohio have GIS or GIS-related data sets that may help in delineating source water protection area for a ground water system. A good starting point to assess potential GIS data in Ohio is the Ohio Geographically Referenced Information Program (OGRIP) web site (<http://www.state.oh.us/das/dcs/ogrip/>). In addition to several federal sites, OGRIP provides Internet links and contacts for geospatial data sets within Ohio state agencies. OGRIP is also working to coordinate and add Ohio local government GIS data contacts into the state site.

Through the OGRIP site we linked to the Ohio EPA Drinking and Ground Waters Division (http://www.epa.ohio.gov/ddagw/pdu/gg_home.html) and identified available GIS data sets. We requested the Ohio Public Water System (PWS) point GIS data set and the Little Miami aquifer data set. We received the PWS location point file but the aquifer data set was being redigitized, although maps of Ohio's Sole Source Aquifer Boundaries are available by county within their web site. For the PWS points, the Ohio EPA was able to provide two options for the data set; it is available in dBASE (.dbf) format and in Arc/Info export (.e00) format. ArcView supplies an import translator that will convert the Arc/Info export file into an Arc/Info coverage, which is readable by ArcView. We used the ArcView import tool to read in the PWS locations. Figure B-8 shows Ohio PWS locations.

Once again through the OGRIP site, we identified the Master Sites List (MSL) database developed by the Ohio EPA Division of Emergency and Remedial Response (DERR). This list is comprised of sites in Ohio where there is evidence of, or it is suspected that, waste management has resulted in the contamination of air, water, or soil and there is a confirmed potential threat to human health or the environment, especially public water sources (for more information see <http://www.epa.ohio.gov/derr/cres/msl/msl.html>). The DERR has posted county maps of MSL locations and attributes at this web site. These county maps appear to have been generated by ArcView (Figure B-9a is an example of the county maps). Addresses of the MSL sites are provided along with the county maps (Figure B-9b). We did not request the MSL point locations from the DERR for Warren County but chose to demonstrate the ability to screen digitize the points directly into the ArcView/BASINS GIS (see below). ArcView software provides the ability to geocode data sets. This means you can match address files with street or zip code data sets to create ArcView shape files (see ArcView manual for more information).

We requested the Little Miami aquifer boundary file from the Ohio EPA office but they are in the process of redigitizing all of Ohio's aquifers. Instead of waiting for the finished product to be available, we decided to digitize the Little Miami Aquifer into the ArcView/BASINS GIS.

Federally Regulated and PWS Sites - Lebanon, Ohio

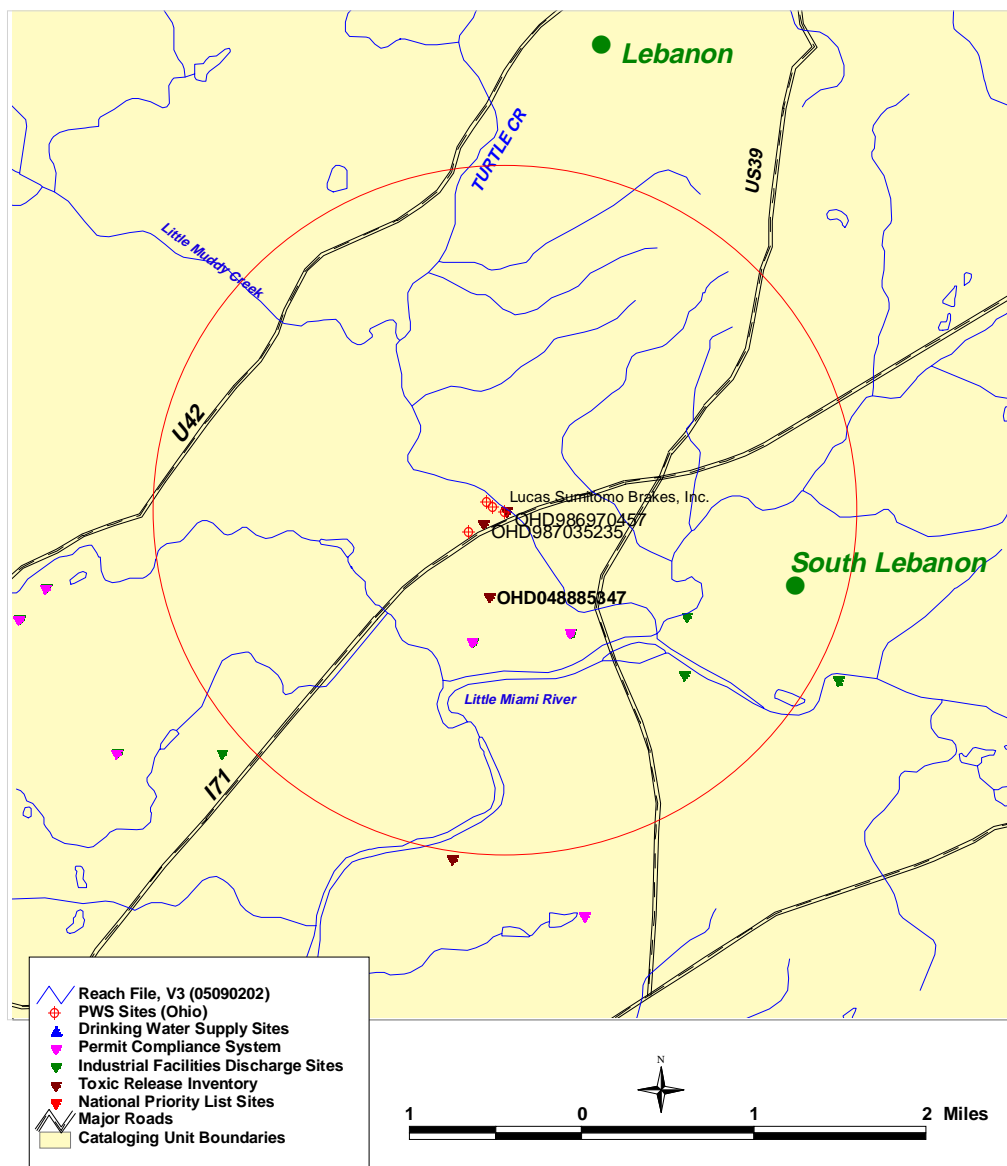


Figure B-8. Map showing federally regulated sites, TRI Sites and identifier, and public water system sites south of Lebanon, Ohio.

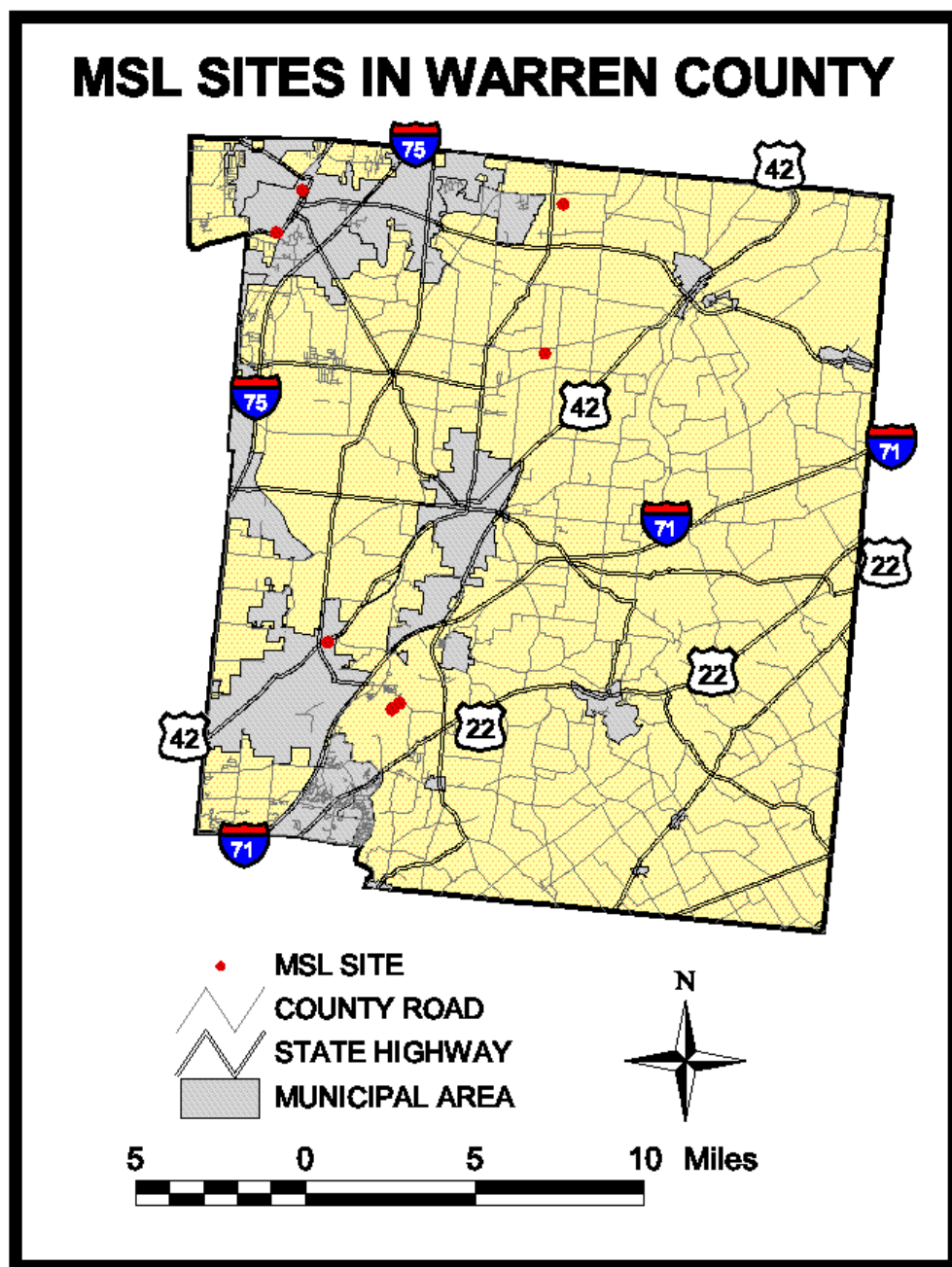


Figure B-9a. Map showing Master Site List sites from the Ohio EPA Division of Emergency and Remedial Response (DERR).

File Edit View Go Communicator Help

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Bookmarks Location: <http://www.epa.ohio.gov/derr/county/warren.html/>

Attributes of MSL sites in Warren County

MSL SITE_	SITENAME	ADDRESS	ZIP	CITY	OHIO ID
1	DIVERSIFIED PRODUCTS	6195 STRIKER RD	45034	MAINVILLE	583-1045
2	FRANKLIN CITY WELLFIELD/UNK SRC	BRIDGE STREET & VAN HORNE AVE.	45005	FRANKLIN	583-1454
3	KINGS MILLS MILITARY RESERVATION	STRIKER RD	45034	KINGS MILLS	583-1264
4	MASON CITY WWTP	3930 US 42	45040	MASON	583-0499
5	PETERS CARTRIDGE FACTORY	1915 GRANDIN ROAD	45034	KINGS MILLS	583-1406
6	SYSTECH LIQUID TRMT CORP	BAXTER RD @ SR 73	45005	FRANKLIN	583-0789
7	TEXAS EASTERN GAS PIPELINE CO	2 MI NW OF LEBANON	45036	LEBANON	583-0802
8	UNION CAMP CORP	300 CHESTNUT DR PO BOX 252	45005	FRANKLIN	583-0831

[Maps for the Master Sites List](#)
(Look for other county maps)

Last updated on 4/22/1997.

Document: Done

Figure B-9b. Web page showing the addresses of the Master Sites Lists sites in Warren County, Ohio.

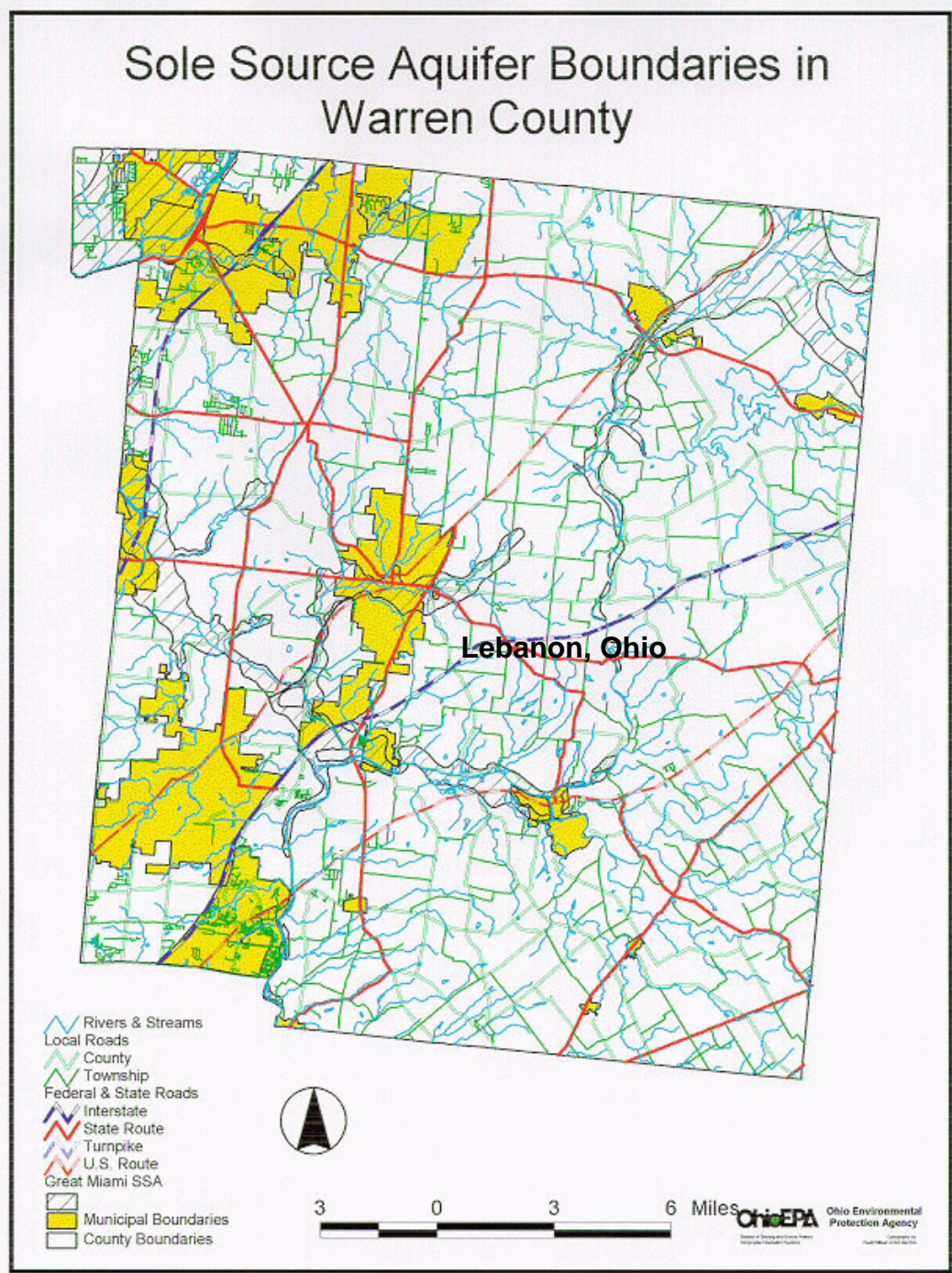


Figure B-10. Map showing aquifer boundaries in Warren County, Ohio.

The reference map we used to digitize was the “Sole Source Aquifer Boundaries in Warren County” (<http://www.epa.ohio.gov/ddagw/pdu/warrenssa.jpg>) (Figure B-10). By adding the aquifer layer we can get a “first cut look” at the relationship of BASINS federally regulated sites, MSL sites, PWS sites to the Little Miami Aquifer. The basic steps to manually digitize a point or area into ArcView are:

1. Open ArcView/BASINS
2. Open Project
3. Under View Menu click on New Theme
4. Click either Point, Line, or Polygon
5. New Theme Windows opens - add name of new theme and path
6. New Theme name is added to theme table
7. Start digitizing - click once for point, double click at end of line or boundary
8. When finished click Stop Editing and Save
9. See ArcView Manual for complete instructions

We have contacted the Ohio Bureau of Underground Storage Tank Regulations (BUSTER) and requested an underground storage location file. For more information on BUSTER data sets and information their web site is <http://www.com.state.oh.us/fire/bustrmain.html>

Comparing ArcView/BASINS with Enviromapper

The lack of complete coverage of PWS sites in the Little Miami Watershed from the ArcView/BASINS package (Figure B-7) was a problem when comparing to the “Enviromapper” map (Figure B-5). But with the addition of the Ohio PWS sites (Figures B-8), ArcView/BASINS now matches the “Enviromapper” map (Figure B-5). The TRI and PCS facilities between Figure B-8 and Figure B-5 match very closely. The “Enviromapper” and BASINS data sets differ in that Enviromapper contains informaton derived from the AIRS (Aerometric Information Retrieval System) Facility Substation (AFS) site and BASINS contains Industry Facilities Discharge Sites.

At this point we want to take a look at individual federal regulated facilities within 2-miles of the Lebanon PWS site. Three TRI facilities were found within the 2-mile radius (Figure B-11). We queried the three TRI sites using the *i* button and chose Amtex, Inc., for further examination. Within BASINS there are several ways to query for facility information and this is just one method to query and display facility specific data. We made the TRI theme active and then selected the TRI site of interest (Amtex) by clicking the TRI site with the pointer tool or drag box tool. Then we opened the theme table and the Amtex facility is highlighted in yellow (grey line on top table in Figure B-12). In the project view, we clicked on the tables icon and opened the TRI

Underground Release Data 1993 table and manually scrolled down the table until the *TRI_facil* matched the Amtex *id* (middle table links to top table in Figure B-12). We then opened the TRI Parameter Table and matched the *Cas_num* to the *Tri_chem_i* in the TRI Underground Release Data 1993 table (bottom table links to middle table in Figure B-12). Figure B-12 shows that the TRI facility, Amtex, released Methylenebis (Phenylisocyanate) into the ground in 1993.

TRI Underground Releases for 1993 - Amtex Inc.

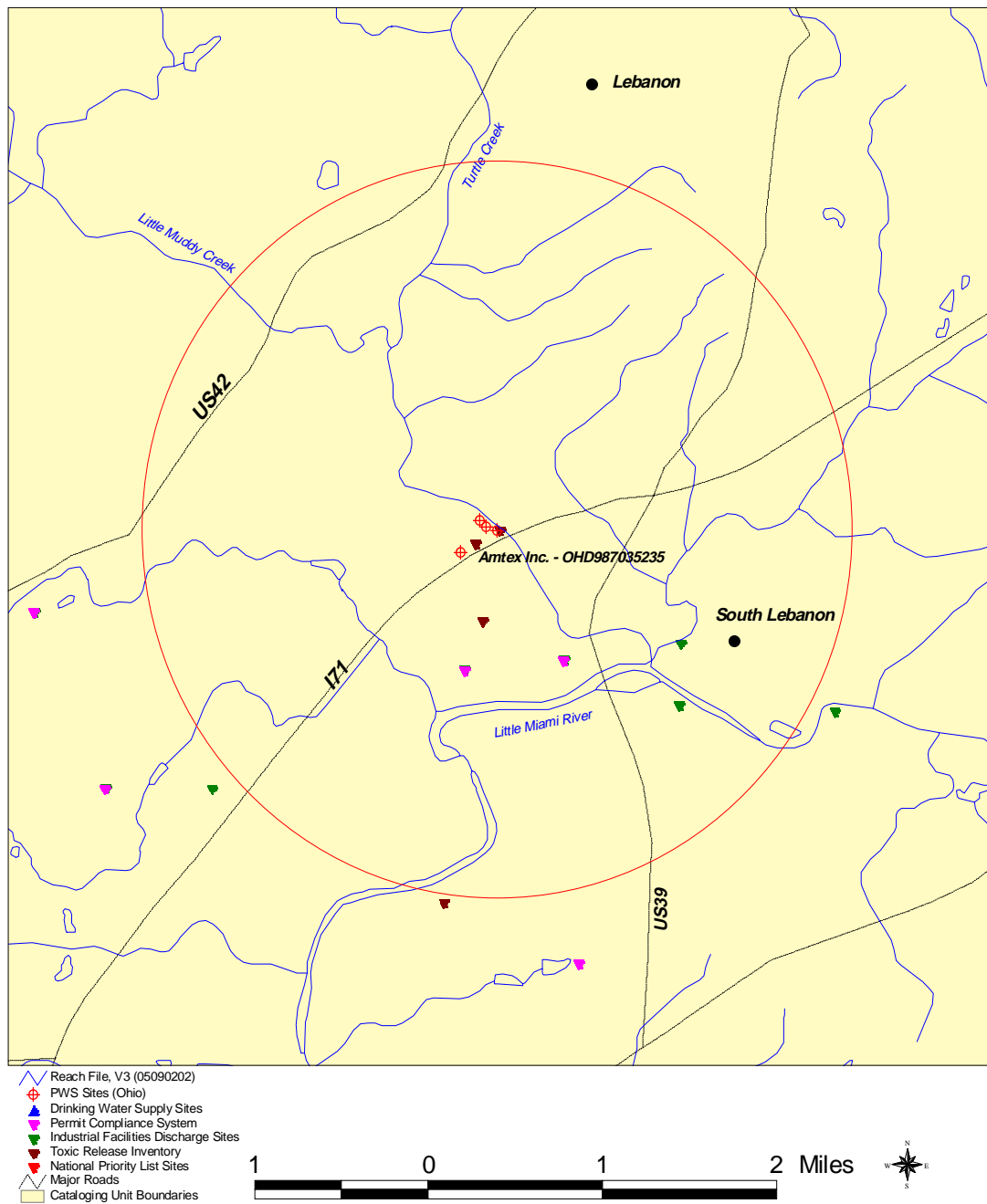


Figure B-11. Map showing all federally regulated sites around the Lebanon Public Water Supply sites (TRI site - Amtex, Inc. is identified).

Figure B-12. BASINS TRI release data base showing Amtex, Inc.

The next step was to query the same Amtex TRI facility in “Envirofacts” to get a look at their database (Figures B-13a through B-13d). The Envirofacts TRI Report indicates that Amtex released Methylenabis(Phenylisocyanate) in 1992, 1993, and 1994.

This exercise demonstrates that in ArcView/BASINS, for a selected TRI site (Amtex), we can build an historical record of released chemicals within an area of interest.

Supplemental Ground Water Information - Digital Raster Graphic Maps

To supplement the BASINS data sets we purchased Digital Raster Graphic (DRG) maps from USGS (<http://mcmcweb.er.usgs.gov/drg/avail.html>). A DRG map is a scanned image of a USGS standard series topographic map (1:250,000, 1:100,000, and 1:24,000). The DRGs are useful for background information and for on-screen review of other data sets. With the addition of the DRG maps to ArcView/BASINS GIS we began to enhance the prepackaged data sets provided from BASINS (Figure B-14).

Supplemental Ground Water Information - Aerial Photographs

We searched for historical aerial photographs within 10 miles of Lebanon. We queried and received responses from Woolpert Consultants, Sidwell Company, USGS/EROS Data Center, Ohio Department of Transportation, and the Warren County GIS Department. For the area around Lebanon we found abundant aerial photographs with varying scales, years, and costs. Available dates vary from 1946 through 1995 and scales from 1 in. = 63,360 ft to 1 in. = 1,000 ft. Photographs are usually not geo-referenced and need to be scanned and processed with real-world coordinates before adding into a GIS. The USGS provides two geo-referenced photographic products, Digital Orthophoto Quadrangles (DOQs), at a scale of 1 in. = 24,000 ft, and Digital Orthophoto Quarter-Quadrangles (DOQQs), at a scale of 1 in. = 12,000 ft. Check USGS for current availability and costs. We found that the Warren County GIS Department is a good source for aerial photographs. They have countywide geo-referenced coverage from the Sidwell Company. The date and scale of the photographs are not currently available from their web site (<http://www.co.warren.oh.us/warrens/gis/>). A new Internet source for free and easily downloadable photographs and imagery is the *Microsoft TerraServer Image Page* (<http://www.terraserver.microsoft.com>) although no aerial photographs were available from TerraServer for Lebanon.

Identifying Specific Ground Water Information - County/Local Data

The Warren County GIS Department is currently developing a GIS Internet site. To date the following county GIS data sets are viewable; Property Map, Plat Book Map, Topo Map, Ortho Photo Map, Sidwell (Aerial Photography), Land Survey, School

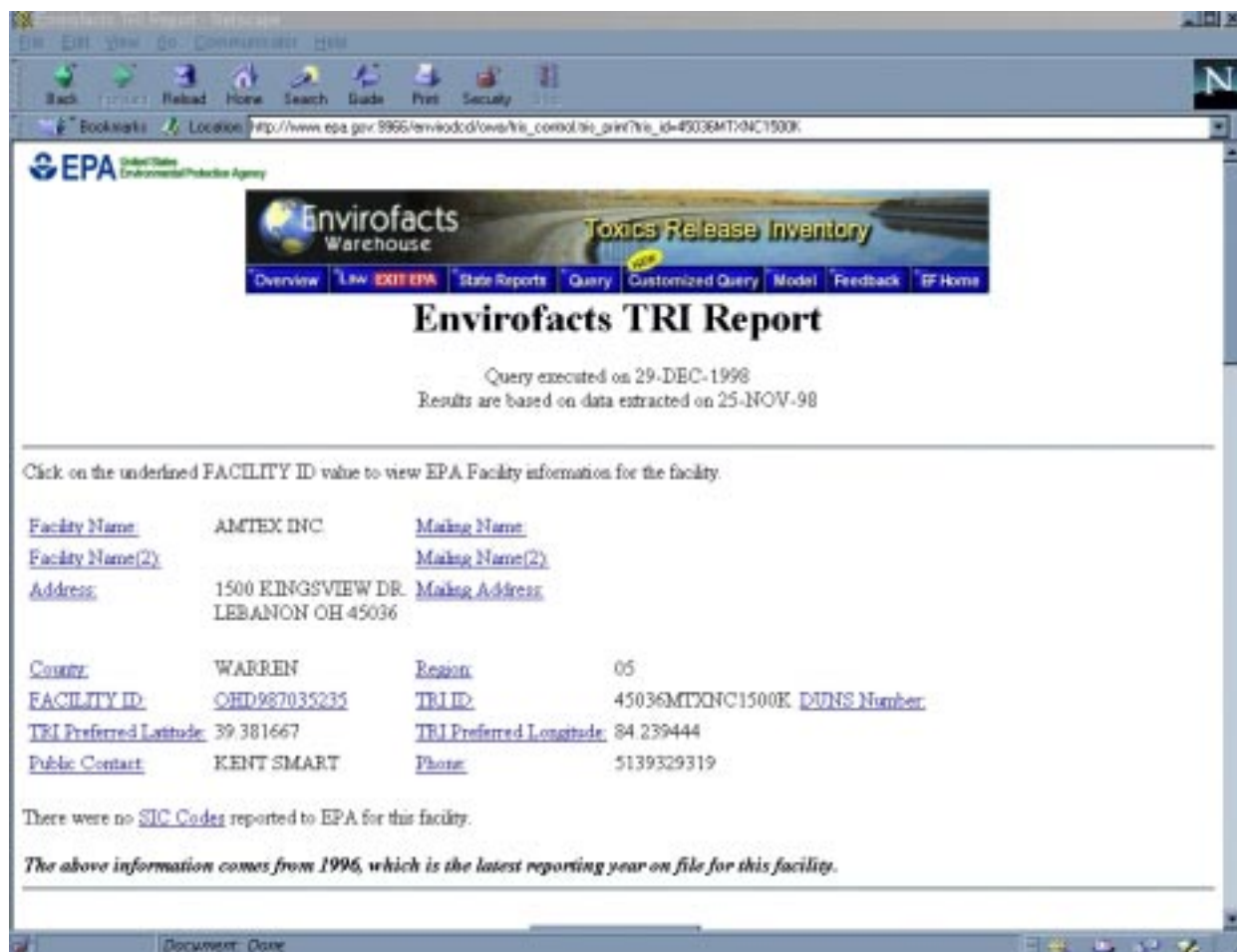


Figure B-13a. Web page showing TRI data from the EPA Envirofacts data base.

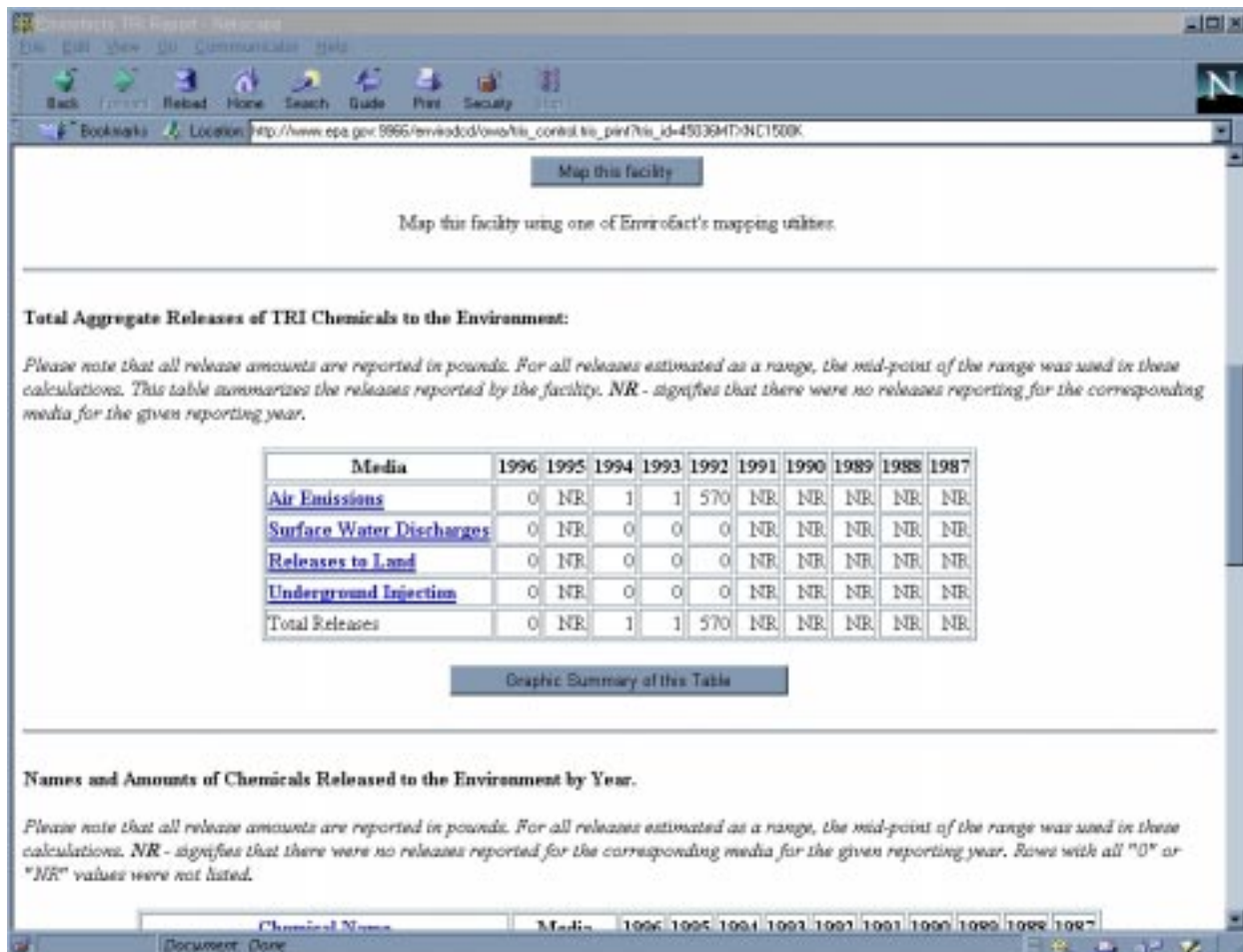


Figure B-13b. Web page showing TRI data from the EPA Envirofacts data base.

Chemsheets TRI Report - Message

File Edit View Go Communication Help

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Bookmarks Location http://www.epa.gov/3366/environod/awa/tri_control/tri_id=4503647/NC15008

Please note that all release amounts are reported in pounds. For all releases estimated as a range, the mid-point of the range was used in these calculations. NR - signifies that there were no releases reported for the corresponding media for the given reporting year. Rows with all "0" or "NR" values were not listed.

Chemical Name	Media	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987
METHYLENEBIS(PHENYLISOCYANATE) (TRI Chemical ID: 000101688)	Air - Fugitive	NR	NR	1	1	570	NR	NR	NR	NR	NR

Discharge of Chemicals into Streams or Bodies of Water:

Please note that there were no discharge of chemicals into streams or bodies of water for this facility for the years 1987 to 1996

Transfer of Chemicals to Off-Site Locations other than POTWs:

Please note that transfer amounts are not included in release totals shown above. All transfer amounts are reported in pounds. For all releases estimated as a range, the mid-point of the range was used in these calculations.

Chemical Name	Year	Release Amount (Pounds)	Transfer Site Name and Address	Type Of Treatment
DIISOCYANATES (TRI Chemical ID: N120)	1996	250	RUMPKER LANDFILL INC. 10795 HUGHES RD. CINCINNATI, OH 45247	LANDFILL/DISPOSAL SURFACE IMPOUNDMENT
METHYLENEBIS(PHENYLISOCYANATE) (TRI Chemical ID: 000101688)	1992	25	RUMPKER LANDFILL INC. 10795 HUGHES CINCINNATI, OH 45247	LANDFILL/DISPOSAL SURFACE IMPOUNDMENT

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Figure B-13c. Web page showing TRI data from the EPA Envirofacts data base.

Lebanon, Ohio - Digital Raster Graphic Map with PWS Sites

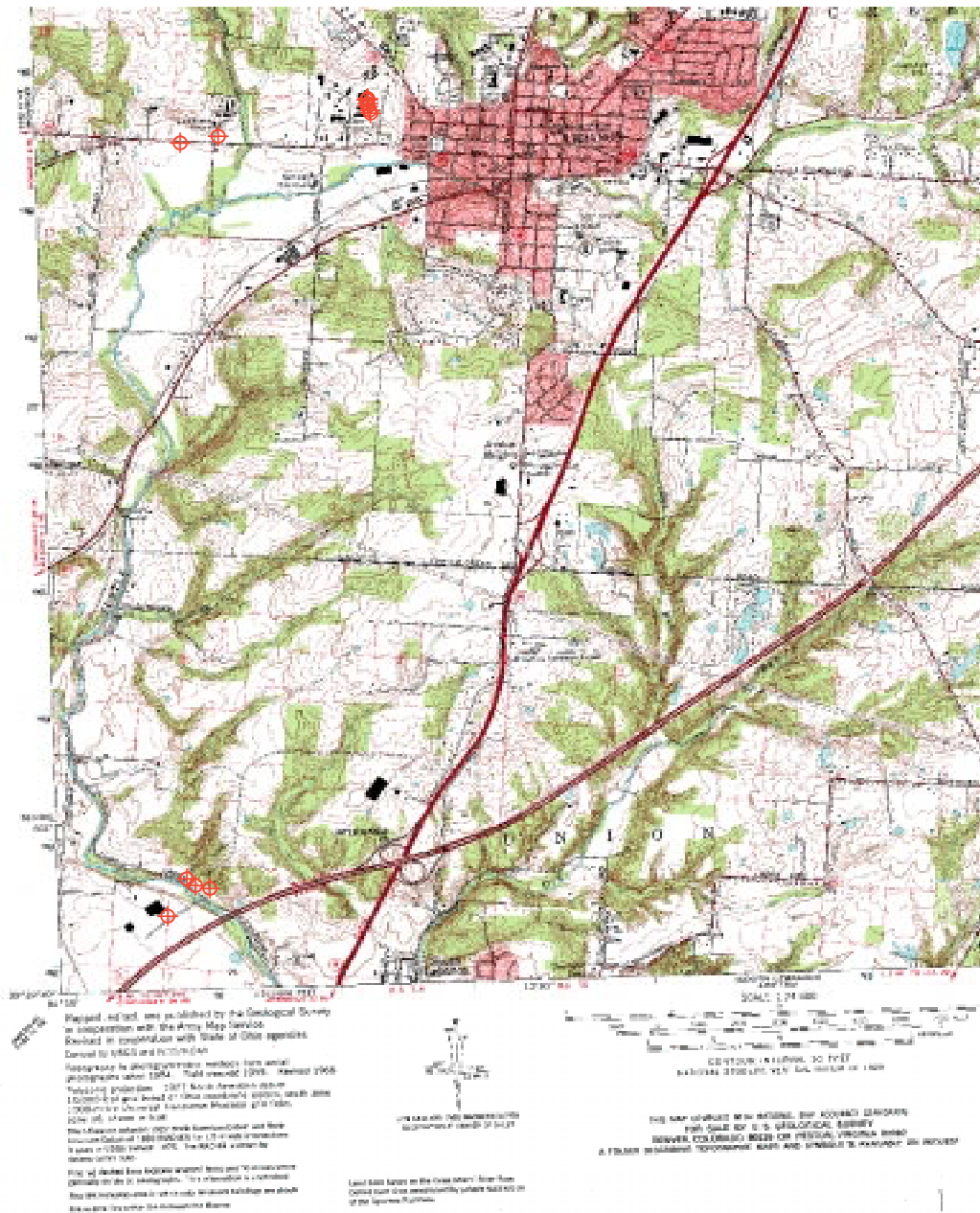


Figure B-14. Map showing USGS Digital Raster Graphic map.

District, and Zoning Map. We did not download any Warren County data sets or contact them for available data. Their Internet address is <http://www.co.warren.oh.us/warrengis/>. They may be a good source for data in the future.

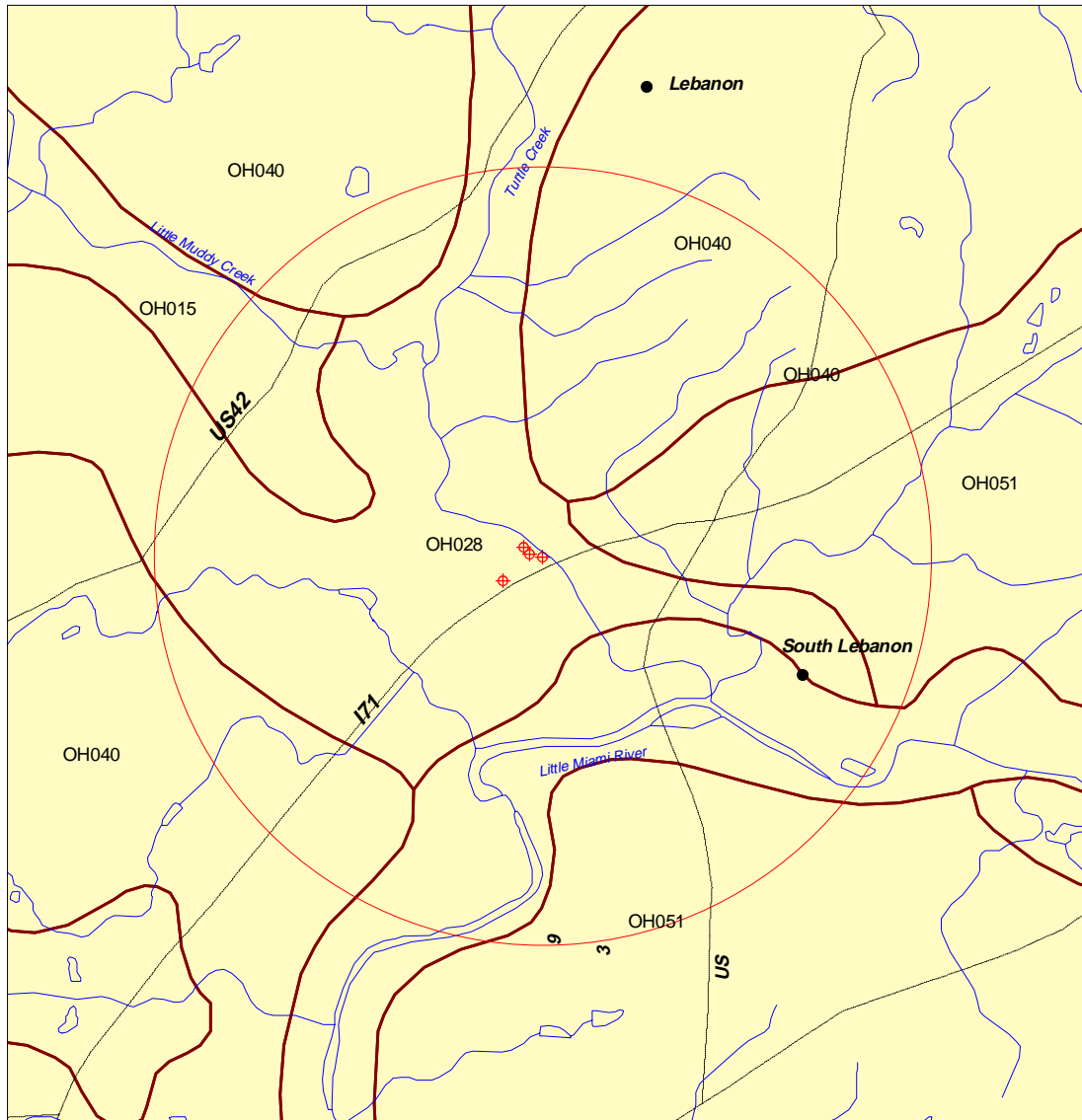
Additional Maps from ArcView/BASINS

We generated four additional maps using data from ArcView/BASINS. The first is the soil data from STATSGO (Figure B-15). This figure also has the related Soil Layer Table pasted onto the map which provides additional soil information. The second map is the Land Use data provided in BASINS (Figure B-16). The third map is the PCS sites within two miles of the Lebanon PWS site (Figure B-17). Figure B-17 is an example of the data mining operation provided in ArcView/BASINS for the City of Lebanon Department of Water and Wastewater and Lebanon Industrial Park PCS sites. Figure B-18 shows all the PCS data stored in BASINS tables that relate to these two sites. The last map shows the MSL sites and Little Miami Aquifer boundary with PWS sites (Figure B-19).

Identifying Specific Ground Water Information - Models

To date (November 1998) the best Internet location found for ground water models and resources was the USGS Ground Water Information Page (<http://water.usgs.gov/public/ogw/>). This USGS site lists over 20 different software packages with a brief description and the type of computer operating system they will run on.

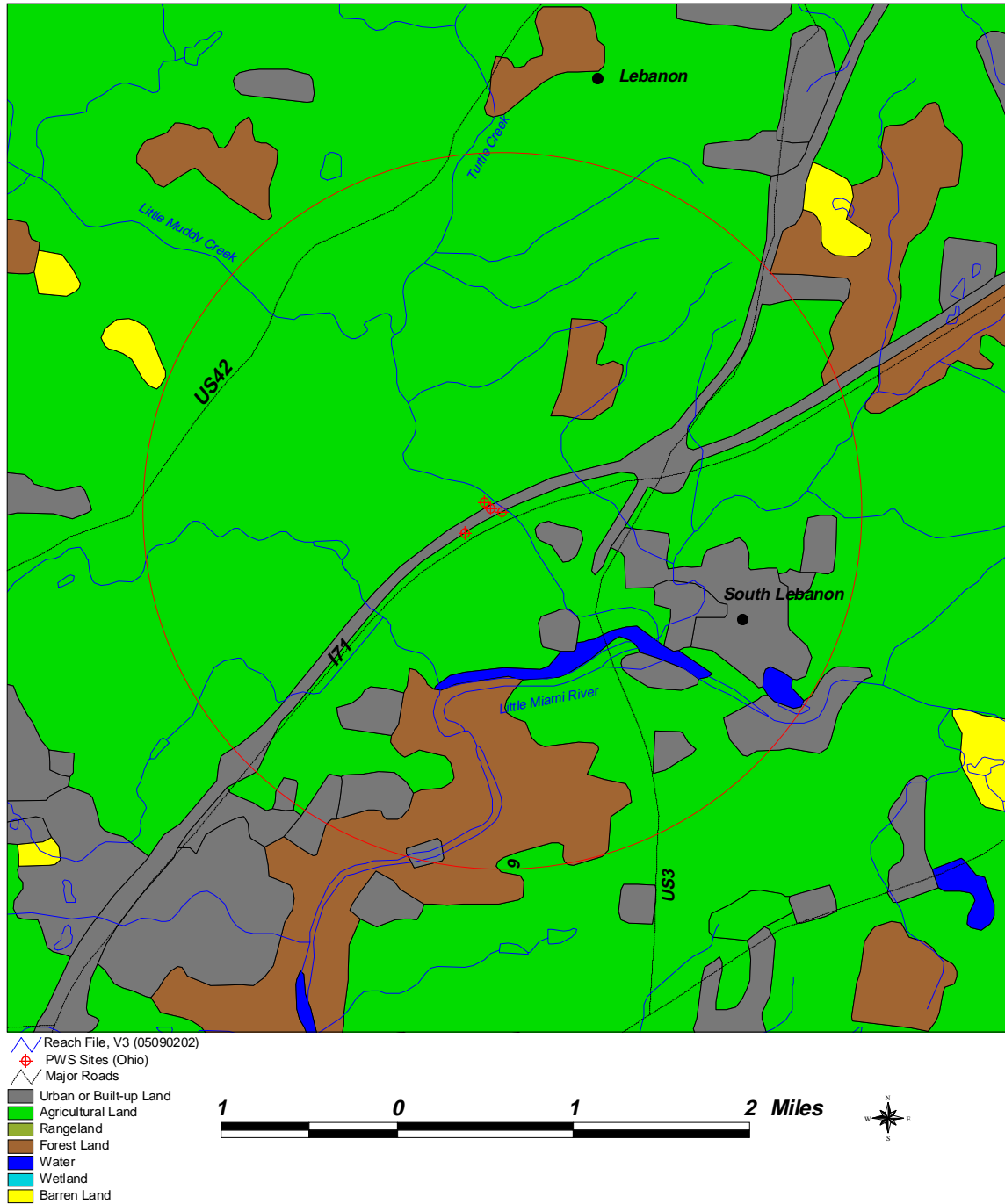
STATSGO Soils with Related Soil Layer Table



Musd	Segment	Musdsegment	SS Id	Layernum	Layerdep	Layerdep2	Texture1	Texture2
OH028	1	OH028 1	OH000 3	2	12	23	C	SC
OH028	1	OH028 1	OH000 3	3	23	30	GRV-CL	L
OH028	1	OH028 1	OH000 3	4	30	60	SR-	S
OH028	2	OH028 2	OH000 3	1	0	12	CL	
OH028	2	OH028 2	OH000 3	2	12	23	C	SC
OH028	2	OH028 2	OH000 3	3	23	30	GRV-CL	L
OH028	2	OH028 2	OH000 3	4	30	60	SR-	S
OH028	3	OH028 3	OH000 4	1	0	12	SIL	
OH028	3	OH028 3	OH000 4	2	12	26	SIL CL	CL

B-15. Map showing BASINS STATSGO soil data with 2-mile circle around public water system for Lebanon, Ohio.

Land Use



B-16. Map showing BASINS Land Use data with 2-mile circle around public water system for Lebanon, Ohio.

PCS and Industrial Facilities Discharge Sites within 2 Miles of the PWS Sites

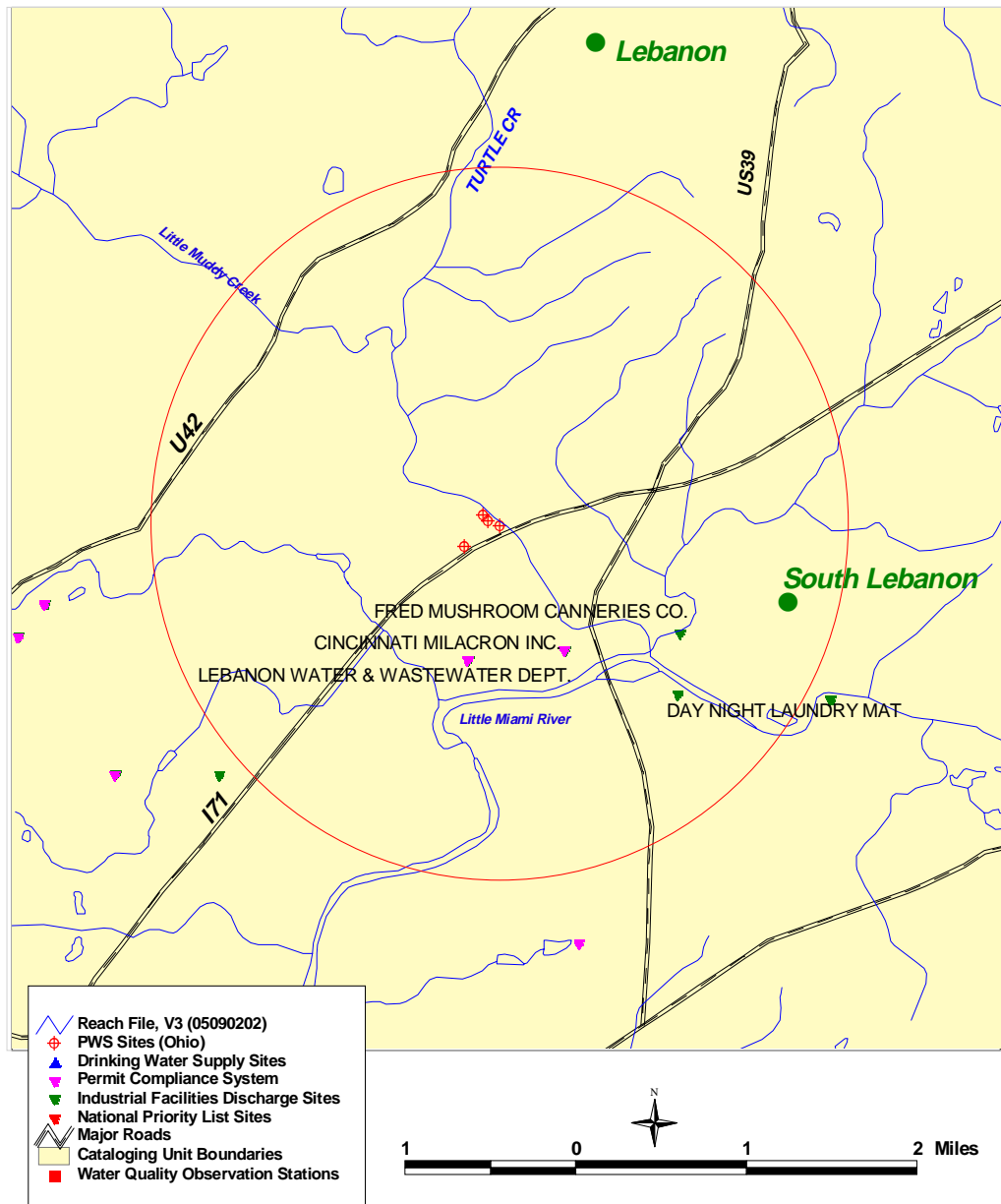
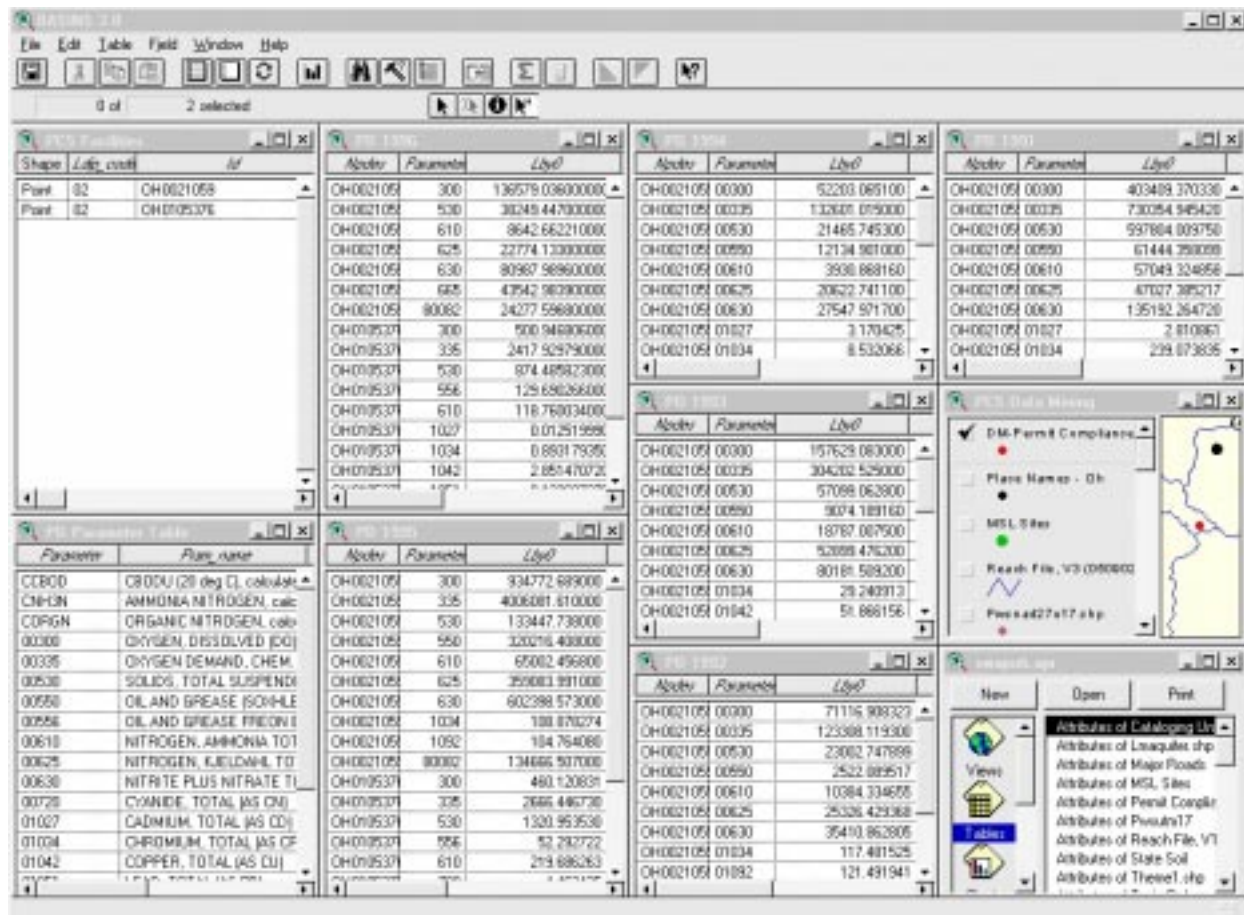
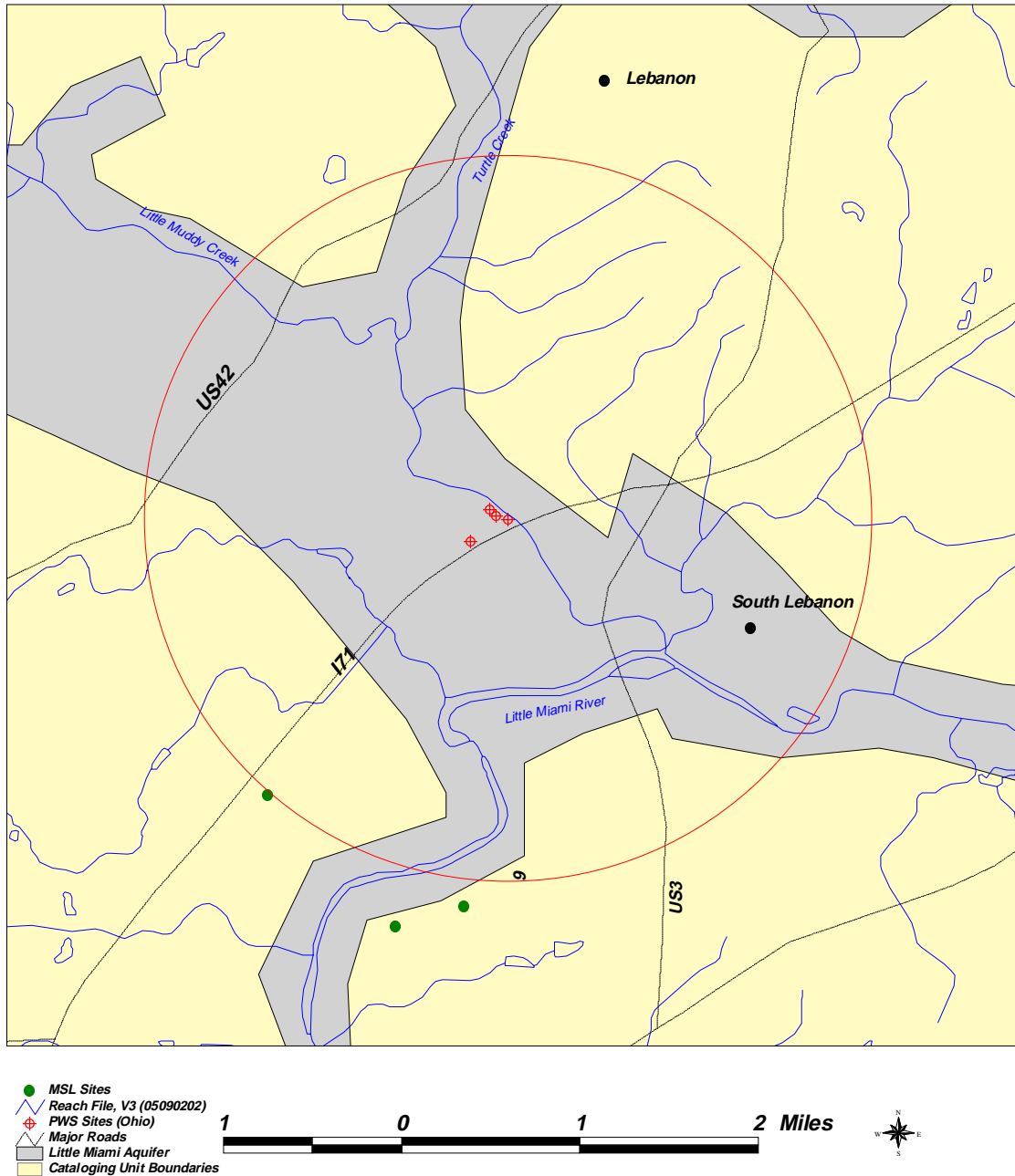


Figure B-17. Map showing BASINS PCS sites within 2 miles of the public water system for Lebanon, Ohio.



B-18. BASINS PCS data base showing PCS sites within 2 miles of Lebanon PWS.

MSL Sites with the Little Miami Aquifer Boundary



B-19. Map showing Master Sites List sites, Little Miami aquifer boundary, and 2-mile radius around the Lebanon, Ohio public water system site.

Appendix C

Case Study C: Procedure for Conducting a Source Water Assessment Plan GIS Evaluation for a Reservoir and Watershed System in Wilmington, Ohio

The following narrative describes the stepwise procedure employed by the LMES GIS Staff in Las Vegas, Nevada, to assess a hypothetical source-water protection area for a municipal reservoir and watershed system in Wilmington, Ohio. Due to the ever increasing use of the Internet by federal, state, and local agencies, Source Water Assessment Program (SWAP) source material and GIS data are becoming more available and easier to use. The amount and quality of GIS data and other source materials available on the Internet are continually increasing and improving. Thus, the Internet resources investigated during this case study should not be considered all inclusive. The SWAP report discusses in detail many of the concepts and data sources used in the following sections.

Available SWAP Information

Please refer to the discussions in Case Study B.

Identifying Available Internet Background Data, Site, and Mapping Information

Please refer to the discussions in Case Studies A and B.

Determine Extent of the Reservoir and Watershed Protection Area

We contacted the Wilmington Municipal Water Division and talked to a city water engineer about the Wilmington public water sources. The engineer indicated that the city receives its drinking water from two sources. The primary source is from Caesar Creek located approximately 12 miles northwest of Wilmington. The secondary source is pumped from Cowen Creek to a reservoir 2 miles south of the city. The city engineer indicated that the secondary water source is used primarily as a backup system if there is a problem with the Caesar Creek source. Figure C-1 shows the location of the primary and secondary water sources for Wilmington.

Wilmington, Ohio - Primary and Secondary PWS Watersheds

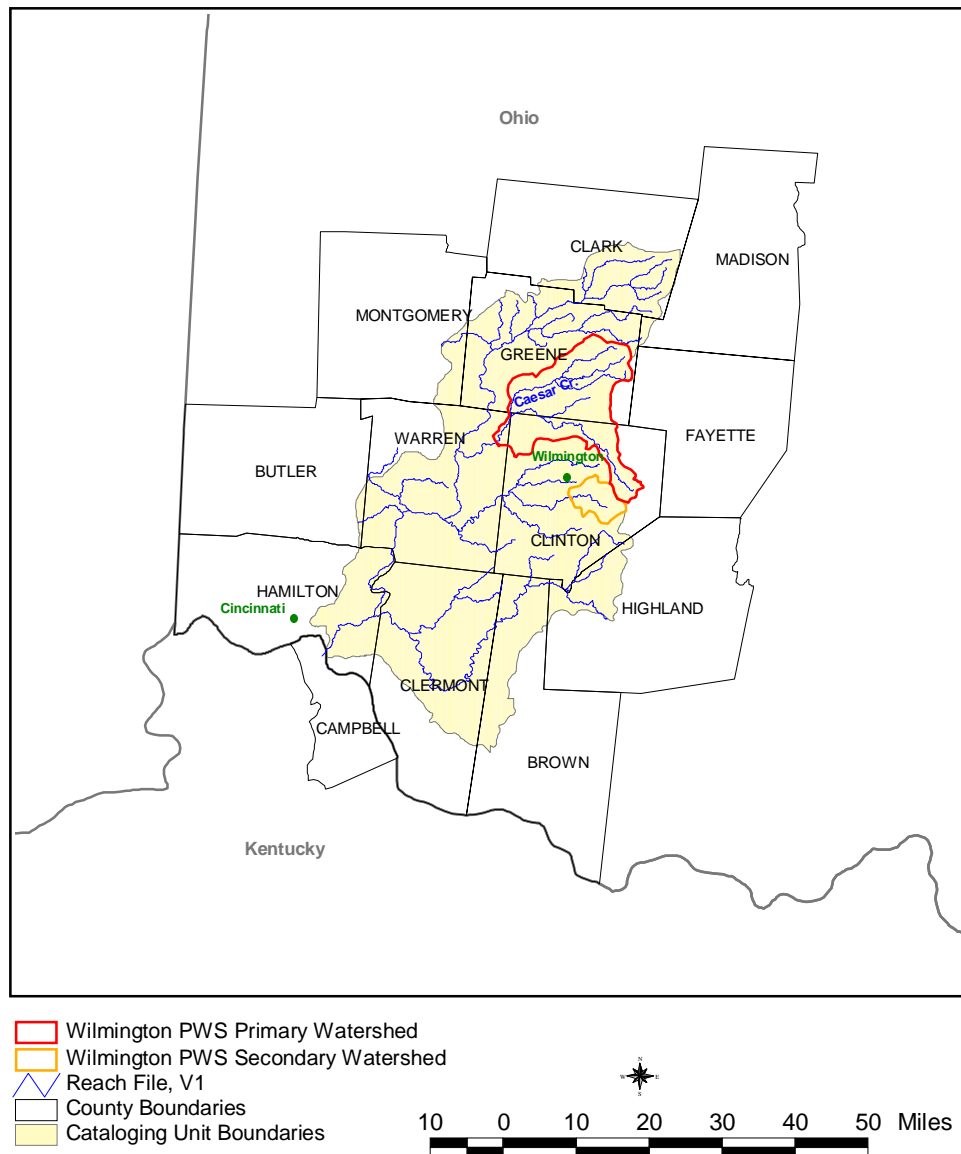


Figure C-1. The primary and secondary water sources for Wilmington, Ohio.

The watersheds associated with the two intake sites were delineated in the same general manner as that used in Case Study A. However, the Watershed Delineator tool was not used; instead, a new theme was created and the appropriate watershed boundaries were manually digitized. The new watershed boundaries were saved as new shapefiles within BASINS. The shapefiles were subsequently imported into the BASINS view.

Collecting Specific Ground Water Information

Please refer to the discussions in Case Studies A and B.

Using ArcView/BASINS

Data themes containing information on federally regulated sites were subsetting in BASINS to include only those sites within the two watershed boundaries as shown in Figure C-2. The lack of complete showing of PWS sites in the Little Miami Watershed by the ArcView/BASINS package was a problem when comparing the watershed to the “Enviromapper” map (Figure B-5). But with the addition of the Ohio PWS sites, ArcView/BASINS matches the “Enviromapper” map. The discussions in Case Studies A and B provide details of this evaluation.

Supplemental Ground Water Information - Digital Raster Graphic Maps

To supplement the BASINS data sets we purchased Digital Raster Graphic (DRG) maps from USGS (<http://mcmcweb.er.usgs.gov/drg/avail.html>). A DRG map is a scanned image of a USGS standard series topographic map (1:250,000, 1:100,000, and 1:24,000). The DRGs are useful for background information and for on-screen review of other data sets. With the addition of the DRG maps to ArcView/BASINS GIS, we began to enhance the prepackaged data sets provided from BASINS.

Supplemental Ground Water Information - Aerial Photographs

We discovered historical aerial photographs (as digital orthophoto quads, as shown in Figure C-3) on a new Internet source for free with easily downloadable photographs and imagery. The new Internet site is the *Microsoft TerraServer Image Page* (<http://www.terraserver.microsoft.com>).

Identifying Specific Reservoir/Watershed Information - Models

Please refer to the discussion in Case Study A.

Wilmington's PWS Watersheds with Federal Sites

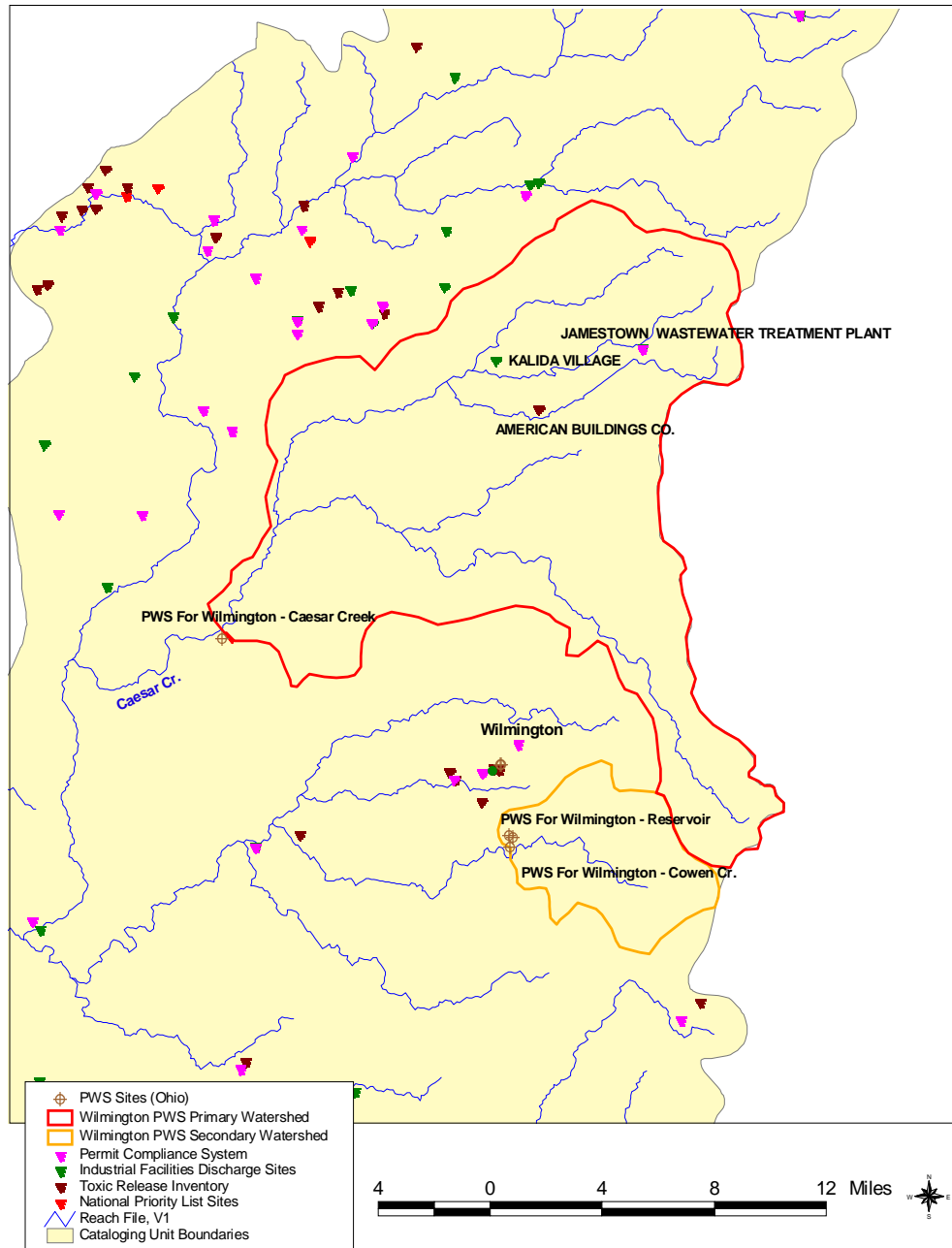


Figure C-2. Federally regulated sites within the primary and secondary watershed boundaries for Wilmington, Ohio.

Aerial Photography of Wilmington, Ohio



⛶ City of Wilmington's Backup Water Supply - Reservoir

Photograph downloaded from Microsofts TerraServer web site

Figure C-3. Aerial photograph (digital orthophotoquad) of Wilmington, Ohio.

Appendix D

State Source Water Protection Contact List

The following list is available online at <http://www.epa.gov/OGWDW/source/contacts.html>.



STATE SOURCE WATER PROTECTION CONTACT LIST

18 September 1998

For updates to this list or inquiries on national programs, call the SDWA Hotline, 1-800-426-4791, or E-mail: hotline-sdwa@epamail.epa.gov.

STATE REGION INDEX

[Link to States' Source Water Protection Pages](#)

Alabama, IV	Idaho, X	Minnesota, V	North Dakota, VIII	Utah, VIII
Alaska, X	Illinois, V	Mississippi, IV	Ohio, V	Vermont, I
Arizona, IX	Indiana, V	Missouri, VII	Oklahoma, VI	Virgin Islands, II
Arkansas, VI	Iowa, VII	Montana, VIII	Oregon, X	Virginia, III
California, IX	Kansas, VII	Nebraska, VII	Pennsylvania, III	Washington, X
Colorado, VIII	Kentucky, IV	Nevada, IX	Puerto Rico, II	West Virginia, III
Connecticut, I	Louisiana, VI	New Hampshire, I	Rhode Island, I	Wisconsin, V
Delaware, III	Maine, I	New Jersey, II	South Carolina, IV	Wyoming, VIII
Florida, IV	Maryland, II	New Mexico, VI	South Dakota, VIII	
Georgia, IV	Massachusetts, I	New York, II	Tennessee, IV	
Hawaii, IX	Michigan, V	North Carolina, IV	Texas, VI	

REGION 1

Connecticut Source Water Protection

Denise Ruzicka
CT Dept of Public Health
MS#51 WAT
PO Box 340308
Hartford CT 06134
Phone: 860-509-7333
Fax: 860-509-7359

Rob Hust
Connecticut Dept. of Env. Protection
Water Management Bureau
79 Elm St.
Hartford, CT 06106-5127
Phone: 860-424-3718

Wellhead Protection

Fred Banach
Connecticut Dept. of Env. Protection
Water Management Bureau
79 Elm St.
Hartford, CT 06106-5127
phone: 860-424-3020

Massachusetts Source Water Protection Tara Gallagher Massachusetts Dept. of Env. Protection Drinking Water Program One Winter Street Boston, MA 02108 phone: 617-292-5930 e-mail: tgallagher@state.ma.us	Wellhead Protection Tara Gallagher Massachusetts Dept. of Env. Protection Drinking Water Program One Winter Street Boston, MA 02108 phone: 617-292-5930 e-mail: tgallagher@state.ma.us
Maine Source Water Protection Paul Hunt Maine Drinking Water Program Bureau of Health, Div of Health Eng. 10 State House Station Augusta, ME 04333-0010 phone: 207-287-6196 fax: 207-287-4172 e-mail: paul.hunt@state.me.us	Wellhead Protection David Braley Maine Department of Human Services 10 State House Station Augusta, ME 04333 phone: 207-287-3194 fax: 207-287-4172
New Hampshire Source Water Protection Sarah Pillsbury New Hampshire Dept. of Env. Services Water Supply Engineering Bureau 6 Hazen Dr., POB 95 Concord, NH 03302 phone: 603-271-1168 fax: 603-271-2181 e-mail: pillsbury@deswspws.mv.com	Wellhead Protection Sarah Pillsbury New Hampshire Dept. of Env. Services Water Supply Engineering Bureau 6 Hazen Dr., POB 95 Concord, NH 03302 phone: 603-271-1168 fax: 603-271-2181 e-mail: pillsbury@deswspws.mv.com
Rhode Island Source Water Protection Clay Commons RI Dept. of Health Office of Drinking Water Quality 3 Capital Hill Providence, RI 02908-5097 phone: 401-222-6867, ext. 2237 FAX: (401) 222-6953	Wellhead Protection Ernie Panciera Office of Water Resources Rhode Island Dept. of Environment 235 Promenade St. Providence, RI 02908 Phone: 401-222-2234 X7603

Vermont Source Water Protection Elizabeth Hunt Water Supply Division Dept. Of Environmental Conservation 103 S. Main Street Waterbury, VT 06571-0403 phone: 802-241-3409 fax: 802-241-3284 e-mail: elizh@dec.anr.state.vt.us	Wellhead Protection Elizabeth Hunt Water Supply Division Dept. Of Environmental Conservation 103 S. Main Street Waterbury, VT 06571-0403 phone: 802-241-3409 fax: 802-241-3284 e-mail: elizh@dec.anr.state.vt.us
REGION 2	
New Jersey Source Water Protection Sandy Kreitzman NJ Dept. Env. Protection Bureau of Safe Drinking Water, CM426 E. State St. Trenton, NJ 08625-0426 phone: 609-292-5550 e-mail: skreitzman@dep.state.nj.us	Wellhead Protection Daniel Van Abs Office of Land and Water Planning NJ Department of Environmental Protection 401 E. State Street Trenton, NJ 08625 phone: 609-633-1179 fax: 609-292-0687
New York Source Water Protection Claudine Jones Rafferty New York State Dept. of Health 2 University Place, RM 410 Albany, NY 12203 phone: 518-458-6743 e-mail: cfj02@health.state.ny.us	Wellhead Protection Warren Lavery New York State Dept. of Env. Conservation 50 Wolf Road, Room 302 Albany, NY 12233-3504 phone: 518-457-0791 fax: 518-485-7786
Puerto Rico Source Water Protection Olga I Rivera Puerto Rico Dept of Health Public Water Supervision Program P.O. Box 70184 Edificio A. Centro Medico San Juan, PR 00909	Wellhead Protection Eric Morales Water Quality Area Puerto Rico Environmental Quality Board P. O. Box 11488 Santurce, PR 00910 phone: 787-751-5548 fax: 787-767-1962

US Virgin Islands Source Water Protection Austin Moorehead VI DPNR/DEP Water Gut Homes 1118 Christiansted, St. Croix 00820-5065 phone: 340-773-0565	Wellhead Protection Austin Moorehead VI DPNR/DEP Water Gut Homes 1118 Christiansted, St. Croix 00820-5065 phone: 340-773-0565
REGION 3:	
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Appendix E

Priority Setting and Risk Weighing Guide for Contaminants in Wellhead Protection Areas

This guidance is derived from *Managing Groundwater Contamination Sources in Wellhead Protection Areas: A Priority Setting Approach* (EPA, 1991b). See that EPA document for more detail.

Assumptions:

7. The wellhead protection area is relatively homogeneous and isotropic and exists in one of the following settings: (1) a water table aquifer, (2) deep source, (3) surface source in a recharge area, or (4) surface source overlying a confined aquifer.
8. The zone of contribution is such that contaminants reach the well.
9. A cancer risk of 1:100,000 can be equated with a lifetime exposure to the reference dose for noncarcinogens, and exposure is through drinking water, not dermal contact or inhalation.

Priority setting tasks:

1. Delineation of a protection area: map the boundaries and characterize the hydrology, soils, etc.
2. Identification of contamination sources: identify all sources; categorize and characterize them. Determine persistence, mobility, and toxicity of contaminants.
3. Estimation of overall risk: assign level of risk values for high, medium, and low, or, alternatively, values from 1 for high to 5 for none. More weight may be assigned to categories of concern.
 - a. At the contaminant source estimate the likelihood of release (L1), quantity of release (Q), and its toxicity (T).
 - b. At the source water intake estimate the likelihood of the contaminant's arrival (L2) and its attenuation during transport (A).
 - c. Estimate the overall risk score (R) for each contaminant using its likelihood (L) of contamination and severity (S) of contamination, where:

$$L = L1 + L2$$

$$S = Q + A + T$$

$$R = L + S$$

The overall risk is the sum of the likelihood of contamination and the severity of contamination. The weight assigned to each category is a matter of judgment. For example, if severity is the primary concern for a particular contaminant (e.g., contained in a tank), then a high risk score would result from the severity of contamination even though the likelihood of contamination (e.g., from tank rupture) is small.