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Patrick L. Lawrence *Editor*

Geospatial Tools for Urban Water Resources

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Preface

Advances in the field of geospatial technologies have resulted in the growth in the application of such methods and techniques to a wider range of challenges and issues associated with urban water resources. The use of remote sensing, geographic information science (GIS), spatial analysis, global positioning systems (GPS), digital mapping, online electronic data resources, and processing techniques are now common tools in addressing urban water quality, storm water, flooding, water supply issues, and overall management of water resources and watersheds in urban communities and urbanizing landscapes. In this volume, the authors address many of the complex concerns and impacts associated with human and natural changes facing urban water resources through their use of a variety of geospatial techniques and tools. The aim of the volume is to present the reader a mix of examples of the evolving use of geospatial methods and applications now utilized in many urban areas to assist decision-makers, planners, and communities in making sound judgments as to how best manage their water resources for both human use and to minimize impacts to the natural environment. It is our hope that through presenting these examples and case studies that readers will gain a broader understanding of the emerging field of the use of geospatial technologies to address urban water issues at a time during which these resources are under great threat from natural and human stresses, such as climate change, declining freshwater supplies, drought, excessive water demand and use, cost pressures associated with urban water infrastructure, natural and technological hazards, growing urban populations, and competing water uses. The chapters are intended to provide a range of insights into the development of the geospatial tools and technologies and their applications to a variety of issues and localities. With these presentations the reader is intended to gain a better appreciation for the range of methods now available to address many urban water challenges and consider how geospatial technologies are advancing our understanding and efforts to address the many complex urban water issues now facing our society.

In his introductory chapter to this volume, Seth provides a comprehensive overview of the types of geospatial technologies and tools available to address urban water issues, including GIS, digital data sets, and spatial analysis techniques. The author outlines the typical types of spatial data often utilized with GIS platforms with specific discussion on those most applicable to urban water issues. Seth also identifies the key data sets necessary to integrate into water resource projects such as land use, digital elevation model (DEM) outputs, hydrological conditions, soil information, and landscape characteristics. The author focuses on the importance of data acquisition and the preparation of metadata in order best organize and present such spatial data. Seth discusses the standard GIS operational frameworks essential for such work including data overlay and manipulation, geocoding and georeferencing, and the preparation of map coordinate system. This chapter also presents several examples of how GIS can be used to assist in resolving urban water management by community planners and others by the preparation of storm water runoff models, simulations of sewer systems to address wastewater collection and treatment infrastructure operations and needs, and linking GIS to urban water resource management models to facilitate community decision-making. Seth provides an excellent summary and assessment of the opportunities and challenges in the use of geospatial techniques to address a wide range of urban water resource issues and as such has provided a welcome and important start to this volume.

With water conservation such a critical issue in many urban areas located in more arid climates, Larson and colleagues consider the use of a spatial approach to addressing water conservation at the neighborhood scale in Phoenix, Arizona. The chapter outlines an innovative method to integrate individual household metered water use with social survey data by use of GIS techniques. The aim is to be able to understand how various socio-spatial relationships are linked to water use, perceptions of water availability and demand, and relationships to water demand within neighborhoods. The results highlight issues of the lack of understanding and poor perception of the value of water conservation efforts and the misunderstandings residents have regarding their own high water consumption. The study points to several critical challenges with urban water conservation efforts and the use of GIS to better understand the complex social dynamics associated with individual and neighborhood water use and conservation efforts – important lessons that can be better understood through geospatial techniques. This chapter highlights the important utility of using such methods to better understand the potential for various water conservation efforts needed to address the important issue of water use and supply in major urban areas where water availability is a concern.

How can one utilize the understanding and roles of community members to better understand and address water uses is a question raised in the chapter by Cutts. The chapter outlines a participatory mapping approach intended to examine cumulative actions of water information providers across metropolitan Phoenix, Arizona. The transfer of basic information from local water municipal providers to water users is a critical aspect for better water use management, especially in regards to supply, demand, cost, and conservation issues. Such information can help individual water uses, in this case homeowners, with the necessary tools to make sound decisions regarding their water use and potential for conservation efforts. Participatory GIS is used to assess the roles of various local water providers to map the cumulative water information landscape – how information on water usage and conservation was being provided to water users. The local water providers were then interviewed to validate the information gathered and to assist in the identification of issues with data collection and management. The results of the survey were examined in order to identify the range of types of information provided on various water conservation methods and the provision and communication of such information to water users. Such research is of fundamental importance in addressing municipal scale efforts to inform and encourage the utilization of a range of water conservation efforts by users so as to address the often inequity between water supply and demand, all too common in major urban areas, especially those located in arid climates.

Goetz and Fiske examine the important connections between changes to urbanization within a region and its impacts to the ecosystem health of a stream as measured by the biotic diversity of species. The chapter presents an overview of research conducted for numerous small streams located in the southern New England region of the eastern United States to examine how land use changes are altering overall ecological aquatic health of these ecosystems. General additive models (GAM) and step-wise multiple linear regression (MLR) are used to assess relationships between land cover types and a series of stream biological indicators. The 2001 National Land Cover Database, developed from the classification of 30 m Landsat Thematic Mapper satellite imagery, was used to create a uniform land cover mapping for each watershed unit within the study area. The major land cover types of impervious surfaces, grass, crops, and forest were analyzed for proximity to streams within individual watersheds. The statistical analysis using the GAM and MLR models was applied to examine three biotic indices and a comparison of differing scales of impacts from various upstream scaled areas. The results indicate that watershed size was not often a significant predictor of biotic conditions, but that the variations in land cover can be important in assessing overall aquatic ecosystem health in the streams. The results of such research can provide important information to assist with more closer examination of land cover changes in watersheds (such as reducing impervious cover) to reduce impacts to stream water quality and overall ecosystem biotic health of these systems.

In urban areas the variety of land uses within urban centers present significant storm water concerns with the resulting runoff from surfaces creating issues of water quality and flooding, issues that Goldshleger and colleagues seek to address. The chapter examines the concerns of changing land uses along the coastal region of Israel where the rapid conversion of open areas and agricultural lands has resulted in major urban development in the forms of residential neighborhoods, commerce, and industry. Techniques from remote sensing and GIS are applied to study land cover/land use changes and their impacts on overall water quality and water quantity. Data collected and analyzed include rain measurements, runoff, and various water quality parameters. During the study period 2007–2009, increases in the urban runoff coefficient were noted along with various impacts of water quality showing higher concentrations of microbes, fecal *E. coli* and coliforms from all land uses. Concerns with water quality were higher associated with industrial areas when compared to residential areas, especially in regards to organic and fuel related compounds. The results also indicated that few water concerns were found with residential runoff, thus suggesting the possibility for storm water capture from these areas and potential reuses. As our landscape becomes more urbanized the study of the associated land cover/land use changes and their impacts on water supply and water quality will become increasingly relevant leading to a key role for the use of geospatial data sets and tools to improve our understand and ability to respond to these challenges.

In their chapter, He and colleagues studied the application of GIS based models to improve understanding of the location and impacts of pollution loadings from municipal combined sewer outfalls and other nonpoint sources in the Saginaw Bay watersheds of Michigan, USA. A spatially distributed water quality model was developed in order to simulate the spatial and temporal distributions of point and non-point sources. The watershed was divided into 1 km^2 cells which are arranged as a serial and parallel cascade of water from cells to simulate the basin storage structure. The model addresses moisture inputs and outputs from the system including potential evapotranspiration and the interactions of surface and subsurface flows. The hydrological model is interfaced into a GIS platform by use of ArcView to process the related runoff parameters of meteorological data, soils, topography, land cover/land use, and hydrography. Results indicated that point sources from municipalities, industries, and commercial locations contribute significant amounts of the total phosphorous into Saginaw Bay, Lake Michigan. Fertilizer applications from non-farmland activities were also an important contributor. Such models of watershed systems are increasingly valuable for basin planning and management efforts in order to better understand and address the complex issues associated with land cover/land use changes occurring so rapidly in many regions and resulting in often complex, interrelated, and serious environment impacts to regional and local water resources.

Eiseman and colleagues present the creation of a GIS based model employed within two urbanizing watersheds in the Toledo metropolitan area in northern Ohio in order to assist a local community effort to identify the highest priority areas for river and wetland habitat restoration. Numerous geographic data sources were collected and compiled, including land cover/land use, surface water networks, forest and vegetation types, topography, soils, and land ownership. The aim was to assess the potential for restoration within the watershed based on physical conditions and the current land management and conservation arrangements already in place at or in proximity to properties. A predictive model was developed that weighted the most important factors to be considered in determining the viability of restoration for streams, wetlands, and streams with adjacent wetlands. The assessment and identification of potential restoration sites was also divided into three main regions within the watersheds to cover forested, urban, and agricultural areas. The initial analysis revealed a large number of sites of which the top 30 % were selected within each region for more detailed assessment and mapping.

Upon field verification and clustering of high value sites, the model resulted in the selection of 33 final restoration sites for which concept plans were developed. The use of geospatial data sets, integrated into a GIS format, and subject to selection criteria, provided for a detailed and validated method for identifying priority stream and wetlands restoration sites.

The challenges of addressing land use changes at the watershed scale are discussed by Czajkowski and Lawrence in their chapter that highlights the creation of remote sensing and GIS based products to assist management within the Maumee basin in northwest Ohio. Landsat satellite imagery, along with field data, was used to determine the predominate land cover/land use types with the watershed on an annual basis for a 5-year study period. In addition, agricultural crop types were identified in order to assess the amount and variation in planting cycles within the watershed as crops have different impacts on the processes of soil erosion and the presence of crop amendments in local streams and creeks, including sediment and nutrients from non-point rural runoff process. The land cover/land use and crop type data was built into a comprehensive online GIS data base prepared for the entire watershed area with the intent to create one source for the essential spatial data sets needed to assist federal, state, and local agencies and decision-makers in addressing the many water resource issues facing the Maumee watershed. Additional work included efforts to document and classify the use of conservation tillage techniques used by farmers throughout the watershed to reduce soil erosion. The development of the various geospatial products provided for an important data set and basis for additional studies and management approaches such as modeling of soil erosion, addressing flooding concerns, examining impact of land cover/land use changes on water quality, and the coordination of regional efforts for watershed planning. This work highlights the important role that geospatial technologies can play in assisting with the many efforts by a diverse number of agencies and organizations to deal with complex water resource issues and the need for centralized and organized data sets and associated spatial product to support such efforts.

The development of so many GIS based data and information sources raises questions as to the utility and use of these digital and often online resources by local and regional planners having to address watershed management concerns within their jurisdictions, which is the focus of the chapter presented by Rousseau and Lawrence. As part of the Maumee Watershed GIS Project (highlighted in Chap. 8 of this volume), a study was undertaken to survey the use of GIS among regional land managers and planners to determine their level of expertise and interest in using GIS to address water resource issues and determine whether the geospatial products prepared by the Maumee Watershed GIS Project were of use and sufficient for their needs. An online survey was conducted by a selected sample of individuals and agencies involved in some capacity with regional planning and water management within the watershed. Results indicated that although there was a great interest in GIS and other spatial data sets, the understanding and application of these to assist with watershed issues was not always clear or extensive. Potential users of the data sets valued the ability to be able to access key information at one online site and also the ability to view and create a variety of many products. Surprisingly over

40 % of the respondents indicated that they did not foresee using the online data site for watershed planning efforts, results that suggest further work is needed to better bridge the gap between the development of geospatial products intended for watershed planning and the users of such data. The study reveals both the opportunities and challenges for connecting those working in the fields of water resource management and watershed planning to the potential important and useful geospatial products available or that could be produced and consider carefully how such data and information could be most useful to assist with decision-making for addressing urban water issues.

Gerwin and Lawrence discuss how GIS driven databases on water quality and ecosystem health indicators for urban streams can be compared to changing land uses in areas of increasing residential and industrial land uses in order to determine the significance of impacts from these changes on stream conditions. During a study of several small streams that drain into Lake Erie, research was conducted to determine whether the trend of urbanization in these watersheds was resulting in declining aquatic ecosystem health. Landsat imagery was used to classify the major land cover/land use types with specific interest in the growth of the urban class. Spatial analysis was then completed within ArcGIS to classify the predominate land cover/land use adjacent to the stream channels, which were linked to the locations where stream sampling had been conducted to assess the condition of the stream ecosystem by use of standard quantitative measures developed by management agencies. Multiple regression analysis was completed to determine whether there was any significant relationship between land cover/land uses adjacent to the streams and their environmental conditions. Although the results of that analysis were inconclusive, a number of other factors related to stream conditions were also examined that indicated key issues in management that are of concern in regards the aquatic ecosystem health of the streams, including excessive channelization, upstream sources of bacteria, sediment and nutrients, and overall lack of aquatic vegetation in the streams. Such studies of the impacts of land cover/land use changes in historically rural landscapes will be increasingly important in many regions of the world where such current and future changes potentially place large numbers of streams, important for drinking water and habitat for natural species, at greater risk.

A growing concern in many water bodies is the potential for the harmful impacts that would result from the contamination of water resources following an oil spill disaster. Dean and Lawrence illustrate the preparation of an emergency response plan for just such an event in the Western Basin of Lake Erie, part of the Great Lakes Basin in the United States and Canada. This chapter outlines the steps necessary to build an online interactive and digital plan for the use during an oil spill emergency where information on infrastructure, equipment, access, site conditions, and environmental factors would be critical to a timely and successful response. In working with the key federal, state, regional, and local agencies and organizations charged with the preparation and – if needed – implementation of oil spill responses in the Western Basin of Lake Erie, the study utilizes the organization of existing geospatial data sets including transportation networks, lake and shoreline physical characteristics, weather and climate, navigation data, along with aerial and satellite imagery in proposing for an integrated online GIS based model for emergency responses. Numerous data layers are identified and compiled as the basis for such a plan which would include information and data on the shoreline environmental sensitivity, land management arrangements, key infrastructure such as marinas, water intakes, pipelines, shipping facilities, and boat launches. The data are organized into a series of digital files that represent the key components of a protection strategy for the western basin of Lake Erie in the contingency of an oil spill event. The chapter also provides examples of a protection and response strategy for a selected site within the basin by illustrating steps that would need to be taken to protect a critical habitat area and demonstrates the utility of a geospatial tool for oil spill response planning through providing an example of its use during a simulated oil spill scenario event. The work highlights the important role that GIS and spatial data can play in addressing appropriate and responsive actions necessary following major environmental disasters and how such technologies are increasingly becoming important and applicable to these events.

As a collection, the chapters in the volume provide an assemblage of ideas, concepts, methods, and results that illustrate how various geospatial technologies can be applied to many typical water challenges in urban and urbanizing areas. As these advances in techniques continue, their application can be considered in examining and better understanding practical and helpful solutions to the management and planning for the valuable water resources in our cities, towns, municipalities, and communities during a period of time in which human populations are rapidly expanding in urban areas worldwide, presenting a myriad of concerns and challenges we as a society so importantly need to address.

Patrick L. Lawrence

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Chapter 1
GIS: A Useful Tool in Urban Water Management

Indranil Seth

Abstract The chapter talks about the role of Geographic Information Systems (GIS) in the development of urban water management. Use of spatial data in electronic format has replaced the old process of studying hard copy maps and other documents to gather information to solve urban water issues. The chapter introduces GIS, GIS data and GIS operations to the reader and then goes on to talk about the role of GIS in urban water management. GIS can analyze the spatial data itself or preprocess it as input data for urban water management models. The chapter talks about how GIS can be integrated with urban water management models and also how other tools can play a role in this system to enhance urban water management decisions. The integration of GIS and the urban water management models is very productive though it has some challenges of its own.

Keywords GIS • Urban water management • Spatial data • Model • Hydrology

1.1 Introduction

Today Geographic Information Systems (GIS) draw immense interest from researchers and engineers alike who are practicing their profession in the field of urban water management. Though GIS has been around since the 1960s (Tsihrintzis et al. 1996) it is only with the emergence of personal computers in the 1970s that it has found widespread use (Seth et al. 2006). Sometimes GIS is referred by users as merely a tool but there is ample historic precedent showing that a tool can stimulate science, and provoke new ways of thinking about problems (Goodchild 1995). One of many areas where GIS has made significant contributions is in the field

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of urban water management. The increasing use of GIS is an outcome of the realization of the fact that GIS can play an effective role in dealing with spatial data used in urban water management. Either GIS as a standalone tool or GIS in conjunction with other tools can be used to solve urban water problems by processing and analyzing the spatial data. One of the major challenges faced by GIS use is of having standardized and more accessible databases. Georeferencing is an important factor in using GIS. A system where GIS is coupled with urban water management models is stronger and more effective in finding solutions to various urban water problems. There is ample literature on the development of the use of GIS and urban water models. Apart from the conventional coupling of GIS and urban water models certain other tools (for e.g. evaluation tools) may be used in conjunction with the GIS-urban water model system. Integration of GIS and urban water management models in specific applications poses many challenges. This chapter provides a few examples on how some researchers have developed GIS based water management systems to meet these challenges.

1.2 GIS

GIS as a technology is designed for storing, manipulating, analyzing, and displaying data in a geographical context (Seth et al. 2006). GIS efficiently relates geographic information to attribute data stored in a database. Large volumes of spatial and non-spatial data can be overlaid and displayed using GIS (Kaden 1993). According to Hatzopoulos (2002), a GIS system is a database of all geometric elements of the geographical space with specific geometric accuracy together with information (which is in tabular form and related to the geographic location). GIS's range of abilities comprise of preprocessing data for analysis, spatial analysis and modeling directly, and post processing results (Goodchild 1993).

1.2.1 GIS Data

GIS can analyze the spatial data itself or preprocess it for water models which then can analyze the data as per specific urban water problems. GIS can also process and display the post modeling data. Spatial data is represented in GIS in vector format or raster format. In raster data there are rectangles which act as fundamental units having uniform hydrologic characteristics (Sample et al. 2001). An example of raster data would be Digital Elevation Model (DEM). DEMs can be used to study the surface terrain and also generate contour maps. In case of vector data coordinate geometry is used to define the unique boundaries of hydrologic characteristics (Sample et al. 2001). Vector data comprises of point, polygon, and line. The data (whether vector or raster) used for GIS analysis and/or urban water modeling depends entirely on the type of application. Land use maps, DEMs, soil imperviousness information maps, contours, 2D and 3D elevation maps, digital orthographic aerial photos, and piping network maps of the drainage area can be used to generate input parameters for an urban storm-water model (Seth et al. 2006). According to Van Der Laan (1992), a raster-based GIS has advantages over a vector-based GIS because virtually all types of data (attribute data, spatial data, scanned data, and DEMs) can be represented in raster format. Along with spatial data GIS also includes databases. These databases are comprised of different parametric data (e.g. soil permeability, precipitation etc.) which can be linked to the corresponding spatial data. Metadata is an important aspect of GIS. Metadata can be regarded as valuable information regarding the actual data.

Data acquisition is the cornerstone of any water resources GIS project (Tsihrintzis et al. 1996). GIS data is available from numerous sources. They may be governmental, private, academic etc. There are numerous GIS data clearinghouses (e.g. GIS Data Depot, Geospatial One Stop etc.) on the internet that can provide GIS data (Seth et al. 2006). Watershed resource inventories can provide GIS data on soils, land cover, land use, topography, geology, climate, demographics, socio-economics, water resources and water quality (Grunwald 2007). Aerial photographs are a type of data which show a bird's eye view of the study area. The National Aerial Photography Program (NAPP) and the National Agricultural Imagery Program (NAIP) are good sources for aerial photographs (Seth et al. 2006). Knowledge about GIS data is very important when one goes shopping for data. Though there is a lot of data out there one needs to be very careful in choosing the right type and amount of data for GIS operations. One of the major hurdles for the full realization of the potential of GIS is having standardized and more accessible databases (Seth et al. 2006).

If the data is not readily available then it can be created. In other words if the existing data does not meet the requirements for GIS analysis or GIS based modeling then the required data can be created. For example piping network data can be derived from hardcopy maps (Seth et al. 2006). These hardcopy maps can be scanned and digitized. The Computer Aided Drafting (CAD) drawings which are created using the above mentioned processes can then be georectified and overlaid on drainage area maps. CAD software like AutoCAD and Microstation are very useful in creating and updating these CAD files. Data can also be created using a Global Positioning System (GPS). Contour maps can be generated from DEMs (Seth et al. 2006). Soil imperviousness can be generated from IKONOS satellite images using various statistical techniques such as Fisher Discriminant Analysis (Herold et al. 2003). Also, land use GIS maps can be generated using data from regional and local agencies (Seth et al. 2006).

1.2.2 GIS Operations

A detailed discussion of the GIS operations is beyond the scope of this chapter therefore a very brief insight for the reader follows. GIS operations include data overlay and data manipulation to preprocess the input data for the water model (Haubner and Joeres 1996). GIS maps can be geocoded and georeferenced to a base data layer (Haubner and Joeres 1996). Georeferencing is an important factor in using GIS to map areas and their characteristics (Seth et al. 2006). All maps, e.g., land use, soil types, elevation, and piping network, when used together must be geographically compatible with each other. In other words, they must have the same map coordinate system. Once the data has been input into the GIS, various analyses can be done with the data to understand the changing spatial patterns of urban water data (Seth et al. 2006). For example, ArcGIS and ArcView extensions, such as Spatial Analyst and 3D Analyst can be used to develop and manipulate spatial relationships between different spatial data types (Seth et al. 2006). Hydrologic simulation results can be evaluated using GIS graphics output and spatial analysis of the post-simulation data (Xu et al. 2001). A complete control of data input and data manipulation is possible because visual display of GIS data compliments the user interface of water resources models (McKinney and Cai 2002).

1.3 Urban Water Management

Urban water management is increasingly playing a critical role in determining the readiness of urban localities to sustain steep population growth. As new sources of water become less and less likely to show up in the near future a major effort is being concentrated by environmental managers towards urban water management. The growth of urban areas can significantly change the physical properties of land surface increasing integrated vulnerability of inhabitants, agricultural land and rural ecological life supporting systems (Niemczynowicz 1999). New and existing tools are being experimented with in order to create a suite of integrated tools to serve as a system to find solutions to urban water problems. The findings from urban hydrological studies based on the calculations and modeling of urban hydrological data is a necessary fundamental for meaningful water management not only in urban areas but also in river basins (Niemczynowicz 1999). In order to turn present problems in urban water management into future opportunities new technological solutions as well as logistic and organizational methods have to be developed (Niemczynowicz 1999).

1.4 GIS and Urban Water Management

Urban water management using GIS as a standalone tool or GIS coupled with various water management models can provide solutions to urban water issues. An urban water model usually requires extensive spatial data because of the complexity of urban surfaces, flow paths, and conduits (Sample et al. 2001). Previously, the process of watershed modeling meant the study of hard copy maps and documents to collect information on land use, soil types, elevation, and piping network for a particular drainage area (Seth et al. 2006). This process is not only tedious and time consuming but also very labor intensive and prone to errors. Using spatial data to gather information on the study area is far more technically & economically feasible and less labor intensive. GIS can be used as a platform to present the spatial information in an electronic format. This would provide easy access to the data at the touch of a button and also facilitate data manipulation, data upgrade, data analysis, statistical analysis, modeling, etc. For example, in storm-water runoff determination, GIS can also facilitate better understanding of the drainage pattern of the study area as the drainage areas may be overestimated or underestimated depending upon lack of spatial information (Seth et al. 2006). According to Djokic and Maidment (1993), GIS is seldom the environment into which water system analysis methods are directly implemented. GIS can preprocess data for urban water models. The urban water models have wider capabilities w.r.t. the GIS software in regards to problem solving capabilities. The natural geographic features/boundaries of the hydrologic basin can be used as boundary conditions of a mathematical model (Sample et al. 2001). This facilitates examination of a wider range of alternatives and provides a living management that can be modified and updated once the watershed conditions change (Xu et al. 2001). Needless to say this realization has lead to the marriage of mathematical drainage models and GIS. According to Pullar and Springer (2000), incorporation of catchment models into GIS has lead to streamlining data input and better interpretation of model outputs. Therefore, GIS is a valuable and frequently indispensable tool for water-related environmental planning and management (Tsihrintzis et al. 1996).

Linking an urban storm-water runoff model and a low cost, PC-based GIS raster package can facilitate preparation, examination, and analysis of spatially distributed model inputs and parameters (Meyer et al. 1993). The same GIS package can also facilitate the display of the model results. GIS offers front-end or back-end applications of existing hydrologic models where front-end applications include the computation of watershed parameters for existing hydrologic models and back-end applications include the cartographic display of computed hydrologic simulation results (Xu et al. 2001; Shamsi 1996). Once the spatial data has been processed by GIS it can be fed into the urban water model for analysis. Analyses can also be done in the GIS itself to understand the changing spatial patterns of the data. Once the urban water model gets the processed data then it can be modeled using different management scenarios and strategies. The impacts of different urban water management strategies vis-à-vis the spatial data can be studied so as to understand the model better and choose the best strategy. Once the model has successfully modeled the strategy the resulting spatial output can be displayed with the help of GIS. Today there are a number of urban water management models available which can be integrated with GIS for analyzing water management strategies.

The coupling of GIS and water management models leads to information exchange between GIS and the model. There are several types of coupling between an environmental model and GIS and these can range from a loose coupling to a tight coupling (McKinney and Cai 2002). According to Shamsi (1998), three forms of information exchange can occur between ArcView and the Storm Water and Wastewater Management Model (SWMM): interchange, interface, and integration (listed in their order of complexity). GIS and the environmental models can be integrated in the following three basic approaches (Fedra 1993; Correia et al. 1999). In the first approach, the environmental models are built into GIS and the user has an interactive access to the coupled system. In the second approach, there is a common interface of the models and GIS with the user. Finally, in the third approach there are two separate systems, the GIS and the model, that may interchange files.

Let us look at some of the literature that is available on the development of the use of GIS in urban water models. Bellal et al. (1996), coupled GIS comprising of DEMs and land use data to a hydrologic model to study partly urbanized basins. Wong et al. (1997) showed how a landuse runoff model can be developed using a GIS coupled with an empirical runoff model. The integration of GIS and a nonpoint source (NPS) model allows managers to evaluate impacts of various Best Management Practices (BMPs) with given hypothetical conditions (Wong et al. 1997). GIS can be used to study the effective scenarios of the BMPs depending on each characteristic, e.g., water quality, water quantity, runoff pattern, piping network, percentage of soil imperviousness of the drainage area etc. (Seth et al. 2006). Xue et al. (1996) and Xue and Bechtel (1997) described the development of a BMP model called the Best Management Practices Assessment Model (BMPAM), which was linked with Arc View to create an integrated management tool to evaluate the effectiveness of BMPs. Bhaduri et al. (2000), showed how a model focused on long-term runoff and NPS pollution impacts can be developed in a GIS framework and applied to an urbanizing watershed. Xu et al. (2001), showed that the integration of GIS and a physically based distributed model may successfully and efficiently implement the watershed-based water resources management. Apart from the conventional coupling of GIS with urban water models GIS-water models can be used in conjunction with other tools or GIS can be coupled with tools other than the water model. Kim et al. (1998), showed that a Planning Support System (PSS) comprising of a GIS, an economic evaluation model, and a sewer simulation model can enhance the ability to generate satisfying sewer design alternatives depending on land use and development. The role of GIS in the PSS was of storm-water and wastewater quantity estimation, sewer networks manipulation, and display of generated sewer design alternatives. Correia et al. (1999), showed the possibility of using GIS and complementary multimedia interactive devices, as tools for the comprehensive evaluation of floodplain management policies. Weng (2001), showed that an integration of remote sensing and GIS can be applied to relate urban growth studies to distributed hydrological modeling where impacts of urban growth on surface runoff and rainfall–runoff relationship can be examined. Hatzopoulos (2002), used the integration of data modeling together with advances in GIS using Universal Model language (UML) programming for urban water management.

Integration of GIS and water management models in specific applications poses many challenges and one of them is adapting the models to the GIS environment

(McKinney and Cai 2002). It is beyond the scope of this chapter to discuss these challenges in detail. Let us look at some of the ways in which researchers have found solutions for these challenges. McKinney and Cai (2002), has shown how the object oriented method can be useful in linking GIS and water resources management models. GIS based Multicriteria Decision Analysis (GIS-MCDA) has become a popular research tool. According to Malczewski (2006), GIS-MCDA can be regarded as a process that transforms and combines geographical data and value judgments (the decision-maker's preferences) to obtain information for decision making. The tools required to fully support an important hydrologic decision are very complex therefore an integrated suite of tools is required and these tools are referred to as Decision Support Systems (DSS) (Sample et al. 2001). The evolution of DSS may be seen as a natural extension of simulation models, GIS, relational databases, and evaluation tools (Sample et al. 2001). Furthermore, Sample et al. (2001), says that the best value for the time and investment in GIS use in urban storm-water modeling and management is when it is integrated into a DSS. Makropoulos et al. (2003), talks about how the development of a Spatial Decision Support Systems (SDSS) in urban water management with a distinct spatial character as an indispensible tool can assist in the decision making process.

1.5 The Future

In the years to come urban hydrology as an applied science will play an ever increasing role in the sustainability of human societies (Niemczynowicz 1999). Therefore GIS use in the field of urban water management has the ability to grow to new heights and set an example for other areas of environmental sciences. We as scientists and engineers need to fully tap on this potential. To make GIS a more prominent feature in urban water management, scientists and engineers have to work with GIS specialists and eventually be trained by them (Seth et al. 2006). The strength of GIS can become a link between specialists and nonspecialists to help them communicate effectively (Sample et al. 2001).

As mentioned earlier one of the many challenges associated with the integration of GIS and water resources management models is adapting models to the GIS environment (McKinney and Cai 2002). Working with spatial data can also be challenging. Acquiring, maintaining, and utilizing the extensive spatial databases required in increasingly used distributed, physically based urban storm-water management models has to be performed by urban water managers (Meyer et al. 1993). A number of socio-economic and environmental factors affect water quality management issues which is becoming more complex and diverse (Huang and Xia 2001).

There is a another school of thought that says that though GIS has to play an important role in urban water management it should not be the sole driving force behind the growth of urban water management. According to Sui and Maggio (1999), users should not be blinded by the fancy maps and graphics of GIS and forget about the real issues of hydrological modeling. One of these issues is a broad conceptual problem in the loose/tight integration of GIS and hydrological modeling because it is merely technology-driven (Sui and Maggio 1999). Instead of being dictated by GIS, hydrologic modeling development should be GIScience based and there should be a coherent spatial-temporal framework consistent with both GIS and hydrological models (Sui and Maggio 1999).

GIS data sources may undergo some changes in the future. To this respect, Seth et al. (2006), has proposed that national and regional level GIS repositories need to be created which can be updated from time to time. These data repositories have to be accessible at the local as well as at the national level. A central body at the national level needs to be established to issue guidelines for local agencies to standardize their GIS data and capabilities (Seth et al. 2006). For example, State and county level agencies managing GIS data such as Wisconsin Department of Natural Resources (WDNR) and Southeastern Wisconsin Regional Planning Commission (SEWRPC) should interact with United States Environmental Protection Agency (USEPA) to make their GIS data more accessible (Seth et al. 2006).

One should always keep in mind that a major hurdle in using GIS technology is obtaining the right kind of data (Seth et al. 2006) from the right source. GIS files should always be compatible with updated data managing and processing software.

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Chapter 2
Identifying the Water Conservation Potential of Neighborhoods in Phoenix, Arizona: An Integrated Socio-spatial Approach

Kelli L. Larson, Dorothy C. Ibes, and Elizabeth A. Wentz

Abstract A key strategy for sustainable water resource management in cities is enhancing water use efficiencies in the residential sector, which accounts for a significant portion of overall demand. Through a novel approach integrating metered water use with social survey data in a Geographic Information System, we examine how residents' perceptions about water consumption correspond to actual residential demand in Phoenix, Arizona neighborhoods. By integrating disparate research approaches, we develop a typology characterizing the socio-spatial relationship between water use, perceptions, and additional determinants of neighborhood water demand. Our findings reveal areas where perceptions do and do not correspond with actual water use rates, thereby informing conservation efforts. Of critical importance to water managers, we pinpoint areas where reducing high consumption rates are confounded by residents' perceptions of low usage rates.

Keywords Water conservation • GIS • Water use • Demand planning

2.1 Introduction

By 2025 two billion people worldwide will face water shortages (WHO 2008). Although water scarcity in relatively poor, undeveloped countries is a critical consideration for meeting basic water needs, wealthy developed nations are also at risk. Because per capita water demand in developed countries is ten times higher than in poorer nations (Kirby 2003), the potential for enhanced water use efficiency is substantial. The risk of water scarcity is perhaps most pronounced in arid cities,

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where rising demands for an increasingly scarce and highly variable resource threaten the "challenge of absolute water scarcity" (Vörösmarty et al. 2000, 287). The U.S. Southwest is particularly vulnerable given historic mega-droughts that have reduced regional water flows to as low as 25% (Monroe 2008). Predictions of a warmer, drier climate will also likely reduce local watershed runoff in the future (Ellis et al. 2008). Situated in the rapidly growing city of Phoenix, Arizona, our study identifies 'hot spots' of high water consumption relative to various determinants of demand in order to assist conservation planning through a targeted, place-based approach.

In particular, we integrate typically disparate datasets and research approaches using a Geographic Information System (GIS) while applying qualitative and quantitative methods to examine perceived versus actual water demand for residential neighborhoods. Considering local perceptions as well as other household and property characteristics (i.e., income, housing age, and vegetative land cover) as critical determinants of demand, our integrated geospatial approach can help to tailor water conservation initiatives to the particularities of places for enhanced effectiveness. Although already significant, the portion of regional water demand attributed to residential uses is expected to grow as houses replace farms and native desert areas in metropolitan Phoenix, AZ (Wentz and Gober 2007). This development involves a shift of land as well as water from farms to households, and as a result, municipal water use will soon overtake agriculture as the leading sector of region-wide demand (Larson et al. 2009b; Keys et al. 2007). In the City of Phoenix (2005), 66% of total municipal demand is used for residential activities, primarily for outdoor purposes such as irrigation and the maintenance of swimming pools in single-family households.

According to Wentz and Gober (2007), three of the four factors determining neighborhood water demand pertain to outdoor water use: lot size, pool ownership, and groundcover type (i.e., irrigation-dependent grasses versus drought-tolerant alternatives). The fourth significant determinant in their demand model was household size, which increases residential consumption due to a greater number of people living in households. Building on this work, which also illustrated distinctive spatial patterns in the determinants of water demand, our mixed-methods study examines residential demand in relation to perceptions and other known drivers of water use, and by extension, local conservation potential.

Our primary study unit is the neighborhood, the scale at which the determinants of water demand (such as household and property attributes) often operate to influence locally differentiated rates of consumption (Aitken et al. 1991). Few water demand studies have been carried out at the neighborhood scale, which we define by census block groups. The integrated methodology offers a geospatial approach to understanding the relationship between perceptual judgments about water use rates, as gathered through a social survey, and actual demand, as observed through household meters in the City of Phoenix, AZ. The application of our findings expands beyond geospatial sciences and human-environment research to inform targeted conservation programming and environmental planning. While identifying areas of low to high demand, we explore the socio-spatial distribution of human-environment interactions by creating a typology of neighborhoods where residents' perceptions do and do not correspond with actual, local water use rates.

Beyond perceptions, we overlay additional determinants of demand—as identified in previous studies (e.g., Loh and Coghlan 2003; Wentz and Gober 2007; Harlan et al. 2009)—to consider how conservation tools might be most effectively targeted to neighborhoods for enhanced water-use efficiency. While marketing or educational materials may appeal more to perceptions and personal ideals about environmental stewardship or knowledge about how to reduce outdoor water use, for instance, regulations or incentives for retrofitting landscapes or household appliances may be more effective where infrastructure or other structural factors significantly influence demand.

The most critical neighborhoods are those where demand is high, since they represent the greatest potential for reducing water use. In areas where perceived water use is low, moreover, tailored conservation messages could shift perceptions while locally instilling a heightened sense of efficacy and responsibility for conservation among residents. Conversely, in high-demand areas where people are aware of consumption rates, other tactics that address non-perceptual drivers of demand (such as irrigation mandates or incentives to convert irrigated lawns into drought-tolerant yards) may be necessary to reduce water use rates. Overall, understanding the relationship between perceptions of water use and actual demand may help to create environmental awareness and resource stewardship in diverse urban neighborhoods.

2.2 Study Background

2.2.1 Mixed-Methods Research

Mixed-methods research involving quantitative and qualitative data analysis has been described as "an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspectives, positions, and standpoints" (Johnson et al. 2007: 113). Our mixed methods approach compares survey data capturing subjective judgments about water use (recorded on an ordinal response scale) to neighborhood demand (measured as the volume of water used by households). Along with combining different datasets into a GIS to assess spatial patterns, we conducted statistical cross-tabs and developed a typology of low to high water-using neighborhoods with varying drivers of demand. This integrated methodology allowed us to examine environmental perceptions in relation to actual resource conditions, while understanding which drivers of consumptions are most critical in particular places. Originally, mixed-methods research evolved from the concept of triangulation, which employs multiple sources of information to confirm that empirical findings are not simply a product of a particular method (Campbell and Fiske 1959; Johnson et al. 2007). More recently, recognition of its utility has expanded to embrace the ability of mixed methods to substantively provide a more comprehensive understanding of complex human-environmental phenomena.

Ruddell (2009), for example, compared qualitative judgments captured by survey data to quantitative measures of environmental conditions—specifically temperature—across diverse neighborhoods in the Phoenix region. In particular, survey respondents noted whether they perceive their neighborhood to be more, less, or as hot as other neighborhoods in the region during 2005. Findings revealed the lack of a statistically significant relationship between qualitative judgments and quantitative temperatures at the aggregate regional scale, but a strong, positive correlation prevailed at the localized neighborhood scale. These results suggest that human-environment relationships may vary depending on the scale of analysis, with stronger relationships between perceptions and actual environmental conditions at the relatively proximate, neighborhood scale.

The relationship between perceptions and actual human-environmental conditions may depend on the nature of the phenomena being studied. For example, the relationship between perceived versus actual water use may deviate from climate conditions, for which local experiences of heat might render perceptions similar to actual temperature patterns. With respect to water use, however, we expect varying relationships between perceptions and actual demand.

Mixed-methods approaches are important for understanding complex human environment relations. Such information can inform planning and decision making. By bringing together data on water use rates, re-lated human-ecological judgments, and other determinants of consumption, our study highlights opportunities for mixed methods research while supporting urban planning and demand management efforts. In addition to obvious strengths, mixed-methods approaches pose substantial obstacles (Johnson and Onwuegbuzie 2004). To provide insights on how to integrate disparate, multidisciplinary ideas, datasets, and analytical perspectives, we also reflect upon the challenges for mixing methods herein. First, though, we explain why we focus on particular drivers of demand, including perceptions and social-structural characteristics of households and parcels.

2.2.2 Determinants of Water Demand

Previous research has investigated the determinants of water demand, concentrating on the relationship between metered water use and household and parcel-level characteristics. Our approach draws upon past work by examining three critical determinants of demand—affluence, housing age, and landscape vegetation. We also integrate attitude theory by considering cognitive judgments about water use as another factor potentially influencing local water use rates. As further explained in the following sections, we then consider which types of conservation programming would be best suited for neighborhoods with varying water-demand characteristics based on integrated understanding of consumptions rate, perceived water use and other determinants of residential demand.

Most urban water demand studies have linked household consumption to household-level demographic and property characteristics. Because of their importance in the study area, we focus on landscaping, housing, and socioeconomic factors as critical determinants of demand. Due to the rising importance of outdoor water uses, factors such as the spatial extent of irrigated lawns, swimming pools, and large lot sizes significantly increase residential water consumption (Wentz and Gober 2007; Syme et al. 2004; Domene and Saurí 2006). As a result, conservation campaigns have recently focused on shifting water-intensive lawns to ‘xeric’ (or dry) yards with rock groundcover and drought-tolerant plants (Larson et al. 2009a). We focus on the amount of grass and other vegetation in neighborhoods, in part because vegetative cover and irrigation practices are more malleable than lot size and pools. Where demand is high due to an abundance of grass, conservation programs could offer incentives to convert lawns to more efficient alternatives or provide information about how to efficiently irrigate lawns.

Reduced indoor water consumption has been linked to the presence of water saving devices and appliances in homes (Renwick and Archibald 1998; Loh and Coghlan 2003). Since newer homes tend to have more efficient appliances, we examine the age of housing in relation neighborhood demand. Where water use is high because of aging or outdated infrastructure, conservation programs could most effectively employ rebate programs or technical assistance to retrofit those households. In an evaluation of residential conservation in Phoenix, Campbell et al. (1999) illustrate that appliance retrofit programs were especially successful when targeted to particular areas, including those where elderly populations may have difficulty installing new appliances such as low-flow toilets. Beyond the efficiency of infrastructure, housing age in the study region also corresponds to historic access to flood irrigation in older areas of central Phoenix. In these older neighborhoods, which commonly have larger lot sizes and more grass relative to newer residential developments, household water use may appear lower than it actually is since flood irrigation for lawns is allocated separately from metered water bills.

Wealth has also been associated with high water use rates in urban areas, both in terms of income (Baumann et al. 1998; Corral-Verdugo et al. 2003; Domene and Saurí 2006) and property values (Aitken et al. 1991; Dandy et al. 1997). Affluence, in fact, was shown to substantially influence water consumption in a recent Phoenix study that controlled for family size and other factors including attitudinal judgments (Harlan et al. 2009). As the authors explain, theories of consumption suggest that people’s desire to achieve success and social status are conspicuously marked by acquiring private possessions and living consumptive lifestyles. In the pursuit of personal satisfaction, therefore, wealthy people can afford to fill their homes and yards with material products (such as pools and appliances) that ultimately increase water use. Therefore, in affluent areas where water use is high, demand management programs might appeal to people's personal identity and sense of prestige by instilling conservation (rather than consumption) as a social standard or norm. By fostering the expectation of stewardship, residents could be encouraged to conserve water through water-efficient irrigation practices, the use of pool covers, or other means targeted to interests in achieving social status and respect. While monetary incentives are less likely to work in wealthy neighborhoods in which people can bear the costs of consumptive lifestyles, recognition-based stewardship programs or mandates on wasteful water use practices might be relatively effective ways to reduce water use.

Overall, specifically targeting conservation strategies based on the characteristics of neighborhoods can enhance the success of programs that aim to reduce water demand, especially considering that water use varies spatially along with neighborhood-level determinants of consumption (Wentz and Gober 2007). For instance, while lot size was most critical in wealthy areas to the northeast and south of downtown Phoenix, the presence of pools in the urban center especially lead to increased demand locally, perhaps due to the urban heat island's effect on water demand (Guhathakurta and Gober 2007). Such spatial patterns are considered in our typology analysis, but first, the role of attitudinal judgments in determining demand and enhancing conservation is explained.

2.2.3 Perceptions and Human-Ecological Judgments

In addition to demographic and structural characteristics of households, residents' perceptions and other subjective judgments may also affect water consumption and conservation behaviors. Balling and Gober (2007) reason that people's outdoor irrigation practices are determined more by how much water they think their landscape needs than by actual vegetation needs. Broadly, attitude theory distinguishes between three types of judgments that potentially influence human behavior (for reviews, see Dunlap and Jones 2002 and Larson et al. 2011): affective or emotional responses to particular phenomena, such as concern about water scarcity; cognitive judgments about the way the world works, including beliefs about how people impact the environment; and, conative or behavioral attitudes that reflect people's intentions to act in a certain way, for example, to conserve water. Previous research has illustrated that concern about water scarcity does not lead to diminished water use in Phoenix, AZ (Harlan et al. 2009). Similarly, affective judgments about the importance of conservation did not lead to reduced water consumption in a San Antonio, TX study (De Oliver 1999). Yet others have shown that positive attitudes about behaviors, along with a sense of efficacy and other cognitive judgments, lead to conservation practices in at least some cases (Trumbo and O'Keefe 2001; Corral-Verdugo and Pinheiro 2006).

In our research, we assess cognitive perceptions about the amount of water residents' use relative to others, since these judgments might influence water use behaviors while also potentially hindering conservation efforts. As Corral-Verdugo and Pinheiro (2006) report, people who perceived others as wasting water were less likely to conserve water in a Mexico-based survey study. Thus, where residents perceive their water use to be less than others, they might actually be less willing to conserve, and therefore, they might exhibit relatively high water-use rates. More generally, high consumption rates may partially reflect a lack of awareness about water demand, such that residents are not motivated to conserve because they think water use is already low. Alternatively, residents who perceive local consumption to be high may have a greater sense of responsibility or efficacy for conservation. If perceptions accurately reflect resource use, however, demand might be low where perceptions of water use are low, or demand might be high where residents' perceived uses are high.

Overall, although numerous studies have found discrepancies between intuitive human judgments and environmental behaviors or conditions (e.g., see Slovic 1987; Stern 2000), other empirical studies have shown influential relationships between perceptions or other attitudinal judgments and water-use practices (e.g., Trumbo and O'Keefe 2001; Corral-Verdugo and Pinheiro 2006). Kurz (2002) proposed that the unreliable relationship between perceptions and behavior necessitates the examination of environmental practices in relation to human judgments and a suite of other potential explanatory variables for specific environmental issues.

Given conflicting findings on the relationships between expressed judgments and observed practices, we specifically examine areas where residents' perceptions of local water use rates do and do not correspond to metered water consumption in Phoenix neighborhoods. We then consider how other determinants of demand, as illustrated by previous studies, explain spatial variation in metered water use rates, perceptions, and possibly their relationship to each other.

2.2.4 Conservation Programs

In part because different policy tools target distinctive determinants of demand and varying motivators for human behaviors (Schneider and Ingram 1990), a mixture of conservation approaches is typically more effective than applying a singular tactic to diverse settings. In Albuquerque, New Mexico, for example, a conservation program encompassing incentives, education, and price increases substantially reduced municipal water demand, even when controlling for climatic factors (Gutzler and Nims 2005). The City of Phoenix has similarly sought to reduce water consumption through varied approaches such as retrofitting houses with water-saving devices, mandating low-flow fixtures, educating the public about conservation, and implementing pricing schemes. Following an analysis of the various conservation techniques used by the city, Campbell (2004) found that pricing, regulation, and repeated personal communication have the greatest potential for significantly reducing residential water demand.

Additionally, while educational water conservation mailings proved ineffective, targeted outreach to children and assistance programs for the elderly yielded promising results. Balling and Gober (2007) further underscore the effectiveness of targeted, multifaceted approaches to conservation, concluding that a demand management program including installation of water saving devices, pricing structures, and educational initiative would be the most effective means of enhancing water use efficiency in Phoenix.

As a whole, the success of different conservation tools depends on the most critical structural and attitudinal (or cognitive) determinants of demand and conservation practices, which may vary in their effect across space and time. Though some factors driving residential water use may be relatively unchangeable, such as the presence of a pool or the size of a house, conservation programs may be able to impact water consumption by altering perceptual drivers as well as land-cover types (e.g., on large lots) and irrigation practices (e.g., in grassy or heavily vegetated yards). Ultimately, conservation programs directed at the specific barriers to reducing water use in particular areas hold great potential for enhancing water use efficiency.

2.3 Methodology

2.3.1 The Phoenix Area

Our study covers diverse neighborhoods in the City of Phoenix. With a population over 4 million people as of the 2010 census, the Phoenix metropolitan area is located in the Sonoran Desert of the U.S. Southwest. Average summertime temperatures can exceed 105°F, with an average annual rainfall of less than 7 in. This low rainfall means that the growing population of Phoenix must rely on water sources that extend beyond the boundaries of the city. Primary water sources are the Salt and Verde Rivers and non-renewable groundwater, in addition to the relatively distant Colorado River. Although urban and suburban residential developments have typically replaced agricultural land in the past, thereby allowing for the transfer of water from farms to houses, new homes are increasingly being built on native desert land that lack access to water resources (Keys et al. 2007). In short, the region has historically had a secure and diverse water portfolio, but increasing demands on ultimately limited water supplies combine with a potentially warmer and drier future to pose uncertainties and challenges to sustainable water resource management in the region. Comparatively high rates of water consumption, moreover, necessitate attention to demand management (Larson et al. 2009b).

2.3.2 Data Sources

Residents' perceptions about water consumption were evaluated by the 2006 Phoenix Area Social Survey (PASS), which followed a multi-step sampling scheme coupled with an ecological study design. First, 94 residential monitoring sites in the Central Arizona– Phoenix Long-Term Ecological Research (CAP LTER) project were categorized into eight groups based on location in the metropolitan region (core, suburban, fringe, retirement communities), median income (high, middle, low), and ethnic mix (predominately white/Anglo or minority). Five neighborhoods, defined by census block groups, were then selected from each of these groups (n = 40) to represent varied socioeconomic and geographic conditions across the region. For each sampled neighborhood, the survey obtained approximately 20 individual responses. Sampled households were given the option to complete the survey online, on the phone, or in-person, and either in English or Spanish. With a final response rate of 51% (n = 808), 73% of respondents were White and 19% were Latino, and 56% of survey respondents were female (Harlan et al. 2007). About two-thirds of the survey respondents had at least some college education, and the median household income for PASS participants was approximately $60,000.

Sixteen PASS neighborhoods reside within the boundaries of Phoenix proper, while the remaining neighborhoods are located in surrounding municipalities. Our analysis herein focuses on the Phoenix neighborhoods for which we also have metered water demand data (n = 322 households in 16 neighborhoods). The analysis employed the following question from the survey to measure residents' perceptions of personal water use: How much water do you think your household uses compared to other similar households in the Valley? Residents responded on a five-point ordinal scale: (1) "much less water," (2) "a little less water," (3) "about the same amount of water," (4) "a little more water," (5) "much more water." With 316 valid responses to this question (excluding "don't know" and 'refuse to answer' responses), our integrated assessment examines individual- and neighborhood-level perceptions in relation to local, aggregate demand.

To protect the privacy of individual water customers, the City of Phoenix provided us with annual water-consumption data (in 100 cubic feet, or *CCF*) at the census block group (CBG) level. Representing neighborhood demand, the metered water-use data analyzed in this study is the total for single-family residences (SFR) in 2005, which closely matches the temporal scale of the 2006 survey data. For each of the 998 neighborhoods, or census block groups, we calculated the average gallons per capita daily (*GPCD*) from the City of Phoenix water records.

Using Eq. (2.1), we estimated the average per capita consumption rate.

$$GPCD_a = \frac{CCF_a \cdot 748}{n \cdot HH_a \cdot 365} \tag{2.1}$$

Where *GPCD* is the estimated Gallons Per Capita Daily for each census block group *a, CCF* is the total annual household water use in 100 cubic feet, *n* is the total number of metered households obtained from the City of Phoenix, and *HH* is the average household size based on the US 2000 Census. Metered demand values (in GPDC) for each neighborhood were analyzed in relation to both individual- and neighborhood-level perceptions based on the demand rates for the census block group in which survey respondents were located. Some residents in our study area received water from the Salt River Project (SRP) through a flood irrigation system that is separate from metered water use. Those properties that receive SRP flood irrigation appear to use less water than they actually do, based on our observed demand rates. This represents a limitation to our analysis, as does the lack of household-level, metered water-use data. These issues and other challenges in mixed-methods research are further described after we present the results of our analysis.

2.3.3 Analyzing Geospatial Human-Environment Information

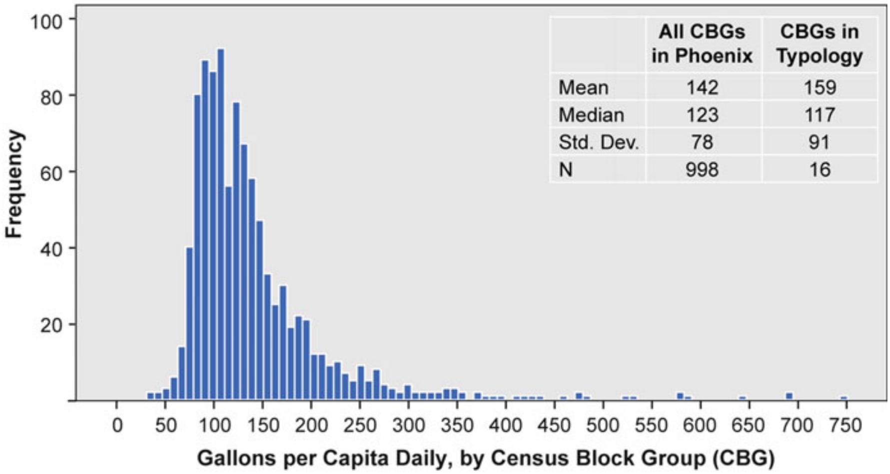
Focusing on neighborhood as the primary unit of analysis, we utilized mixed methods to:

1. describe socio-spatial trends in actual versus perceived demand in Phoenix;
2. identify the extent to which perceptions and actual water use do and do not correspond across varying neighborhoods; and,
3. explain the patterns of single-family residential water use relative to perceptions and other key drivers of demand.

First, we calculated descriptive statistics and created histograms and maps to evaluate the distribution and socio-spatial patterns of actual and perceived water demand. Second, we categorized metered demand and perceived use as relatively low, moderate, and high to illustrate where matches and mismatches occur through cross-tabulations of the two variables. Specifically, actual water use was categorized based on equal intervals to reflect low, average, or high demand as, respectively, 0–100, 101–200, and >200 GPCD. Individual perceptual judgments, originally recorded on a 1–5 Likert-type scale, were also converted into three categories wherein responses of 1 (*much less*) and 2 (*a little less*) were classified as low perceived use, 3 (*about the same*) as average, and 4 (*a little more*) and 5 (*much more*) as high perceived use. To capture collective perceptions by neighborhood, equal intervals were used to classify mean perceptions, wherein <2.5 was classified as low, 2.5–3.5 as average, and >3.5 as high perceived use. In the third step, we developed a typology of 16 in-depth case study neighborhoods, where we have both types of data, to illustrate the relationship between low to high demand, related perceptions, and other critical determinants of water consumption locally. Finally, we recommend how information from our integrated socio-spatial analysis might be used to strategically target diverse geographic areas with the most effective conservation programs and policies.

2.4 Results

Actual water use rates were highly variable (Fig. 2.1), with the highest water demand rates in wealthy, moderately aged neighborhoods. Meanwhile, residents largely view their use of water as low to average but typically not above normal



	All CBGs in Phoenix	CBGs in Typology
Mean	142	159
Median	123	117
Std. Dev.	78	91
N	998	16

Fig. 2.1 Single-family residential water demand by Phoenix neighborhoods (Census Block Groups, or CBGs)

consumption (Fig. 2.2), which could hinder conservation initiatives. While half of the neighborhoods underestimated their consumption, the other half held perceptions that matched actual water demand rates. All of the high-use neighborhoods fell under the perceptual categories of low or average water demand. Although statistical analyses determined no significant correlations between perceived and actual water-use rates as a whole, our integrated analysis and neighborhood typology offer insights for enhancing the effectiveness of water conservation efforts based on perceptions and other critical determinants of demand.

2.4.1 *Socio-spatial Patterns of Water Demand and Perceived Use*

Per capita water use rates across Phoenix census block groups (n = 998) ranged from 32 to 746 GPCD (see Figs. 2.1 and 2.2), with a mean of 142 and standard deviation of 78. For the 16 neighborhoods in our typology, water demand ranged from 65 to 353 GPCD, with a mean of 159 GPCD and standard deviation of 89. Although these neighborhoods display a similar pattern of water use compared to the broader region, the very low and high water-use areas are not represented in our in-depth typology sample. Most notably, several neighborhoods had extremely high (>350) GPCD rates that are worthy of further investigation. Our focus herein, however, is the relationship between low to high water demand and perceived rates of usage for diverse neighborhoods in Phoenix. When

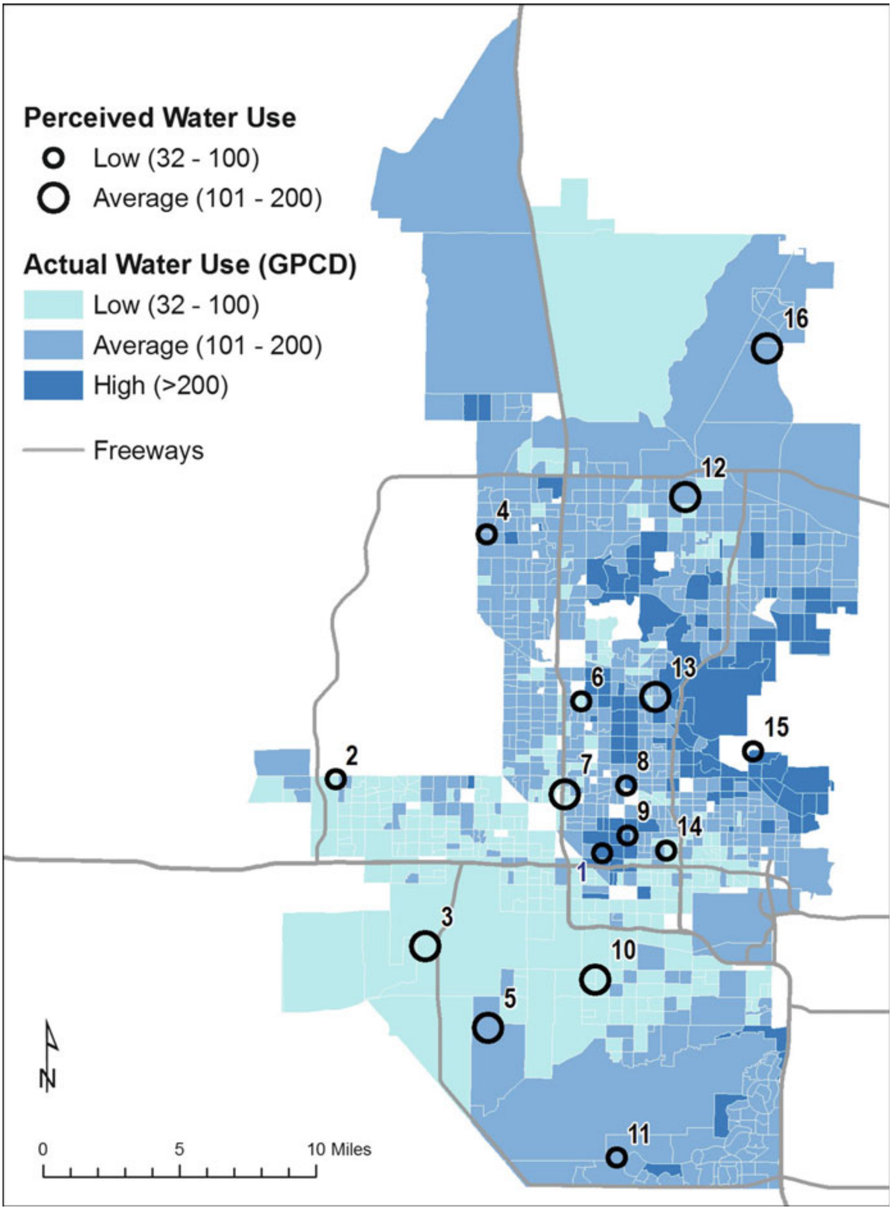


Fig. 2.2 The spatial distribution of water demand and perceptions about consumption rates by neighborhoods in the city of Phoenix, Arizona

per-capita water demand was reclassified into low to high consumption for City of Phoenix neighborhoods, 29% (n = 293) exhibited low water usage, 58% (n = 580) had moderate rates of use, and 13% (n = 125) had high consumption rates (see Fig. 2.1). For our typology neighborhoods, 38% (n = 6) fell into

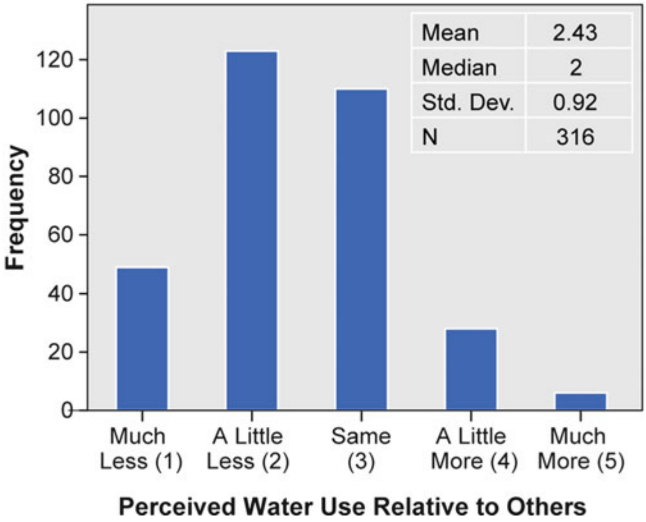


Fig. 2.3 Residents' perceived water use rates: frequency of survey responses (N = 316)

the low-use category, 38% (n = 6) had average water demand, and 25% (n = 4) exhibited high rates of consumption. While high demand neighborhoods are concentrated in east-central Phoenix, including some areas of the downtown, low-demand census block groups are distributed across the city (Fig. 2.2).

Residents' perceptions about water use were analyzed at two spatial scales to capture the individual judgments of Phoenix-based survey respondents as well as the aggregate sentiments of local residents in neighborhoods with low to high demand rates. Individual perceptions (n = 316) for personal water consumption ranged from 1 (*much lower*) to 5 (*much higher)*, with a mean response of 2.43 (i.e., a little less than average demand) and a standard deviation of 0.92 (Fig. 2.3). At the aggregated scale, mean perceptions for our typology neighborhoods (n = 16) ranged from 1.85 to 2.76, with a standard deviation of 0.25. These results suggest that residents tend to see their water consumption habits as normal, or about average, and many individuals perceive themselves as using relatively low amounts of water.

Reclassified into three broader categories to reflect perceived water use (i.e., low to high), 54% of individual respondents said they use less water than others, 35% said about the same (or average), and 11% said they use more than others. At the neighborhood scale, perceptions about water use ranged from low (56%) to average (44%), with zero falling into the high perceived-use category (Table 2.1). In terms of their spatial distribution, the Phoenix neighborhoods with both low and average perceived water-use rates were scattered around central and newer fringe areas of the city, but those where residents perceive their water use as relatively low tended to be more centrally located and in western portions of the city (Fig. 2.2). Since nearly half of the neighborhoods displayed a collective sentiment indicating a dominant perception of low consumption, our findings may suggest a weak sense of responsibility among residents for conserving water.

Table 2.1 Low to high perceived water-use categories

Level of analysis	Perceived use	Percent (N)
Individual residents (n=316)	Low	54 % (172)
	Average	35 % (110)
	High	11 % (34)
Neighborhoods (n=16)	Low	56 % (9)
	Average	44 % (7)
	High	0 (0)

Table 2.2 Cross-tabulations: perceived vs. actual water use at individual and neighborhood level

			Perceived Use: Percent (N)		
Level of analysis			*Low*	*Average*	*High*
Actual water demand (by CBGs)	Individual residents (N = 316)	*Low*	22% (70)	11% (35)	4% (14)
		Average	*19% (59)*	15% (47)	4% (12)
		High	*14% (43)*	*9% (28)*	3% (8)
	Neighborhoods (N = 16)	*Low*	25% (4)	13% (2)	0 (0)
		Average	*19% (3)*	19% (3)	0 (0)
		High	*13% (2)*	*13% (2)*	0 (0)

Note: Mismatches in perceptions and usage rates are *gray-shaded* for emphasis. *Italics* represent especially troublesome discrepancies, that is, since water demand is high relative to perceptions

2.4.2 Cross-Tabulations for Perceived vs. Actual Water Use

Integration of the datasets began with running cross-tabulations to explore patterns of low to high actual versus perceived water use based on the data that were classified into broader, ordinal categories (Table 2.2). For individual residents, 40% of the Phoenix-based survey respondents (n = 125) displayed a match between their perceived and actual water demand, with just over half of those in the low/low category. While these residents correctly perceived water use to be comparatively low, very few survey respondents (3%) in high-demand areas perceived water use to be high. Of the 79 respondents (26% of the total sample) in high demand neighborhoods, 90% perceived water use to be about average or below normal.

The majority of individuals displayed a disconnect between their perceptions and actual water demand. The most common mismatch was for average-demand neighborhoods in which residents (19%) perceived their water use as low. Second, and more troublesome, are the individuals (14%) who perceive their water use to be low but live in high-demand areas. In total, 42% of Phoenix-based respondents underestimated their water consumption relative to metered water-use rates, while 19% overestimated water demand by indicating they use average to relatively high amounts of water when local rates are actually low to average. Perhaps residents' perceptions of high use encourage conservation locally in some areas. However, our results indicate that perceptions largely do not reflect neighborhood water consumption rates, thereby potentially obstructing efforts to reduce residential water demand.

Considering perceptions at the neighborhood scale, the findings are very similar to the household-level patterns. In the aggregate analysis, the majority of neighborhoods (58%, or n = 9) exhibited a disconnect between perceived water use and actual demand rates, with most perceiving water use to be lower than it actually is. While only 13% collectively overestimated the rate of demand relative to actual metered usage rates, 45% of neighborhoods underestimated water use. For the high-use neighborhoods in our intensive sample, all five exhibited perceptions indicating low to typical rates of consumption. None of the neighborhoods in our typology sample appeared to exhibit a shared awareness of relatively high water-use rates locally, even though metered data reveals that a quarter were located in areas with high consumption rates.

Moreover, all of the neighborhoods where perceived water use corresponded with metered demand (44%) were located in areas with low to average consumption rates. Statistically, perceptions and actual environmental conditions were not correlated at either the individual level of residents (Spearman's rho = −0.018, p = 0.751) or the aggregate level of neighborhoods (Spearman's rho = 0.289, p = 0.278). The overall lack of a significant relationship between perceptions and actual neighborhood water demand indicates that cognitive judgments may have a tenuous influence on actual water use. Also, the small sample of neighborhoods with both survey and metered data available limits our understanding of the perception–outcome relationship, as discussed further below. Yet the patterns in perceptions and actual water demand—generally and in relation to each other—are informative, especially considering the structural factors that may explain neighborhood water use.

Next, in order to further reveal determinants of water demand (beyond human judgments), we complement our quantitative analysis of perceptions and actual water demand with a typology of our 16 in-depth neighborhoods for which we have both types of data. By characterizing local water use rates, related perceptions, and structural determinants of demand, our approach informs targeted conservation planning based on the factors most likely to influence water use and conservation in residential neighborhoods, especially for 'hot spots' with excessive consumption.

2.4.3 *Typology of Neighborhood Water Demand and Determinants*

In linking perceptions and other critical determinants to water consumption—namely, age of housing, annual median household income, and vegetative ground cover, the high-demand neighborhoods (n = 4) in our typology encompassed older homes and higher income residents compared to areas with lower water-use rates (Table 2.3). The one low-income ($20–40,000) neighborhood with high water demand was the oldest neighborhood in this category and the second oldest in the typology sample (n = 16). Similar to other areas, and in spite of high local demand, residents in the high water-demand neighborhoods exhibited the widespread perception of low to normal consumption. The mismatch was most extreme

Table 2.3 Typology of neighborhood water demand and determinants

GPCD	Actual use	Perceived use	Mean age of homes	Income ($k)	% Mesic cover	NBHD	SRP flood irrigation
65	Low	Low	68 years	40–60 k	10	1	Y
79	Low	Low	12 years	40–60 k	54	2	N
94	Low	Low	31 years	40–60 k	53	4	Y
99	Low	Low	49 years	20–40 k	14	6	N
92	Low	Average	9 years	20–40 k	93	3	Y
96	Low	Average	8 years	40–60 k	75	5	Y
116	Average	Low	61 years	20–40 k	19	8	Y
117	Average	Low	56 years	40–60 k	37	9	Y
177	Average	Low	15 years	> $80 k	13	11	Y
101	Average	Average	43 years	20–40 k	83	7	Y
133	Average	Average	39 years	20–40 k	85	10	N
183	Average	Average	14 years	40–60 k	25	12	N
272	High	Low	62 years	20–40 k	32	14	Y
324	High	Low	40 years	> $80 k	27	15	Y
237	High	Average	39 years	40–60 k	40	13	Y
353	High	Average	14 years	> $80k	11	16	N

Notes: *Gray-shading* highlights the neighborhoods where preceptions do not match water demand rates. As for data sources, metered water use for 2005 was obtained from the City of Phoenix; perceived water use from the 2006 Phoenix Area Social Survey (*PASS*); income data from the 2000 Census; mean age of homes from 2007 parcel data indicating the year of construction (obtained from the Arizona State GIS data repository); flood irrigation data from the Salt River Project (*SRP*); and finally, the mesic cover variable, which represents the percent of a neighborhood with vegetation cover greater than bare soil, was classified by Stefanov et al. (2001) based on 1998 Landsat TM data

(for areas where perceived use was low, rather than average) in relatively old neighborhoods. Surprisingly, though, these high demand areas have a lower amount of vegetative cover (30% ‘mesic,’ or relatively lush landscapes) than neighborhoods with low (50%) and moderate (44%) demand. This finding may be due to data limitations, such as the fact that flood irrigation is excluded from the metered demand data. Yet for our typology neighborhoods, access to flood irrigation does not clearly correspond to relatively low demand rates (Table 2.3), and overall, our findings suggest that factors other than groundcover are more critical determinants of water use.

While percent grass cover does not appear linked to neighborhood water demand rates, an interesting pattern emerged when we examined the average amount of green vegetation in areas that cognitively over- and under-estimated consumption rates (Table 2.3). First, those neighborhoods that overestimated demand had far more green vegetation (84%) than both those that underestimated demand (26%) and those that most accurately estimated demand (46%). This pattern suggests that neighborhoods dominated by less lush landscapes with fewer lawns— for example, with desert-like rock groundcover and drought-tolerant plants such as cactus might falsely perceive local water use to be low when, in fact, pools, irrigation practices, indoor appliances, or other factors lead to increased consumption rates. Thus, conservation efforts should focus not only on converting lawns and lush residential yards to non-grass, xeric alternatives, but they must also concentrate on the proper irrigation techniques and other practices that conserve water.

Comparatively half of the neighborhoods with moderate demand (n = 6) exhibited perceptions that underestimated consumption. These areas also contain older housing (mean of 38 years) compared to low water-demand areas (Table 2.3). Although less affluent than the high-demand neighborhoods, the income levels widely ranged from low ($20–40,000) to high (>$80,000). Yet the average-use areas that accurately view their water demand to be moderate have more grass and other green vegetation than other areas (64% compared to 23%). Meanwhile, residents in low-demand areas that overestimate water use had more vegetative cover than those who accurately perceive demand to be low (on average, 84% compared to 33%). These water-efficient neighborhoods, which most accurately perceive demand (i.e., to be low), also encompassed newer homes with residents of more modest income levels compared to the other areas. Thus, while perceptions about water consumption appear most influenced by the visible greenness of vegetation in residential neighborhoods, high-demand areas with older infrastructure, wealthy residents, and relatively xeric landscapes could be specially targeted for enhanced water-use efficiency (Fig. 2.4a, b).

2.5 Applications and Significance for Socio-spatial Research

Drawing on the strengths of an integrated, spatial approach, we had two primary goals in this chapter. The first was to illustrate a mixed-methods research approach and its applications to water conservation planning, and the second was to reflect on the opportunities and challenges associated with integrating diverse datasets in human-environment research. Reflecting on our methods and finding, we recommend targeted approaches for reducing residential water demand while outlining research needs for integrated socio-spatial analyses that enhance understanding of and planning for human-environment interactions.

2.5.1 Planning Applications for Integrated Geospatial Analysis

Currently, many conservation programs in the study region of Phoenix, AZ employ voluntary programs based on educational outreach and financial incentives to reduce residential demand (Larson et al. 2009b). While some previous conservation programs have been targeted to particular populations, as with a toilet-retrofit program for elderly people, many efforts to conserve water are wholesale campaigns that encourage people to reduce their consumption. Generic programs such as “Water, Use It Wisely” (http://www.wateruseitwisely.com/), which attempts to instill a conservation ethic among the broad public in Phoenix and elsewhere, may be severely hampered by the overriding perception among residents that they already use water in an efficient manner. These misperceptions must be addressed, especially in high-demand neighborhoods where seemingly

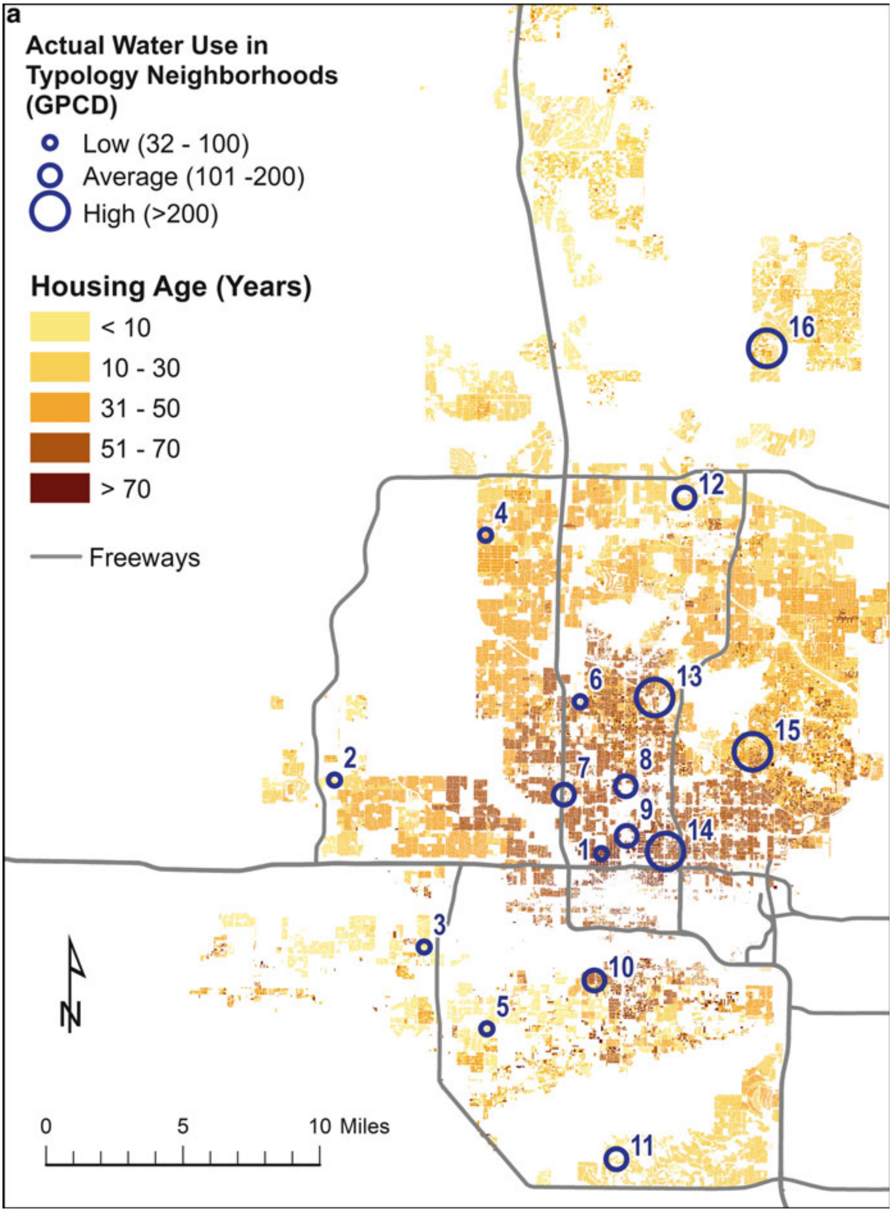


Fig. 2.4 (**a**) Mean housing age (Data from Maricopa county 2006) (**b**) Median annual household income (Data from U.S. census 2000)

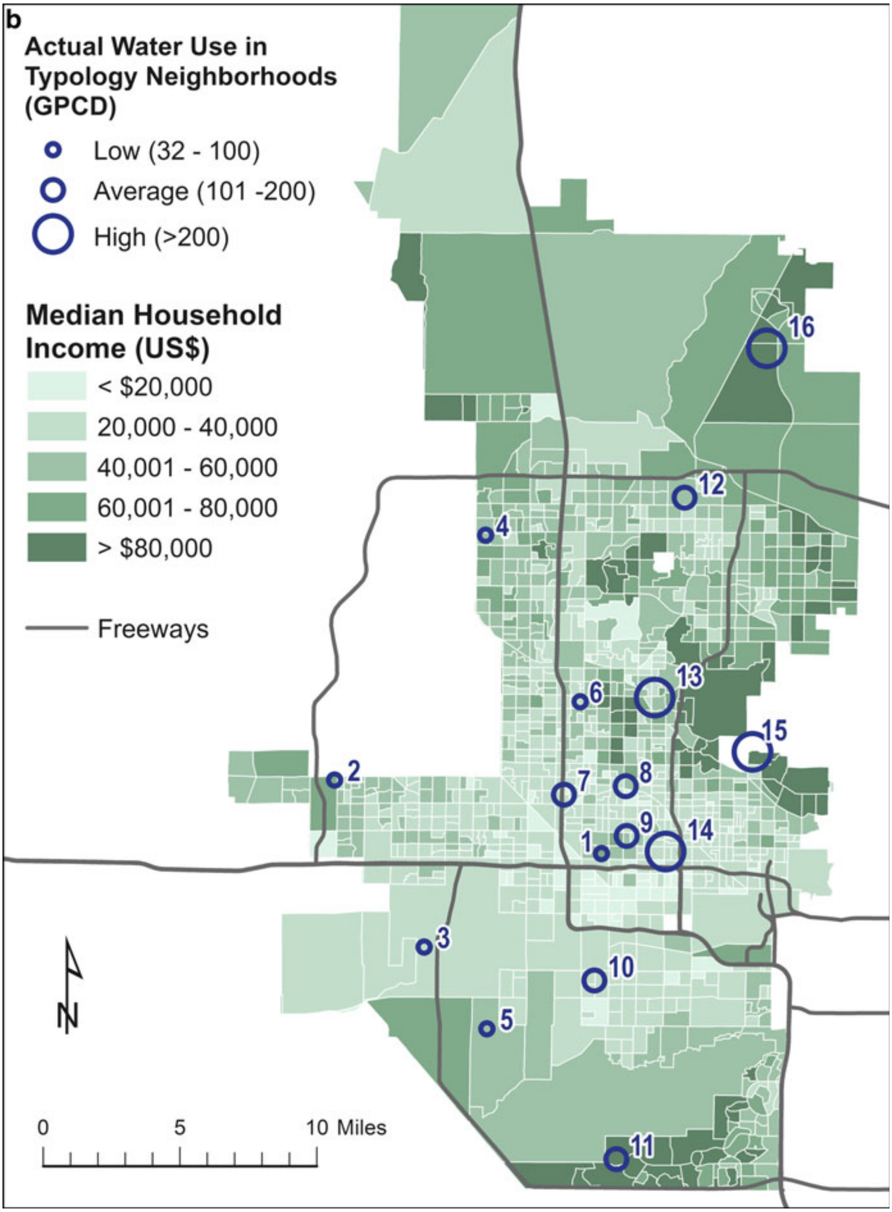


Fig. 2.4 (continued)

water-efficient, desert-like landscapes appear to leave local residents thinking they use relatively small amounts of water. In these areas, descriptive information about actual resource use (e.g., indicating high rates relative to others) and associated evaluative signals (e.g., a sad-face emoticon to suggest that high consumptions rates are bad) could motivate behavior change by raising awareness, instilling a sense of efficacy, and establishing the social expectation for conservation (Schultz et al. 2007).

As a whole, targeted outreach programs illustrating high consumption rates in areas people underestimate their usage can enhance conservation through the integration of diverse spatially referenced datasets that represent environmental conditions along with perceptions or other human judgments. In our neighborhood typology, residents most underestimated their water use in areas with relatively drought-tolerant landscapes. This finding suggests that residents who are surrounded by ‘xeric’ (dry) landscapes may be prone to view their water use as low, while those in grassy, ‘mesic’ (wet) areas with lots of green vegetation may more accurately perceive their water use rates. This result is not surprising since a popular conservation strategy in many arid cities is to promote xeric landscapes that encompass rock groundcover and drought-tolerant plants, as opposed to traditional mesic lawns, because of their water-saving potential (Martin 2001). Yet simply changing the vegetation and groundcover in yards may not be sufficient for reducing demand, as indicated by highly consumptive neighborhoods with xeric landscapes in our study.

With respect to this finding, it is relevant to note that grassy yards have been shown to significantly increase water demand across all Phoenix neighborhoods, although pools and lot size had substantially larger effects than groundcover in a study of residential demand by Wentz and Gober (2007). Thus, although low demand among heavily vegetated neighborhoods in our intensive sample may not fully represent city-wide trends, factors other than grass or vegetative cover seem to be more important determinants of demand. While we found that landscaping factors may influence the accuracy of perceptions about residential water use, our study and others (Martin 2001; Balling and Gober 2007) indicate that people’s behavioral water-management practices critically affect consumption rates above and beyond both groundcover or vegetation and irrigation technologies. In particular, residents tend to over-water drought-tolerant landscapes due to the common use of automated systems to irrigate xeric yards with rock groundcover.

While automated technologies could be managed to enhance the efficiency of irrigation, they are often not set or changed to meet the minimum plant needs or to respond to current, local climate conditions (Balling and Gober 2007). In high demand areas with relatively xeric landscapes, effective conservation efforts might entail providing specific information on how best to irrigate yards with an automated system or perhaps marketing ‘smart’ irrigation timers to enhance water-use efficiency. This new ‘smart’ technology removes some of the possibility for human error in over-watering yards by reading weather information (e.g., temperatures) from satellites to automatically adjust the irrigation schedule based on local climate conditions (e.g., how much it has rained recently).

The adoption of efficient technologies is critical not only for reducing outdoor water use. Hard-wired efficiencies (that depend less on human perceptions and management practices) are also important for conserving water indoors, especially in affluent areas with abundant consumer goods (e.g., appliances) and in older neighborhoods with outdated infrastructure (e.g., toilets). Although financial incentives or rebates could further encourage the adoption of conservation techniques such as low-flow showerheads or efficient washing machines, simply marketing ‘innovative,’ ‘high-tech,’ ‘environmentally-friendly’ technologies may alone appeal (without financial incentives) to residents who are conscious about their social identity or concerned about water conservation. This is particularly true in wealthy high-demand neighborhoods, where social status may be more important than the costs of conservation strategies. As a whole, since past survey research has shown that residents express widespread, affective concern about water conservation and related environmental issues (Harlan et al. 2009; Larson et al. 2011), conservation specialists could tap into latent concern about water use as they encourage the adoption of more efficient practices and technologies.

In sum, the integration of diverse data sources in GIS allowed us to identify areas where residents’ perceptions, along with local housing, landscaping, and social characteristics, can be best targeted to achieve water conservation in residential neighborhoods. Beyond the planning applications, our study advances knowledge about human-environment interactions and also provides insights into mixed-methods, socio-spatial research.

2.5.2 Methodological Challenges and Lessons Learned

Although mixed-methods research has proven worthwhile in validating research and enhancing knowledge, obstacles must be overcome for integrated analyses to reap the basic science and applied benefits they offer in fields such as sustainable water governance. First, and perhaps most fundamentally, acquiring data at identical temporal and spatial scales can be difficult given the disparate sources of information that capture the relevant phenomena. In our study, we were fortunate to gain access to metered water data for the same time period as our social survey of perceptions, but the availability of water-use records only at the aggregate scale limited our ability to analyze household-level water demand in relation to residents’ individual judgments in a spatially explicit manner. Where such data are available, future studies should conduct additional integrated analyses to improve understanding of how individuals’ views correspond to and influence actual household-level water demand, both in general and across varying geographic scales and contexts. Especially because the relationship between attitudinal judgments and behavioral outcomes is complex and often tenuous, mixed-methods analyses at multiple scales is essential for advancing knowledge about where and why cognition and actual conditions (or, in other words, attitudes and behaviors) correspond and how their association with other factors informs the implementation of the most effective strategies for conservation or other environmental planning objectives.

Analysis of urban-environmental systems requires the integration of data to reflect both physical attributes and subjective human understanding, and by extension, the use of quantitative and qualitative research techniques. While social surveys often collect ordinal data to capture people's subjective perspectives on the environment, integrated analyses with other data types (such as continuous water use records or categorical variables for the presence or absences of flood irrigation) is necessary to capture diverse, observable human-environment conditions. Some statistical models and multivariate tests may be appropriate for such analyses, but scale discrepancies or limited sample sizes may render only qualitative analysis feasible. With metered water demand at the neighborhood scale, we were only able to examine 16 neighborhoods for the fully integrated portion of our analyses. As a result, we developed a typology using a richly descriptive, case study approach in which we compiled an array of information on the intensive sites for which we had data on both perceived and metered water use. To achieve our main goal of identifying neighborhoods where perceptions do and do not match consumption, we coupled this analysis with a simple cross-tabulation after reclassifying the two different variables into relatively low, average, and high rates of usage.

Our combined methods of data collection and analysis reflect what was possible given the nature and availability of the variables used to capture environmental perceptions and actual conditions. Though the generalizations we can make based on conducting inferential statistics are limited by our focus on 16 neighborhoods (i.e., as the primary unit of analysis), the mixed-methods approach involving quantitative and qualitative techniques was essential for overcoming data limitations. Further, the explanatory power of our integrated analysis was bolstered by interpreting our findings in light of related studies (for example, Wentz and Gober 2007) that have analyzed the same or similar data in distinctive ways. Broadly, such approaches—engaging in "thick description" with multiple sources of information—are constructive for understanding highly contextual and multi-scalar human-environment dynamics (Adger et al. 2003).

2.6 Conclusions

Though our sample size does not allow us to make sweeping generalities, our typology reveals interesting patterns in perceived water use, actual demand, and neighborhood characteristics. The relationships between perceived versus actual water use were common across the household- and neighborhood-level analyses of perceptions. Even though the associated correlations were not statistically significant at either scale, the fact that many neighborhoods cognitively underestimate demand while others overestimate or accurately perceive consumption rates is instructive. In highly consumptive neighborhoods, which represent critical target areas for conservation, residents' perceptions indicate a lack of awareness about water use rates. This is especially true in areas with relatively xeric, desert-like landscapes, which seem to perpetuate residents' false perception of low water consumption. In order to address these misperceptions, we recommend developing informational and marketing campaigns to establish a sense of responsibility for conservation in these neighborhoods as well as to raise knowledge about appropriate watering techniques for drought-tolerate landscapes that are commonly overwatered.

Where perceived water use matches demand, however, alternative strategies might be more effective. Given that affluence and the age of housing appear to substantially influence water demand, for instance, conservation programs that encourage the adoption of more efficient technologies and infrastructure can help to hard-wire efficiencies in highly consumptive households. Utilizing GIS and mixed research methods, our neighborhood approach assists with strategically targeting conservation efforts in geographic areas with similar determinants of demand. Yet to fully understanding complex human-environment interactions, integrated research at multiple scales—from individual households and neighborhoods to municipalities and entire regions—are needed. Although socio-spatial research must overcome challenges associated with disparate data types and sources, the richness of information provided by mixing quantitative and qualitative analyses furthers holistic understanding of coupled human-environment systems.

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Chapter 3
Evaluating Collective Effects: A Participatory Approach to Mapping Public Information About Water Issues in an Uncertain and Politicized Context

Bethany B. Cutts

Abstract This chapter focuses on developing theoretically defensible and politically sensitive metrics through a participatory geographic information system (PGIS). This is particularly useful in cases where information related to a water governance problem is distributed across a variety of organizations in a variety of formats. The chapter describes a participatory mapping exercise relate to public outreach and then compare differences in available water information availability across metropolitan Phoenix, Arizona. The PGIS process led to a different set of outcomes than conventional approaches to GIS data collection and analysis. Each map uses a different combination of data aggregation (census tract, zip code, or distance buffer) and accounting method (a count or an economic proxy). This accommodates diverse data sources and participant concerns while also addressing conventional GIS concerns like the modifiable aerial unit problem.

Keywords GIS • Water use • Participatory mapping • Urban areas

3.1 The Role of Pubic Information in Water Management

In the arid southwest of the United States, as in many other regions, populations growth and climate change present dual challenges to water supply and water quality science and policy. Over the past 150 years, there has been a strong motivation to displace the desert with water intensive agricultural and domestic landscapes. This led to substantial overdrafts on many aquifers, damming on all but one major river, and construction of open canals to channel Colorado River water uphill over

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hundreds of miles (Reisner 1993). More recently, population growth in sprawling urban regions like Phoenix and Las Vegas have replaced agricultural areas. Initially, this transformation led to a decline in water use since, acre for acre, extensive (e.g., single-family-home) residential areas use less water than agricultural areas. However, development that extends beyond the traditional reach of agriculture, to the desert, and more intensive, vertical residential development will increase Phoenix metropolitan water demand beyond that previously used by predominantly agricultural systems (Gober 2005). Additionally, most climate models predict that the southwestern U.S. will become drier with precipitation occurring in fewer, more extreme events (Allan and Soden 2008). Winter precipitation in the mountains is less likely to fall as snow and the smaller snow pack will melt earlier in the spring (Barnett et al. 2008). The shift in both supply and demand will challenge water management structures that were built under the assumption that variation in natural systems occurs within a historic range of experience (Milly et al. 2008).

As with many water governance structures, public information is an important, but poorly understood policy tool[1] (Weiss and Tschirhart 1994; Steyaert and Jiggins 2007; Larson et al. 2009). The ways that Phoenix chooses to mitigate for and adapt to the impacts of climate change on water and related elements of the environment depends on the priorities of the local policy community as well as residents and their ability to make decisions or take action; as individuals and groups. Public information concerning water, established through formal and informal policy channels, can inform decision making at neighborhood, municipal, and larger political scales. The information available, and the people to whom it is available, will make a difference in the types of questions that get asked about our future and the answers that people find acceptable. Should I buy a house with a pool? Should I support a homeowner association policy to prohibit xeriscaping? Should we adopt a different price structure for water? Should we maintain groundwater stores for the future at the expense of growth? Should we try to negotiate new interstate water agreements and build pipelines to carry water from the Mississippi River? Should we elect officials who promote an economy that is less dependent on growth?

Often the ways researchers examine knowledge transfer to the public through outreach and information campaigns are not consistent with the way the public experiences this information *in situ*. In Arizona, for example, the state government mandates that water companies serving over 250 acres include an education component in their conservation strategies (Jacobs and Holway 2004). Some cities provide additional public information programs as part of an alternative to realizing reductions in per capita water use (Hirt et al. 2008). Additionally, environmental groups, museums, and other special interests also play a role in educating the community about local water issues. Each program addresses some of the ecological and social components of water conservation, water

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[1] Following Carr and Wilkinson (2005), politics are defined as the policy, legislative, management, and resource allocation decisions. In this case, the resource being allocated is public information about water supply and water quality in metropolitan Phoenix, AZ.

pollution, water transportation, and water storage. These may provide sources of corroborating or conflicting information. There has been little examination into the patterns of education created by such diverse sets of information sources.

Information provides empowerment through knowledge and through inclusion. Through decisions about where and how to provide the public with information, government agencies, non-profits, and other high-order decision making and decision influencing bodies legitimate the concerns of particular subgroups of the public by providing locally available and accessible information. The overlap in the methods and locations organizations use to provide the public with water information may create a metaphorical landscape that inadvertently acknowledges some audiences and disenfranchises others. In this case, there are two benefit streams that can be derived from receiving water information; improved familiarity with content, and the sense that your interests matter to larger decision making bodies.

3.2 Information as a Spatially Differentiated Good

Information is defined as data on the environment available to humans to evaluate, interpret, synthesize, and remember (see McCreadie and Rice 1999). This definition allows for information use to be constrained or changed by the prior experiences of users. Under this definition, information about the environment can be critical to building knowledge, instigating or changing community action, and challenging the structures of privilege (Hill 2003; McCreadie and Rice 1999; Gandy 1988; Palmquist 1992). Access to information can lead to political and decision making power (Doctor 1992; Gandy 1988, 1993). Depending on how exposure to information is distributed, it can compound or mitigate disparities in power associated with socioeconomic class or degree of social organization (McCreadie and Rice 1999).

The paucity of studies examining geography as a barrier to exposure to environmental information is partially due to a tendency for evaluations of information campaigns to focus on the outcomes of those campaigns, rather than the access to information during those campaigns (Syme et al. 2004; Noar 2006). Conversely, information seeking studies consider information exposure as an immeasurable component of the context in which information seeking occurs (McCreadie and Rice 1999). The process of gaining knowledge through information campaigns transcends organizational boundaries and relies on a series of exposures to information over time, especially when information is presented in the absence of an environmental crisis (Birkland 1997). Affecting public awareness requires repetition until new information becomes an unconscious component of decision making (Dagenbach et al. 1990; Bargh and Chartrand 1999).

Research on information seeking suggests that proximal sources of information are most likely to be used across a variety of professional settings. Doctors (Menzel and Katz 1955), research and development scientists (Gerstberger and Allen 1968), and other groups (e.g. Rogers and Shoemaker 1971; O'Reilly 1982) have frequently been found to rely on accessible forms of information over higher quality sources that are difficult to locate. Similarly, the health and environmental information literatures have acknowledged differences in information acquisition and issue-specific attitudes across rural to urban gradients (Morrone and Meredith 2003) and proximity to relevant features like rivers and lakes in the biophysical environment (Larson and Santelmann 2008; Brody et al. 2002). These literatures have also noted that information use and pro-environmental attitudes tend to correlate negatively with the degree to which an individual identifies with commonly marginalized groups (racial, ethnic, and cultural minorities, low socioeconomic status, and low educational attainment).

3.3 Objective

This research develops a method to assess the likelihood that the public encounters public information given that (a) there are differences in record keeping systems and standards across organizations and (b) public information that is provided through different mechanisms may have different impacts.

3.4 PGIS Case Study

Through interviews and surveys (described in Cutts et al. 2008), water information providers expressed an interest in understanding the spatial patterns of effort to inform the public to water about water issues in metropolitan Phoenix, Arizona. The process described here is an aim to quantify the differences in the public's exposure to these programs over the course of a year. The aim is to test the hypothesis that the effort organizations make to inform the public about water issues varies across the metropolitan Phoenix. The prediction is that regions characterized by populations typified as less engaged in environmental issues in studies of individual environmental attitudes will be less likely to live in regions of the city with a lot of locally available information so that: (1) the percent of the population that is Latino/a will be higher in regions with low information availability, (2) the percent of the population that rents their homes (a proxy for income that is not highly correlated with ethnicity in Phoenix) will be higher in regions with low information availability, (3) the larger the population of school-aged children, the greater the likelihood that the region will have high amounts of water information, and (4) the relationship between the variables above may vary across regional geographic identities of the East Valley, West Valley, and Phoenix (see Fig. 3.1). These predictions are derived from the expressed perceptions of water information providers about the characteristics of program *users*. In this paper however, I focus more specifically on the process and methods used to create the data set.

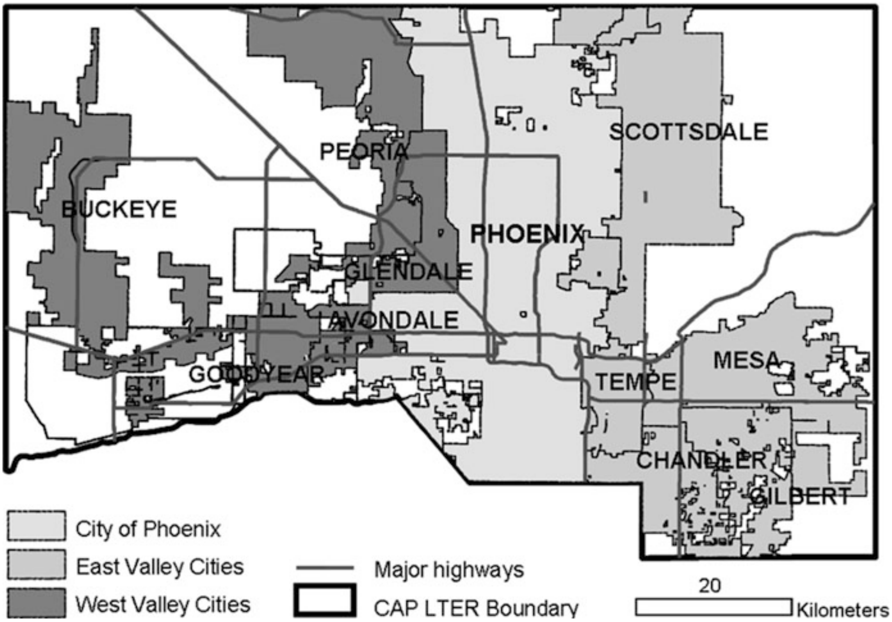

Fig. 3.1 Map of the study region with city boundaries, also noting designation of "East Valley" and "West Valley" regions used in analyses

3.5 Why Participatory GIS?

Geographic Information Systems (GIS) has been defined many different ways and with only a few exceptions (e.g. Harvey and Chrisman 1998; Poore and Chrisman 2006), these definitions focus on computing applications capable of creating, storing, analyzing and visualizing geographic information, placing little emphasis on the political dimensions of these processes (Dunn 2007). In traditional GIS methods, data precision and accuracy is a product of the quality of the record keeping systems that generate the data set and often (in the case of mapping exposure to toxins from smokestacks, for example) a product of the distributive modeling choices of the researcher (Sieber 2006). The potential to criticize the false precision and accuracy of these mapping efforts grows exponentially as the quality of the data set degrades (from an empirical perspective). This can contribute to a framework for research that relies only on data sets that are easy to access and may limit the scope of scientific inquiry as well as the types of knowledge and knowledge holders that are most easily assimilated into a GIS. Often, as demonstrated in this paper, there is a strong theoretical or applied reason to consider mapping alternate forms of knowing or find ways to validate and improve a data set built from diverse record keeping systems and to acknowledge the political and cultural components of mapping efforts.

Participatory GIS (PGIS) evolved as a way of recognizing a wider suite of information types and information sources and types to GIS.[2] "Participation" in PGIS can range from information sharing, consultation, involvement in decision making, initiating actions, and evaluating the applications of the mapping process (McCall 2003). The field, while diverse, is united by a common interest in context or issue-driven GIS that celebrates the multiplicity of geographic realities rather than the technical aspects of finding solutions. It aims to understand how users engage with geographic information and often has aims that relate to: community development, capacity building, public access to official data, inclusion of marginalized groups, one or more real-world applications, and advancing social theory and qualitative research as it relates to democratic spatial decision making (Dunn 2007; Aberly and Seiber 2002). PGIS often focuses on a bottom-up approach to GIS applications and recognizes the potential for maps to be used as forms of political empowerment (Elwood 2006).

The flexibility that allows PGIS to address questions when it is necessary or preferable to accommodate imperfect formal data sets, collective knowledge of participants, and alternative conceptions of space (McCall 2003; Dunn 2007). By recognizing more information types and sources, PGIS applications aim to provide a more socially aware GIS that affords greater privilege and legitimacy to indigenous sources of knowledge (Dunn 2007). In establishing itself as a more aware GIS, PGIS involves a deeper analysis of what constitutes knowledge, how it should be represented, and evaluated (Dunn 2007). Definitions of acceptable levels of accuracy and precision shift as researchers strive to represent spatial phenomena with fuzzy distributions (McCall 2003). It is well suited to questions that must be answered using imperfect data as it can use the collective knowledge of participants to fill in data missing from existing records, include alternative conceptions of space, and lend legitimacy and accountability to the final map (McCall 2003; Dunn 2007).

Figure 3.2 presents the dominant mental model for PGIS. It is iterative and includes as many relevant stakeholders as possible. The organization or individual convening the creation of a participatory GIS may support an academic or political agenda; and this may be for the benefit of the individual organization or the group. There is an emphasis on the transformative potential of participation and an interest in iterative and diverse forms of interaction.

3.6 PGIS Process

To identify water information providers within the study boundary, the study used use researcher-initiated internet searches and participant generated lists. Organizations remained in the population of WI providers if a representative

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[2] PGIS often includes processes through which stakeholders provide data and define mapping outcomes, but can also enlist participants in designing technical systems for non-expert access to data. Here, the focus is mainly on PGIS via the first mechanism.

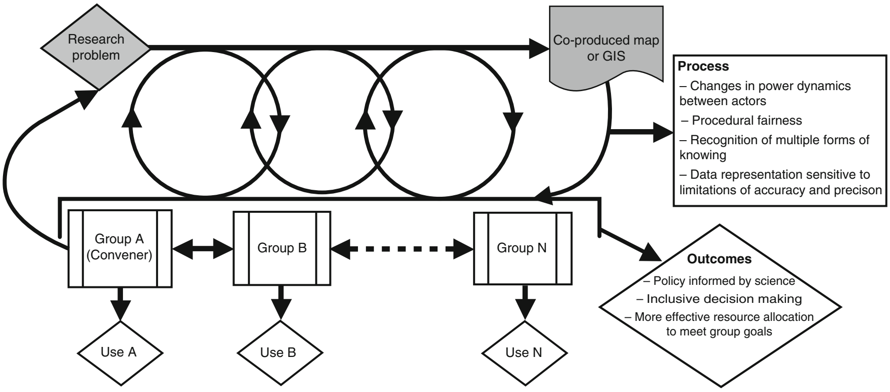

Fig. 3.2 Conceptual diagram of the mental model of participatory geographic information systems (*PGIS*). PGIS studies focus on heterogeneity and independent uses of co-produced maps and GIS. There is a strong emphasis on process

Table 3.1 Organizations providing water information to some or all of metropolitan Phoenix, AZ

Type of water information organization	Total identified	Respondents
Water provider	13	10
Education or research group	11	8
Environmental nongovernment organization	7	7
Government agency (not including water utility)	5	2
Multi-organization coalition	3	2
Total	39	31

A total of 31 organizations participated in the research

confirmed that "providing the lay-public with information about local water supply, quality, policy, or aquatic ecosystems" was within the organization's purpose. WI providers listed other organizations active in the region and researchers contacted new additions. The organization list was considered complete when all organizations had been contacted and conversations and internet searches no longer revealed new organizations. In total, 39 organizations were identified representing water providers (including both private and public agencies), education and research groups, environmental non governmental organizations, governmental organization not focused on water as a utility, and coalitions involving multiple organizations from one or more of the categories above (Table 3.1). The process is outlined in Fig. 3.3. The left hand side of the figure indicates the phases of participation while the right hand side indicates the process of building the data set from research question formation (fully explained in Cutts et al. 2008) through to analysis. Horizontal breaks map particular phases of participation to stages in building the data set.

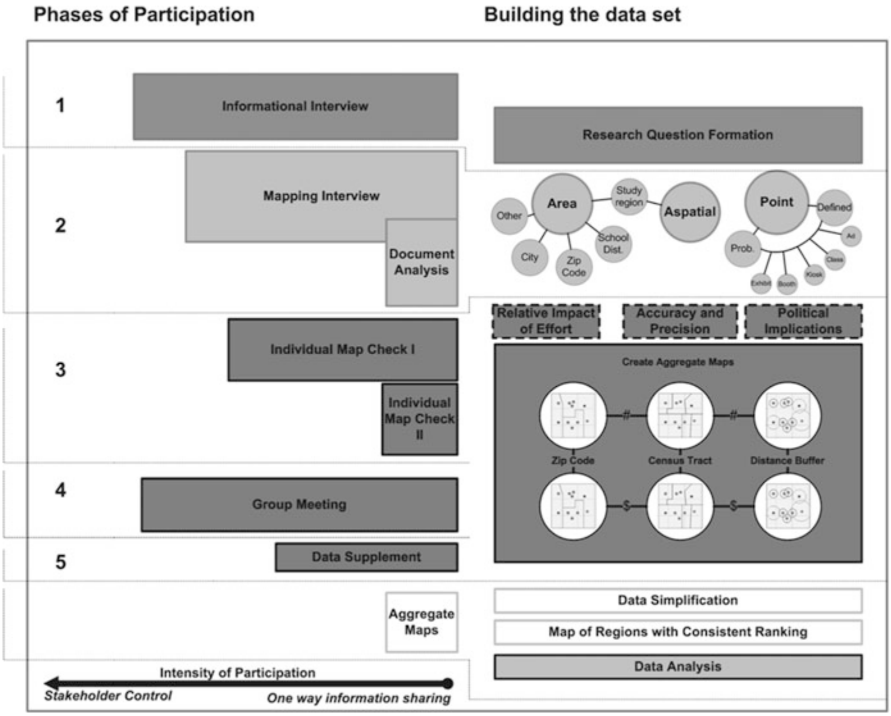

Fig. 3.3 Conceptual diagram of methods linking phases of participation on the *left* with the stage of data development on the *right*. The length of the bar representing each phase of participation corresponds to the intensity of participation while the width corresponds to the number of organizations participating. Both *sides* of the diagram read chronologically from *top* to *bottom* with phases of participation *shaded* to match the corresponding step in building the data set

The ultimate goal of this research step was to produce a map of the cumulative water information landscape. However, several tactical issues needed to be addressed before this could happen: water information providers needed to verify their information individually to assure some degree of accuracy, a method for representing both point and area-based data needed to be discussed and agreed on by all participants, and a method for including some measure of program quality needed to be developed. The literature was consulted and several options were created to accommodate the variable methods of data representation and program quality. These are discusses in the section below. The reactions of stakeholders to individual maps and alternative data representations are discussed.

3.6.1 Reconciling Points and Areas

In the first data collection phase, structured interviews were conducted with 29 of the 39 organizations actively providing water information to residents living within the metropolitan Phoenix region. Questions focused on the location, extent, and participation rate of all programs that aimed at educating the general public about water issues between June 2005 and June 2006 (using a method similar to Brown 2005). Water information program information extracted from websites, annual reports, and other organization documents to identify the location and extent of water information programs to supplement interview information and provide some basis for including organizations unable to participate in initial interviews.

Responses were translated into spatial extents using ArcGIS version 9.0 (ESRI 2004). Translating interview responses about water information programs resulted in two initial data types: points, when information was dispersed from a central location and polygons, when information was dispersed directly to the public (Fig. 3.3). For example, if an interviewee representing a municipal water supplier responded that there were brochure kiosks at all the libraries in a city, the water information programs were initially points georeferenced to the libraries. In a few instances, interviewees provided probabilistic information about points. In one instance, an organization mentioned attending 5 or 6 of a possible 30 neighborhood events in a particular city. All neighborhood events were identified and a note was made of the probability that an event occurred there. This probability was used to give more weight to events that occurred with certainty. In the case of information campaigns that distributed materials to the homes, polygons were used to represent information extent. These included school-based programs (presumed to reach adults dispersed throughout the district), mailings, and local news sources.

The literature provides several potential remedies to reconcile differences in the representation of point and area information. Methods vary from more complicated space-time prisms, distance decay functions or path analyses used in transportation research to more simplistic container-based count methods. Given the relatively inconsistent reporting habits or water educators, simpler methods were determined that might be more appropriate for this case study (as in Brody et al. 2002). Water information providers did not have complete records of distances traveled by attendees. Two methods were devised that might be appropriate given the nature of the data: using political boundaries (census tract and/or zip code) as a container-based method (Griffith 2005) and creating distance buffers to assign an area to points. This resulted in three types of representation (illustrated in Fig. 3.4).

Container methods simply count the number of events that occur in a pre-defined space. It was assumed that all points falling within each polygon were designed to serve that population offering either zip codes or census tracts as potential boundaries. The weaknesses of these container-based methods for establishing exposure to environmental phenomena are well known among environmental justice scholars (Buzzelli and Jerrett 2003; Buzzelli et al. 2003; Mennis 2003), but given the relative subjectivity built in to data representation, creating multiple representations and comparing the consistency of results across representations

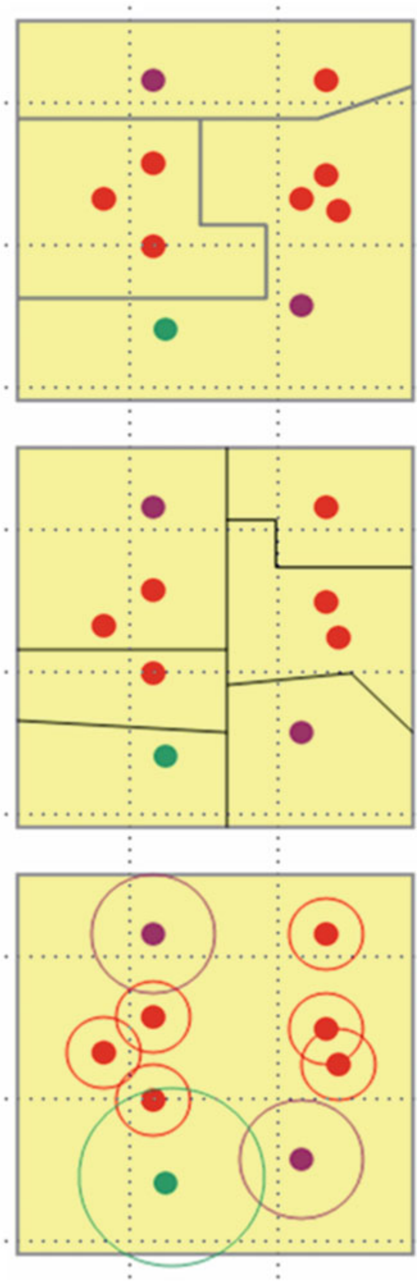

Fig. 3.4 A diagram of the three methods of aggregating water information effort. These are (from *top* to *bottom*): counting all *areal* and *point* information for each *census block*, counting all *areal* and *point* information for each zip code, and creating areas for *points* using buffers based on the average distance to nearest neighbor for *points* and summing all overlapping areas

presents the most appropriate option for reducing the effect of arbitrary data boundaries (modifiable areal unit problem). The distance buffer method increases the total number of polygons in the sample, but allows for more information program boundaries that are less dependent on (potentially irrelevant) political boundaries (Omer 2006). In this representation technique, residents from one city are permitted to attend events hosted in another city if they are closer to their home. It was proposed that to determine the radius of the circle by assuming that rational behavior would encourage information seekers to go to the closer of two similar information sources. Average distance between similar points was used to determine the radius of the buffer. Using the interviews with water educators as justification for the coding system, unstaffed permanent information kiosks were classified points, staffed temporary information booths, classes, billboard advertisements, and interactive permanent staffed demonstrations or exhibits (buffer radii: information kiosk = 10 km, booth = 17 km, class = 15 km, ad = 34 km, exhibit = 45 km). Values inside overlapping buffers were summed. This is a simplistic approach sometimes used in transportation research (Kim and Kwan 2003).

3.6.2 Reconciling Effort

The second problem with the data representation involves the expected impact of one program versus another. Research on the diffusion of innovation suggests that there may be differences in the effectiveness of broadly applied informational materials and those targeted to community leaders or those with a pre-existing interest (Rogers 1995). To try to accommodate the differences in the likely impact of a course in arid landscaping that attracts a few people, but offers deep knowledge in a variety of issues, with more popular advertising through newspapers, which reach substantially larger audiences, but contain less information and can be easily ignored, an economic proxy was developed to create a relative ranking across programs requiring different types of user participation. This method assumes that each organization strives to allocate resources (including financial and volunteer capital) effectively and efficiently, maximizing information transfer and the potential for use (O'Reilly 1982; Saunders and Jones 1990). The economic proxy uses a combination of real expenses and estimated costs to create standardized "per program" estimates. Each estimate can then be calculated as a per capita expense for the intended reach of the program.

Economic Proxy = {[material production cost] + [volunteer hours × hourly wage for similar work as a paid position + total paid wages] + [material development and implementation costs]}/[total population of estimated service area].

The proxy can be summed across all programs operating in the same geographic extent to calculate the cumulative effort to inform the public across all organizations. Example calculations for programs appear in Table 3.2.

Table 3.2 Examples of economic proxy calculations used to rank the effort to reach the public associated with each water information effort

Information program	Calculated expense	Data source
Insert included in other mailing	[$0.055 printing cost per mailing × number of households)/number of households (assume postage charge included in cost of primary reason for mail)]	www.printingforless.com US Census 2000
Organization member mailing	[($1.055 for 28 page printing + 0.80 for mailing) × (number of members in region (by city if possible))/ total households in region]	www.printingforless.com US Census 2000 Organization documents
Residential water audits	[(12.50*2.5 pay hours pay) × (Average round trip 40 miles at $0.43 per mile) × 395)/population of city]	US Census 2000 Organization documents government mileage reimbursement Comparable job advertisement
Newsletter	[($0.20 to print) × ($0 0.32 to send to homeowners)]/number of households	www.printingforless.com US Census 2000 US Postal Service
Cable channel still-screen public service announcement	$2000 screen shot/households in intended service area	US Census 2000 Station rates listed online
Xeriscape rebate and rebate information	(Estimated total rebate dollars dispersed × effort to advertise rebate)/ city population	US Census 2000 www.watercasa.org

3.6.3 *Results of Participation*

The data was presented to stakeholders as a mechanism for further improving my representation of their perceptions regarding the relative value of each measure. They were asked to comment on the merit of each proposed representation method and the economic proxy. To allow organizations to validate the information mapped from their interview, maps were made available to each organizational representative through a password protected website. Links were also provided to a short evaluation survey where there responses could be recorded. Comments ranged from full support to rejection of the maps and the information that were intended to represent. The respondents were mainly confused by perceived inconsistencies in the way they reported (and were recorded) information as points and areas. Their responses also revealed that they were not equally well equipped to interpret a map. Further, some respondents indicated deep skepticism over the proposed economic proxy measure. A few comments are provided below. Many comments were supportive:

> This map closely represents our outreach efforts for the period specified. Respondent 1

or constructive:

> The map does not (probably because I did not provide you with) information about the distribution of our education programs to teachers throughout the Valley. Also, in 2006, we invested in radio advertising throughout the year on a number of stations which are broadcast throughout the regions (and state). Also, the online [proprietary education program] was successful with participants throughout the region. Respondent 3

while others challenged the merit of the economic proxy:

> I'm not sure how you'd determine the economic expense per person for the entire population when it comes to paid advertising or an unpaid news story. These are VERY effective education tools to reach adults but I'm not sure your method of representing them is an accurate way to do it. Respondent 4

and validity of the underlying data:

> ... direct comparisons between the cities shouldn't be made because we all have such different budgets [constraints] and various service area characteristics to work with. Overall, I think it would be very helpful if you better defined what you're calling a program, an adult education program, and a school education program. Like I said before, I'm not so sure the programs from each study participant are being compared equally. Respondent 12

The challenges mounted by the water information providers indicated that the data in its initial form was not acceptable to some participants. As concerns were began to be discussed with those who had participated in the map validation process, it became clear that water information providers, especially those working in the municipal water sector, had been discussing the maps informally. Through these networks, they uncovered several differences in the way they had interpreted my request to know more about their information programs. It also became clear that the study had used terms to describe water information programs that had very specific (and different) connotations for the respondents. For example, the study used the term "information kiosk" to describe a place where members of the public could get pamphlets or other printed materials to take away. Some of the water educators demonstrably insisted there were no information kiosks as part of their information campaigns. It was only after more time was spent talking that it was realized that they defined kiosks as stations for the public to interact with human and/or technological resources.

Through the correspondence following the map evaluation, it appeared that many of the concerns water information providers had regarding the project could best be addressed though a group meeting. In the meeting, we discussed the origin of the project and its goals and had hoped that an explanation of how the research contributed to science and a collaborative approach to assuring the data better met the goals of science and the stakeholders would help the water information providers who felt most poorly represented and most threatened by the potential uses of the information to continue their involvement. Before the meeting, a new map was created for each organization based on information following the first map check. All 39 organizations in the initial data frame were invited, regardless of whether or not he had participated in the interviews, regardless of whether or not they had provided data in the map data collection phase. This stage of participation was mediated by two other people: a scientist capable of lending additional support to the research approach, and an administrator of the grant funding the research project, who could validate the importance of stakeholders in research and remind them of the organization's commitment to conducting research that is considerate of their needs and concerns.

To begin, participants were told that the entire meeting would be tape recorded and then they would be given a short presentation of the research and the interpretation of its potential uses, both to me and to them. The process that had been used to develop the maps was discussed and the questions and concerns that had been expressed in the previous research step were summarized. Questions following the presentation related to concerns over the credibility of the data collection methods, and the political ramifications of the economic proxy. There was a general progression from aggressive statements that criticized the study outright to more collaborative statements focusing on ways we could work together to improve the underlying data and its representation.

In relation to the different mapping choices, stakeholders initially questioned how the buffers were created as well as the reliability of information they had provided about water information programs, making statements like:

> I think some of this would be great information if I could rely on it. . .I don't know if I'm confident I can provide information to you that would give you that radius. City representative 1

To reassure her, a university researcher unaffiliated with the project summarized the iterative research process we were all involved in and normalized the level of disagreement emerging over the data for City representative 1. He said:

> This is often the sort of process – you start something, you initiate it, you take a stab at it, and you get some of it right and some of it wrong and you correct it and keep going. So that's what this is all about. Making a mid course correction.

As the conversation continued, it became increasingly clear that providing individual maps to survey respondents had created concern over the way the politics of funding for public information campaigns, especially among agencies with water supply management responsibilities. Ultimately, this uncovered concern over the implications of different data representation techniques that had not been anticipated. For the municipal governments, especially, there was concern that water management policies that mandate public information would make other cities, without those mandates, appear to be lagging in their efforts. As one participant noted:

> Another thing that is going to happen with things like brochure distribution is that The City of (X) is required to provide brochures. . .to every new account. . .The City of (Y), we're not under the same restrictions by ADWR (Arizona Department of Water Resources)....when you put something like that down on a map, we're going to look very poor. . .So something needs to be noted. City representative 3

In response, another municipal representative said:

> I just wanted to tag on with (City representative 3), I think that is a really important part that shouldn't just get a little footnote or caveat…Non per capita (cities) are required to do things and it will end up looking like they are doing things and the GPCD[3] is not. When basically, the GPCD cities have met there GPCD and they are not required to do these other things. City representative 1

Stakeholders were also leery of the political ramifications potentially resulting from the use of the economic proxy, though over time, they came to understand why it had been proposed and agreed that it made sense to use standardize numbers that were relatively unresponsive to actual organizational expenditures, since volunteers support many of the programs.

City representative 1 voiced concerns over the way the economic proxy has been explained as a means to rank the relative impact across highly variable programming efforts. She said:

> I think the economic proxy is a very good thing if it is accurate, but it is very scary if it is not. It's incredibly scary. I mean my eyes got real big looking at it…I know that if any of our council members saw this map, or even saw how much of the pie chart is water use it wisely, they would have a cow. City representative 1

Another water information provider asked for clarification.

> Okay so if I understand your economic proxy, you're just assigning a supposed number to printing an item whether or not it is going to cost the city anything or just, what I'm getting at is, are we looking at what the city is actually spending on conservation or is there no correlation there? Representative from multi-organization coalition 1

The process involved in creating economic proxy idea and its intention was explained before the conversation continued. As we negotiated the meaning and process for calculating the economic proxy, trying to find a satisfactory solution, we began to reach an acceptable compromise. It became clearer that the presence of a dollar sign and false precision of the economic proxy was more concerning than weighting programs relative to the effort they required. Participants made statements like:

> Is there a way to measure the intensity without using the dollar amount? Because that is not really reflective of our dollar amount. City representative 1

And:

> You see, and I think for us that (information on outreach effectiveness and cooperation and collaboration among water information providers) is a really important thing. And with our high water users and things like that, it would be really useful to lay this over. For that reason, I want to make sure you have really good, accurate information. City representative 2

that indicated they saw value in continuing the project. By the close of the meeting, the participating water information providers were able to agree to a set of conditions regarding the analysis and distribution of results from the study. It was agreed to

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[3] GPCD stands for "Gallons per Capita per Day" and is the standard metric against which conservation success is measured in the active management areas under the Arizona Department of Water Resources. However, as the quotation points out several cities in metropolitan Phoenix operate under an alternative policy that mandates additional public information programs in lieu of meeting water use reduction targets (Hirt et al. 2008).

create a comprehensive list of all previously reported water information events and publications and a list of desirable data formats. In return, the waster information providers agreed to provide updated information, correcting 2005–2006 data and contributing new information for 2006–2007. Further, it was agreed that both count and economic proxy calculations would be aggregated into "high" "medium" and "low" categories across *all* organizations before any analysis or public presentations. Lastly, the study would use all six representations for analysis.

The resolution required all participants to make an additional time commitment to the project. The methodological solution circumvented potential challenges to the scientific credibility of the data by increasing the consistency in data reporting measures and definitions used across all participants.

Differences in record keeping systems still presented a problem, but the complete list of water information programs could aid recall. It was agreed with the water information providers that the cumulative map should be constructed using all combinations of three aggregation and two accounting methods, therefore offering more weight to persistent differences in effort to inform neighborhoods with different proportions of renters and minorities. Given the relative subjectivity built in to data representation, evaluating each of the representations that had been created and by comparing the consistency of results across representations presents the most appropriate option for reducing the effect of arbitrary data boundaries. While both academic and water information provider participants acknowledged that *participation* in water information opportunities was unlikely to be constrained by the boundaries in any of the representations, more specific methods of estimating the distances people traveled for these events seemed likely to imply greater accuracy and precision than exists in the underlying data.

Participants also agreed that the low level of consistency in reporting style meant that using continuous data in either the program count or economic proxy accounting methods presupposed a level of certainty and differentiation that we weren't sure was accurate. Instead, the study would divide the range of water information effort scores created through count and economic proxy approaches into classes using a quantile assignment method, assigning categories of "high", "medium", or "low" information using either the number of programs or economic proxy scores, depending on the representation.

In total, 31 of the 39 (79%) water information organizations contributed to one or more of the participatory stages and have information represented in the final maps. These groups represent each class of stakeholder: water utility providers, education and research groups, environmental nongovernmental organizations, non-utility governmental agencies, and collaborative stakeholder partnerships.

3.6.4 Results from the Final Map

Organizations provided the public with a range of information through landscaping classes, information about technology rebates, advertisements about water conservation methods, and community meetings about the using reclaimed water for irrigation.

Fig. 3.5 Illustrations of water information levels as constructed through participatory mapping approaches. Each *panel* represents the map resulting from a unique combination of aggregation technique (census tract, zip code, or distance buffer) and accounting method (count or economic proxy). These are: (**a**) Census tract (count), (**b**) Census tract (economic proxy), (**c**) zip code (count) (**d**) zip code (economic proxy), (**e**) distance buffer (count), and (**f**) distance buffer (economic proxy)

They also provided information through articles in local newspapers and broadcasts over public access, canvassers out to talk about climate change, meetings about riparian habitats, giveaways at football games, banners on main streets, and puppet shows. Each of these programs represents an attempt by an organization to share information and insight interest in local water supply and water quality with the public.

Maps in Fig. 3.5 panels a–f indicate that cumulative effort of water information providers to educate the public about water issues is not distributed evenly or

Table 3.3 Summary of significant predictors of access to higher amount of water information across all six water information maps

	% Latino	% School-aged children	% Renters	Adjusted R^2
West Valley				
(a) Count-based census	+	−	−	0.00
(b) Economic-proxy based census	+	−	+	0.43
(c) Count-based zip code	−	+	−	0.42
(d) Economic-proxy based zip code	+	+	−	0.27
(e) Count-based distance buffer	−	+	+	0.10
(f) Economic-proxy based distance buffer	−*	+*	+*	0.15
Phoenix				
(a) Count-based census	.	.	.	
(b) Economic-proxy based census	+*	−	−	0.05
(c) Count-based zip code	−	+	−	0.14
(d) Economic-proxy based zip code	−	+	+	0.40
(e) Count-based distance buffer	+*	−*	+*	0.18
(f) Economic-proxy based distance buffer	+	+	+*	0.11
East Valley				
(a) Count-based census	−	+	+*	0.13
(b) Economic-proxy based census	−	+	+*	0.11
(c) Count-based zip code	+	−*	+*	0.28
(d) Economic-proxy based zip code	+	−	+	0.29
(e) Count-based distance buffer	−	+*	+*	0.11
(f) Economic-proxy based distance buffer	+*	+	+*	0.14
Consistency map	−*	+	+*	0.08

Logistic regression for each geographic unit

Note: + indicates a positive association with high water effort; − indication a negative association with high water effort; * indicates a statistically significant relationship ($p < 0.05$)

randomly in any representation. Collectively, the maps show variability in the spatial arrangement of high and low amounts of water information. Most notably, the distance buffer technique (Figs. 3.5e, f) varies dramatically from both the census blocks and zip code aggregation methods. There are also notable differences in the ranking produced by using the program count and economic proxy technique. The most notable differences occur in central Phoenix, where census tracts and zipcodes are much smaller due to higher population densities, restricting the geographic extent of some cultural resources. Table 3.3 contains descriptive statistics. Notably, Phoenix has no areas classified as receiving high water information availability ranking in either census tract aggregation. Mean Latino ranges from 13.34 to 31.17%, percent School-aged children ranges from 23.03 to 25.57%, and percent renters ranges from 16.32 to 34.34%.

Separate logistic regressions for the East Valley, Phoenix, and the West Valley tested the relationship between our predictor variables (% Latino, % renters, and the

Table 3.4 Logistic regression analysis for patterns in consistency of ranking

Predictor	N	β	SE β	Wald's χ^2	df	p	eβ (odds ratio)
Consistency	1220						
% Latino		−1.946	0.541	12.923	1	<0.0001	0.174
% School-aged children		1.668	1.242	1.804	1	0.179	5.301
% Renters		4.387	0.468	87.881	1	<0.0001	80.411
Constant		−0.686	0.251	7.452	1	0.006	0.504
Tests of model coefficients				χ^2		p	Cox and Snell R^2
Overall model evaluation				105.306	3		0.083

High information effort = 1

% school-aged children) and location near high or low levels of water information exposure. In each of the analyses (Table 3.3), high is the reference category. All reported results indicate the increase in probability of a region's rank as an area of high water information exposure with a unit increase in the predictor variable. The Cox and Snell R^2 for the models ranges from <0.001 to 0.40 indicating a broad spectrum of model fits across regions (West Valley, Phoenix and East Valley) and mapping techniques. Models using zip codes have the highest adjusted R^2 values and results. Variables are significant most often in the distance buffer models (see Cutts In Review for a full explanation).

In a logistic regression comparing the areas consistently ranked high to those consistently ranked low, finding that % Latino was negatively significant, there was no relationship between high water information and % school-aged children, and % renters was positively related to water information availability. The full model appears in Table 3.4.

3.7 Discussion

The purpose of this study was to examine the extent to which effort to inform the public about water issues might result in some populations having access to lower amounts of information than others. Representing the data through seven separate maps led to changes in the significance and direction of factors related to the distribution of water information. Latino populations were less likely to live in high effort regions (Prediction 1) in the West Valley and when we consider only consistently ranked regions. However, Latino/a populations were significantly *more* likely to live in high education neighborhoods in Phoenix across two representations and in the East Valley in on representation (Table 3.3). When significant, the proportion of the population renting their home was always *larger* than expected by chance. This is counter to the expectation. Similarly, populations of school-aged children are *smaller* than expected by chance, in direct opposition to out expectation (Prediction 3). The observed differences within region as well as shifts in the direction and significance of the models between the West Valley, Phoenix, and the East Valley indicate support for geographically-based differences. While no one organization intentionally limits the distribution of water information, the effort of each organization is often constrained by financial resources, time, and space. This is compounded by similar restraints across the spectrum of water information providers.

Results reiterate the profound influence mapping choices can have over results. With the exception of high water information availability for renters in the East Valley, there is variation in the direction and significance of all variables for each set of models. Across maps, the City of Phoenix appears to exhibit the most variability in assignment of high or low exposure to water information (Fig. 3.5). This likely reflects the influence choices in mapping has over results and is related to the higher population density in urban core areas. In census block and zip code representations, the impact of programs in these areas applies to a very limited geographical region, whereas in the buffer distance maps, a larger area of influence is possible. Another striking difference is the inconsistency between the count-based and economic proxy maps constructed using the buffer distance. The economic proxy affords a much different scenario for the distribution of water information programming effort. Small, relatively "low-value" water information efforts receive less weight. These tend to be either ephemeral (a booth at an event or a banner on Main Street) or centers that host pamphlets from multiple water information campaigns. The higher concentration of effort by water information providers in central Phoenix and the East Valley is evident in the maps.

Without further analysis, it is difficult to interpret the meaning of higher rates of education provision in census blocks with large renter, and/or Latino populations. It could be that water information providers see these people as most vulnerable to water scarcity and water quality problems. Combining spatial methods with other types of data can elucidate these differences and lead to deeper consideration of ways in which spatial and other differences my interact. Even in areas where water information providers exert a lot of effort to reach the public, motivational and topical mismatches may limit the accessibility of this information. Organizations may, for example, rely heavily on information frames that rely on egoistic motivations when particular populations are more likely to respond to biocentric or altruistic prompts (Johnson and Macy 2001). Information campaigns might focus on conservation technology when water quality information may be the topic most likely to engage people in discussions about the complexity and interconnectedness of local water systems. Unavailable or inaccessible material could, in turn, reduce the capacity of some residents to advocate for their interests in local water supply, quality, and uses.

PGIS involving water providers in metropolitan Phoenix informs a fundamental question about how information is provided to the public across multiple organizations. Analyzing public information as the product of many separate efforts is challenging because there are wide disparities in record keeping across organizations. Using participatory mechanisms to account for these differences in a way that is viewed as fair by participants is one way to work around a perceived lack of data. By arguing that public information as a component of recognizing particular audiences as well as a source of education, this chapter points out new implications for both incidental and intentional interactions between organizations adressing the same issues.

The interactions between water information providers may create or perpetuate disparities in content availability and/or the perception that communities have a legitimate stake in future water supply and quality issues. The study considers the role differences in information availability may play in recognition justice and empowerment toward present and future environmental decisions, finding that there differences in proximity to water information lends only weak spatial support to the perceptions among water information providers that Latino/as and renters are less likely to use information, and those with school-aged children should know more (Cutts et al. 2008). However, the likelihood of the public to encounter information does vary across the region.

By considering organization-level knowledge about water information programs as partial, this research acknowledges the social context of program creation and dissemination (Robbins 2003), redressing a common limitation of many environmental information studies (Renwick and Archibald 1998; Kaiser and Fuhrer 2003). The representation incorporates both the diversity of public information program types and record keeping systems among water information providers. Information entered in to the GIS incorporates an indivisible combination of documentation and perceptions of information sharing effort by the water information providers. It includes fuzzy and layered zonal information, blurred and multiple boundaries, uncertain locations, dynamic flows, and empirically graspabable but imprecise terms (Egenhofer and Mark 1995; McCall and Minang 2005). Therefore, the data represents the cumulative “naïve geography” or perception of action among participating water information providers as much as it does the physical location of information provided across organizations.

3.8 Conclusions

Movements for public inclusion in decision making as well as shifts in global, regional, and local shifts in climate, temperature, and precipitation have contributed to a perception that educating the public about water supply and water quality is an essential part of managing water (Jury and Vaux 2005). Water information is both an environmental amenity and a symbol of inclusion capable of being inequitably distributed. If it is provided unevenly, then information provision may systematically create and perpetuate difference in access, empowerment, or a perception among some communities that their opinions and interests are of marginal relevance. The system of recognition politics of a single public information campaign may be attenuated or amplified by the collective effort of multiple information campaigns. Although previous research indicates that environmental educators perceive that high-need audiences may have low access to information (Morrone and Meredith 2003) there have, until now, been no studies on the cumulative impact of education programs focusing on a single issue (Enviros-Ris 1999). This may be in large part due to a predilection for GIS without participation (Dunn 2007). The study makes novel contributions through its application of PGIS as a mechanism for revealing, standardizing (to some extent) and spatializing public information, which is an important component of many water governance structures.

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Chapter 4
On the Relationship Between Stream Biotic Diversity and Exurbanization in the Northeastern USA

Scott Goetz and Gregory J. Fiske

Abstract Stream macroinvertebrate diversity is a commonly used indicator of aquatic health, reflecting overall ecological integrity within a watershed. Our study made use of two metrics of stream biota, the Hilsenhoff Biotic Index (HBI) and the diversity of *Ephemeroptera*, *Plecoptera*, and *Tricoptera* (nEPT) species, to develop statistical models relating land cover information within watersheds to these stream biotic health indicators. The study area in southern New England included over 100 small streams, which make up a substantial portion of the region's largest catchments. General additive models (GAM) and step-wise multiple linear regression (MLR) models were used to explore the relationship between the land cover and the biotic indicators. Although the GAMs explained a greater amount of the variation in the stream biota metrics, the MLR models were also consistently reliable predictors of nEPT and HBI. This research indicates land cover can be used as a robust predictor of stream biological indicators of small catchments (HUC12) in the region, and help to target streams for restoration or protection.

Keywords Aquatic • Biodiversity • Habitat • Impervious • Land cover • Land use • Remote sensing • Species richness • Water quality • Stream • Watershed

4.1 Introduction

The links between land cover and water quality, including stream health, have long been known but not until recently have analyses over large areas been conducted (Mitsch et al. 2001; Nilsson et al. 2003; Carlisle and Meador 2007). This is partly a result of wider availability of land cover information from regional to national

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scales (Wickham et al. 2004; Homer et al. 2004). Impervious surface areas (the built environment, like buildings, roads, parking lots) increase the amount of pollutants within and the temperature of runoff reaching streams. Forested riparian buffers, on the other hand, preserve or increase stream quality by contributing leaf litter, regulating temperature and sunlight, deterring erosion and retaining nutrients (e.g. Jordan et al. 1997; Lowrance et al. 1997; Groffman et al. 2004). Despite a great deal of effort, much of the progress that has been made in restoring the health of the nation's waterways has been offset by continued urban, suburban, and exurban development (CBPO 1998; Wickham et al. 2005). The expansion of impervious surface areas associated with this urban growth disrupts aquatic biology and degrades water quality by inhibiting infiltration, increasing peak flows, reducing base flows, reducing lag time between storm events and peak discharge (i.e., increased flashiness), facilitating the overland transport of pollutants, and increasing sediment loads associated with stream channel incision and erosion (see updated review by Schueler et al. 2009).

Other impacts result from the associated loss of resource lands (forests, wetlands and riparian buffer areas), which serve ecological functions such as filtering water flows and buffering chemical pollutants (e.g. Goetz et al. 2004). Many of these pollutants arise from impervious surface areas, particularly the roads and parking lots built to accommodate increased vehicle use. The adverse effects of these changes can be mitigated by increased vegetation cover, landscape configuration, and low-impact development techniques, which together reduce the volume and velocity of overland flows, uptake excess nutrients and pollutants, maintain stream bank integrity, provide shade that reduces stream warming, and generally reduce the negative ecological and economic impacts of urbanization.

As a result of the processes described above, landscape configuration modifies the relationship between land use and in-stream biological metrics, such as the widely used index of biological integrity (IBI). Those elements that may have an effect on stream quality at the catchment scale, such as water chemistry (Sponseller et al. 2001) and non-point source pollution (Paul et al. 2002), may not retain their predictive power at more local (e.g. riparian or near-stream) scales, and vice versa (Jones et al. 2001). With particular reference to the relationship between stream macroinvertebrates and watershed scale land cover, distance to the stream channel appears to be a key variable that can influence the relative importance of specific land cover variables (Walsh et al. 2005; King et al. 2005; Goetz and Fiske 2008). Recent work also emphasizes the spatial arrangement of landscape patches (Strayer 2006), gradient/slope complexity (Snyder et al. 2003), and dominant substrate (Lammert and Allan 1999). Assessing the influence of riparian zone land cover over large areas has also increased in recent years as a result of more widely available high resolution sources of land cover data with relevance to riparian buffer mapping and monitoring (see review by Goetz 2006). It is thus now more feasible to use comparable metrics of riparian buffer properties, combined with those of stream hydrology, lithology, and other landscape metrics to more fully assess the influence of human land use on stream ecosystems at a variety of spatial scales (Allan 2004; Brabec et al. 2002; Grimm et al. 2008; Nilsson et al. 2003; Parsons et al. 2002).

In earlier work the statistical association between land cover variables mapped using high resolution satellite imagery (impervious cover, tree cover, and trees and crops in the riparian buffer zone) and stream ecology assessments was documented across 246 small watersheds within central Maryland (Goetz et al. 2003; Snyder et al. 2005). These watersheds spanned a wide range of land uses, from predominantly agricultural to mostly residential. Stream conditions assessed by state departments of natural resources and other groups made use of indices of biological integrity (IBI), and stream ecological health was ranked as excellent, good, fair, or poor, based on a combination of the IBI scores and physical stream properties such as dissolved oxygen, pH, and temperature (Van Ness et al. 1997; Yetman 2002). Related analysis of land cover variables and landscape configuration metrics, such as mean distance from impervious areas to the stream channel along a topographically defined flow path, and indices which define the dispersion or aggregation of land cover within the watershed, indicated the potential of these as independent predictors of stream biotic health (Snyder et al. 2005). Most recently, the research expanded that analysis to the state of Maryland, making use of the Maryland Biological Stream Survey (MBSS) data sets, and showed that both IBI and nEPT had a strong correlation to moderate resolution imagery (30 m Landsat imagery) (Goetz and Fiske 2008). Here the focus is on extending these earlier analyses to another geographic region with quite different geological substrate and a different set of biotic indicators, and testing the relative utility of landscape configuration in this context.

4.2 Study Area and Data Sets

4.2.1 Study Area

The study area comprises the southern portion of New England, including the states of Massachusetts, Rhode Island, Connecticut, and southern Vermont (Fig. 4.1). Weather in the region is characterized by warm and humid summers, with rainfall generally around 90–150 cm annually. Daily winter low temperatures tend to remain below freezing from November through March, although winter temperatures and snowfall have both increased in the four decades preceding 2005 (Burakowski et al. 2008).

The watersheds we focused on cover approximately 7000 km^2 of formerly glaciated land underlain by mostly granite and metamorphic bedrock. These watersheds include most of the large drainage systems in the area including Narragansett and Buzzard's Bays, and the Connecticut and Taunton rivers. Land cover in this area is generally forested with small amounts of agriculture in the Connecticut River valley, cranberry growing in Southeastern Massachusetts, and steadily increasing exurbanization characterized by low density residential development scattered between large urban centers like Boston, Providence, and Worcester.

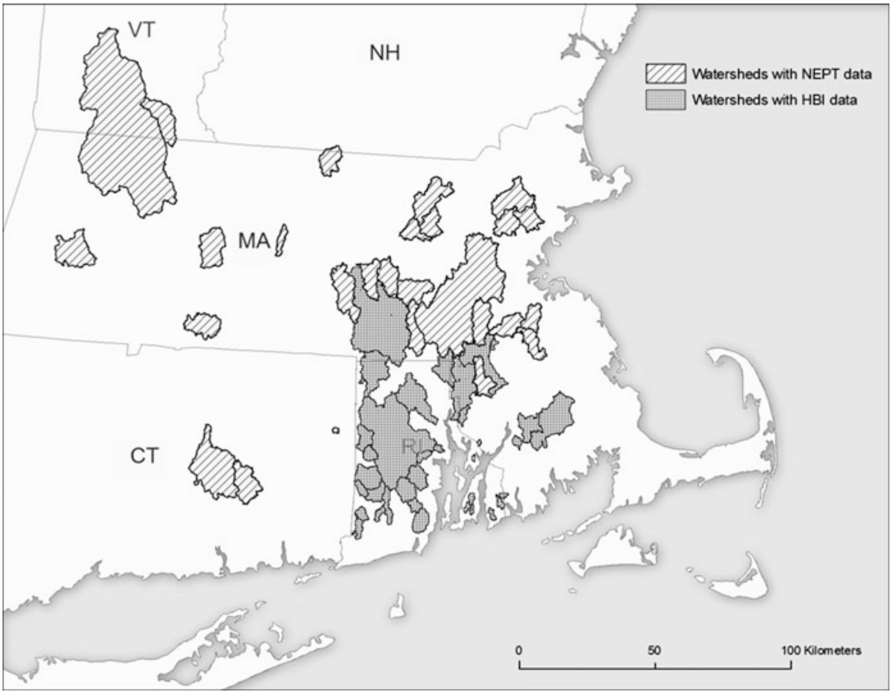

Fig. 4.1 Map of southern New England, USA, showing the extent of watersheds

4.2.2 Sensitive Taxa

This study developed models on both number of EPT individuals (abundance) and number of EPT taxa (genera). Total EPT abundance (NEPT) was defined as each individual within the Ephemeroptera order (mayflies), Plecoptera order (stoneflies), or Trichoptera order (caddisflies). The number of EPT taxa was simply a tally of the number of different genera represented by NEPT, which can also be considered as EPT taxa diversity or taxa richness.

These data were obtained from the U.S. Geological Survey's National Water Quality Assessment (NAWQA) program, which has collected chemical, biological, and physical water quality data from watersheds across the country since 1991. At the time of this study, data from over 7,000 surface sites could be found within the NAWQA archives, including biological data for over 2,500 stream reach segments. A search of the online NAWQA Data Warehouse (http://water.usgs.gov/nawqa/data) was restricted to the southern New England states of Connecticut, Rhode Island, and Massachusetts. The tabular results from the search included sample station ID and geographic coordinates, as well as the Order and Genus attributes necessary for calculating number of EPT individuals (abundance) and number of EPT taxa (richness). After restricting dates of interest to those within the range of the land cover information, and filtering out repeated sampling at the same location (keeping the most recent), we had a sample of 32 sites with NAWQA data in southern New England (Fig. 4.1). No sampling locations for sensitive taxa were located within Rhode Island.

4.2.3 HBI

Our research made use of the Hilsenhoff Biotic Index (HBI) for data collected across 83 stream reaches in Rhode Island and Southeastern Massachusetts. The HBI, developed in the late 1970s by William Hilsenhoff at the University of Wisconsin, rates stream biologic integrity on a scale of 0–10, with the lower values representing an excellent ranking and the higher values representing poorer conditions (Hilsenhoff 1987). The HBI scale incorporates the tolerance of each taxa identified during stream reach inspections to organic pollutants (Robinson 2004). The HBI is one of several metrics from the Wadeable Stream Condition Index used for stream health monitoring in Rhode Island, and a Rapid Biomonitoring Protocol (RBP) index used to rate stream health in Massachusetts. The Rhode Island portion of these data ($n = 39$) were part of an archive of 11 years of biomonitoring data, collected by Sara da Silva (University of Rhode Island) (2003), the Rhode Island Department of Environmental Management and Environmental Resource & Wetlands Assessment, and Nelson, Pope & Voorhis LLC of Melville, New York (da Silva, *personal communication*). The HBI metric information for Massachusetts ($n = 44$) was provided by the Massachusetts Department of Environmental Protection, Division of Watershed Management. These data were concentrated on the Taunton River watershed area of southeastern Massachusetts, but also included samples from the Blackstone and 10-mile watersheds (see Fig. 4.1).

4.2.4 Land Cover Metrics

The land cover metrics used in this analysis included maps of percent impervious surface cover, percent tree cover, and categorical (presence/absence) of grassland and crop cover. These data sets were derived from National Land Cover Database 2001 (NLCD), available through the U.S. Geological Survey's EROS Data Center. The NLCD data set, produced using 30 m Landsat Thematic Mapper satellite imagery, covers watersheds across the nation (including our entire study area) using a consistent classification scheme (Homer et al. 2004). From this categorical map product, we extracted Grassland/Herbaceous and Pasture/Hay land cover information (NLCD classes numbered 71 and 81) to identify areas dominated by grass vegetation cover. Corresponding crop cover was derived using NLCD class 82 (Cultivated Crops). The NLCD percent impervious surface cover map was used to identify areas of human development as a more continuous variable (ranging from 10 to 100 % for each 30 m image pixel), while the continuous percent tree cover reflected the comparable proportion of land cover in a more naturally forested state (again ranging from 10 to 100 %).

4.3 Approach

4.3.1 Watershed Delineation

Our research involved both local high-resolution elevation data sets and coarser nationwide data sets to delineate the catchment areas upstream of our sample points. Where high-resolution elevation data were available, including Rhode Island and southeastern MA, a digital elevation model of 5 m horizontal spatial resolution was built. Where these data were unavailable, we used the National Elevation Data set (http://ned.usgs.gov), which has a 30 m spatial resolution.

The areas upstream of each sample point in the HBI and EPT analyses were defined in two ways. One was to generate the area of contribution (catchment) to each sample point, with additional areas of contribution for sample point upstream along the same stream reach. The other was to combine (aggregate) those sample points along the same stream reach and link only the biological sample data to the lowest sample point (highest stream order) along the reach. These are referred to as the *catchment* and *aggregated* watershed sampling schemes throughout the remainder of the paper. Each of the watershed sampling schemes were generated using standard GIS hydrology functions/tools available in ESRI® GIS software. These tools derive watershed boundaries based on topographic variables (slope, aspect and elevation) derived from digital elevation data sets.

4.3.2 Landscape Distance Weighting

Weighting land cover metrics with some form of inverse distance weighting has been explored elsewhere in the context of land cover assessments of stream biota (e.g. King et al. 2005; Baker et al. 2006; Snyder et al. 2005). A landscape distance weighting methodology was designed to capture the relative importance of land cover information based on its proximity to the stream channel (after Goetz and Fiske 2008). For each watershed in the study area, a distance-weighted surface was developed, allowing us to use the distance from the stream channel and catchment "pour point" independent of adjacent watersheds. The first component of the distance weighting scheme is a distance to stream channel, where for each 30 m cell within the watershed distance is calculated to the closest cell that defines the stream channel. These values are scaled between 0 and 1, with 1 representing the greatest possible distance. The second distance metric incorporates the amount of tree cover within each pixel (30 m grid cell) of the watershed.

Originally containing values of 0–100%, the tree cover layer was also scaled between 0 and 1. The inverse distance is then calculated for both of these components, providing two data layers, one depicting the inverse distance to stream, with values closest to the stream being the highest (at or near 1), and the values furthest from the stream being the lowest (at or near 0). These two data layers are combined (multiplied) to provide a scaled landscape weighted cost surface that reflects the potential buffering capacity of tree cover on both overland and, to a lesser extent depending on rooting depth, subsurface flow. Each of the other land cover classes (impervious, grass and crop cover) were then multiplied by the landscape weighting scheme. Results using this distance-weighting scheme for each watershed were compared to results without using distance weighting. Analyses was conducted using ESRI® GIS software, making use of Python and Arc Macro scripting languages to summarize the data for further statistical analysis.

4.3.3 Statistical Analyses and Predictions

A stepwise Multiple Linear Regression (MLR) and General Additive Model (GAM) was used to test the relationship between the biotic metrics (EPT and HBI) and the land cover variables. In addition to the NLCD land cover layers (percent impervious, tree cover, grassland, and cropland), predictor variables included watershed size and the landscape weighted transformations of the land cover variables. The response variables were the stream biotic metrics: HBI, EPT abundance and EPT richness (Fig. 4.2). The same predictor and response variables were used for both the landscape weighted and the non-weighted tests.

As in previous research, a forward stepwise MLR and GAM was used to predict stream biota indictors from the land cover metrics. These procedures allowed us to train a linear model on a portion of the data (90%) while withholding a selection of the data (10%) for cross validation. Predictor variables were iteratively selected based on their relative power in explaining variance within the response variable. Finally, the best fit models were used to create a map of predicted stream biotic quality for each HUC12 watershed, which were selected because they encompassed a comparable total watershed area (size) as those for which HBI and EPT metrics were derived and aggregated.

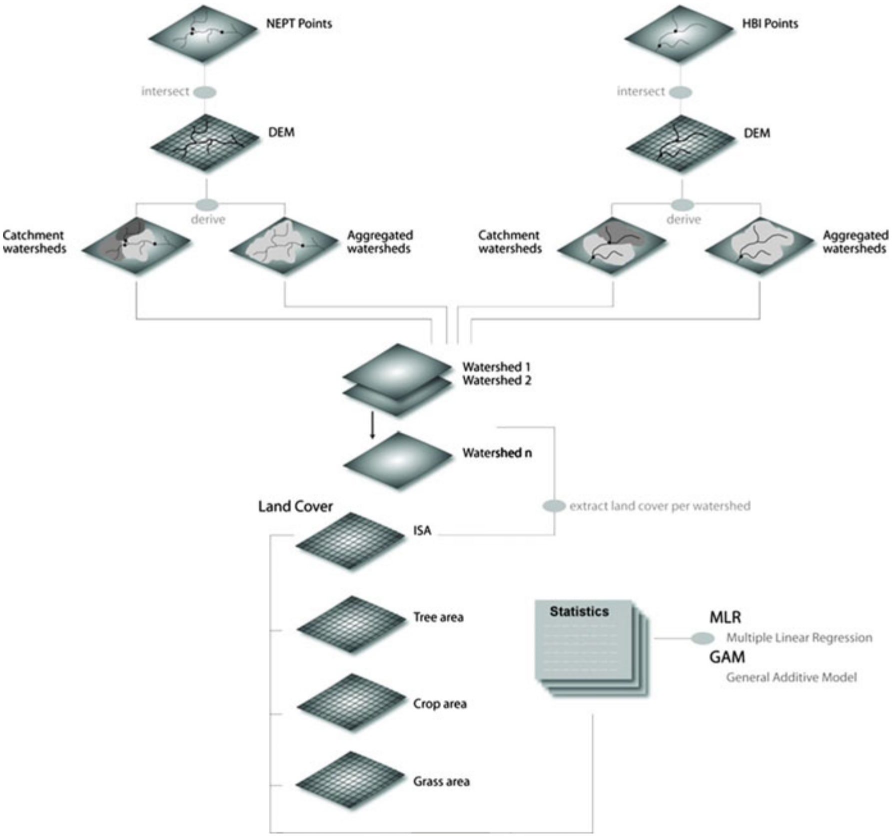

Fig. 4.2 A flow chart indicating the methodology used in comparing land cover metrics with stream reach biological indices data for southern New England

4.4 Results

4.4.1 Land Cover Predictors of Stream Biota Metrics

The relationships between the land cover metrics and the biotic indicators is shown in Fig. 4.3. In general, the amount of impervious surface and tree cover had the strongest correlation with the stream biotic metrics. These two metrics are inversely correlated to one another. The relationship between percent imperviousness within a watershed and nEPT produces an R^2 of 63 %, percent tree cover to nEPT, 41 % (p-value $\leq$ 0.001), while HBI to imperviousness produces an R^2 of 14 %, with percent tree cover, 34 % (p-value $\leq$ 0.001). The effectiveness of the landscape distance weighting was not consistent in terms of improving model predictions, despite generally higher simple correlations between the biotic indicators and land cover variables weighted

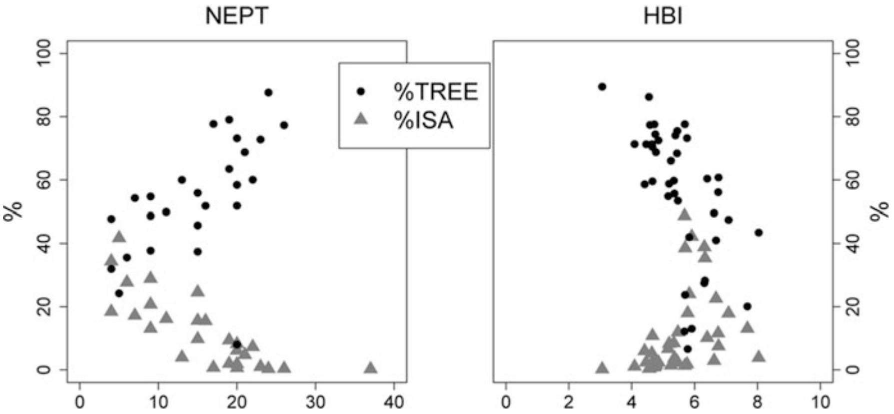

Fig. 4.3 Graph mosaic indicating the plotted values of percent impervious surfaces and percent tree cover land cover metrics versus the HBI and nEPT biotic indices. These values are further stratified by landscape weighted or non-weighted scenarios

for landscape configuration. The amount of crop and grassland showed little to moderate relationships with the stream biotic metrics, which may be a result of relatively low amounts of these land cover types in the study area.

4.4.2 Statistical Analyses

The GAM and MLR models identified the key predictor variables for all three stream biotic indices and allowed us to compare the effectiveness of landscape weighting, as well as the differences between different definitions of upstream area (catchment vs. aggregated watersheds) (see Tables 4.1 and 4.2). With few exceptions, the GAM and MLR models selected percent impervious area to be the key predictor variable for number and abundance of EPT, as well as the HBI. Percent tree cover was also a key predictor variable, being selected second for most of the MLR models, while the size of the watershed (area) was a significant predictor only in the GAM model results. Crop and grasslands were consistently poor predictor variables for all scenarios.

The GAM models produced the highest R^2 values, with 76 % reported for both EPT abundance and richness within the catchments watershed scenarios, which had slightly but systematically higher explained variance. There was no clear indication that catchment predictions were systematically better than the aggregated watershed predictions, as both scenarios produced R^2 values within a few percentage points of one another. The poorest R^2 values were generated from the models that predict HBI, and this was consistent for both the GAM and MLR approaches. To explore the effect of differing data collection methods used between states, we divided the two HBI data sets for Massachusetts and Rhode Island. The results presented in Tables 4.1 and 4.2 show the fit (R^2) values for

Table 4.1 Tabular results of 'multiple linear regression' statistical analysis for all scenarios

Multiple linear regression										
Watershed		Primary selected variables		R^2	ΔR^2		p-value		n	
NEPT		*Non-weighted*								
	Aggregated	ISA,Tree,Crop		65 %			***		27	
	Catchment	Tree,Grass,Area		74 %			***		32	
		Landscape weighted								
	Aggregated	ISA,Tree,Crop		61 %		−4 %	***		27	
	Catchment	ISA,Crop,Grass		70%		−4 %	***		32	
NEPT Taxa		*Non-weighted*								
	Aggregated	ISA,Crop,Grass		67 %			***		27	
	Catchment	Tree,Grass,Area		72 %			***		32	
		Landscape weighted								
	Aggregated	ISA,Tree,Grass		68 %		1 %	***		27	
	Catchment	ISA,Tree,Grass		69 %		−3 %	***		32	
HBI		*Non-weighted*								
	Aggregated	Tree,Grass,ISA_{MA} Tree,Grass,$Area_{RI}$	68 $\%_{MA}$	50 $\%_{RI}$			$***_{MA}$	$***_{RI}$	11_{MA}	28_{RI}
	Catchment	ISA_{MA} Tree,Grass,$Area_{RI}$	69 $\%_{MA}$	48 $\%_{RI}$			$***_{MA}$	$***_{RI}$	47_{MA}	36_{RI}
		Landscape weighted								
	Aggregated	ISA,Grass,$Tree_{MA}$Tree,Area,$Grass_{RI}$	68 $\%_{MA}$	40 $\%_{RI}$	0 $\%_{MA}$	−10 $\%_{RI}$	$***_{MA}$	$***_{RI}$	11_{MA}	28_{RI}
	Catchment	ISA,Crop,$Tree_{MA}$ Grass,ISA,$Area_{RI}$	51 $\%_{MA}$	41 $\%_{RI}$	−18 $\%_{MA}$	−7 $\%_{RI}$	$***_{MA}$	$***_{RI}$	47_{MA}	36_{RI}

*** $p < 0.001$

Table 4.2 Tabular results of 'general additive model' statistical analysis for all scenarios

General additive model										
Watershed		Primary selected variables	R^2		ΔR^2		p-value		n	
NEPT		*Non-weighted*								
	Aggregated	ISA,Area		71 %			***		27	
	Catchment	ISA,Crop		74 %			***		32	
		Landscape weighted								
	Aggregated	ISA		76 %		5 %	***		27	
	Catchment	ISA,Area,Grass		76 %		2 %	***		32	
NEPT Taxa		*Non-weighted*								
	Aggregated	ISA,Grass		72 %			***		27	
	Catchment	ISA,Area,Tree		76 %			***		32	
		Landscape weighted								
	Aggregated	ISA,Grass,Crop		69 %		−3 %	***		27	
	Catchment	ISA,Area,Crop		76 %		0 %	***		32	
HBI		*Non-weighted*								
	Aggregated	n/a_{MA} $ISA,Crop_{RI}$	n/a_{MA}	$60\ \%_{RI}$			$***_{MA}$	$***_{RI}$	11_{MA}	28_{RI}
	Catchment	$ISA,Crop_{MA}$ $ISA,Tree_{RI}$	$51\ \%_{MA}$	$47\ \%_{RI}$			$***_{MA}$	$***_{RI}$	47_{MA}	36_{RI}
		Landscape weighted								
	Aggregated	n/a_{MA} $ISA,Crop,Tree_{RI}$	n/a_{MA}	$59\ \%_{RI}$	n/a_{MA}	$-1\ \%_{RI}$	$***_{MA}$	$***_{RI}$	11_{MA}	28_{RI}
	Catchment	$ISA,Crop,Tree_{MA}$ $ISA,Crop_{RI}$	$43\ \%_{MA}$	$44\ \%_{RI}$	$-8\ \%_{MA}$	$-3\ \%_{RI}$	$***_{MA}$	$***_{RI}$	47_{MA}	36_{RI}

*** $p < 0.001$

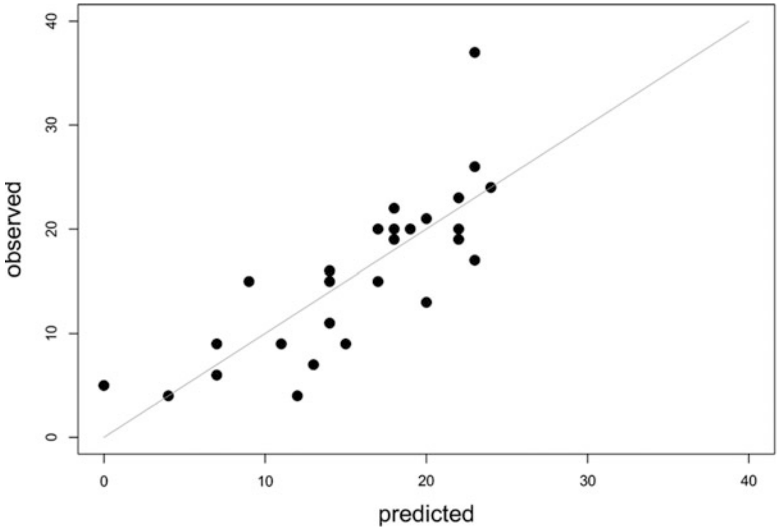

Fig. 4.4 A graph showing the output predicted vs. observed number of EPT for the aggregated training watersheds in southern New England. These results are from an MLR model that did not utilize landscape weighting of the land cover variables

Table 4.3 Tabular results comparing general statistics for predicted vs. modeled watersheds for nEPT scenario

		Land cover variables			
		% ISA	% Tree	% Crop	% Grass
Predicted	Min	0.01	10.42	0.00	0.10
	Max	53.75	91.15	31.03	52.21
	Mean	6.16	64.44	1.66	7.86
	Std dev	8.82	16.69	3.23	6.84
Modeled	Min	0.24	8.04	0.00	1.59
	Max	41.75	87.66	1.60	10.75
	Mean	12.25	55.50	0.51	4.98
	Std dev	11.53	19.01	0.43	2.88

each state individually. Splitting the HBI data this way limited the number of samples needed for robust GAM or MLR models of the landscape weighted watersheds in Massachusetts. Furthermore, low sample sizes for each of the tested scenarios precluded the use of other data intensive approaches, such as decision-tree models, which have performed well in other studies of this nature (e.g. Goetz and Fiske 2008) (Fig. 4.4).

Although the GAM results produced higher R^2 values overall, they also were less consistent. The models were run several times for each scenario, to iterate on variable selection and generate a different data subset for testing and validating the models. The MLR results, on the other hand, were consistently more robust. Considering these findings, we used the MLR models, and watersheds of southern New England (with land cover relative to those we used to build the models – Table 4.3), to produce a map of predicted nEPT (e.g. Fig. 4.5). This same model

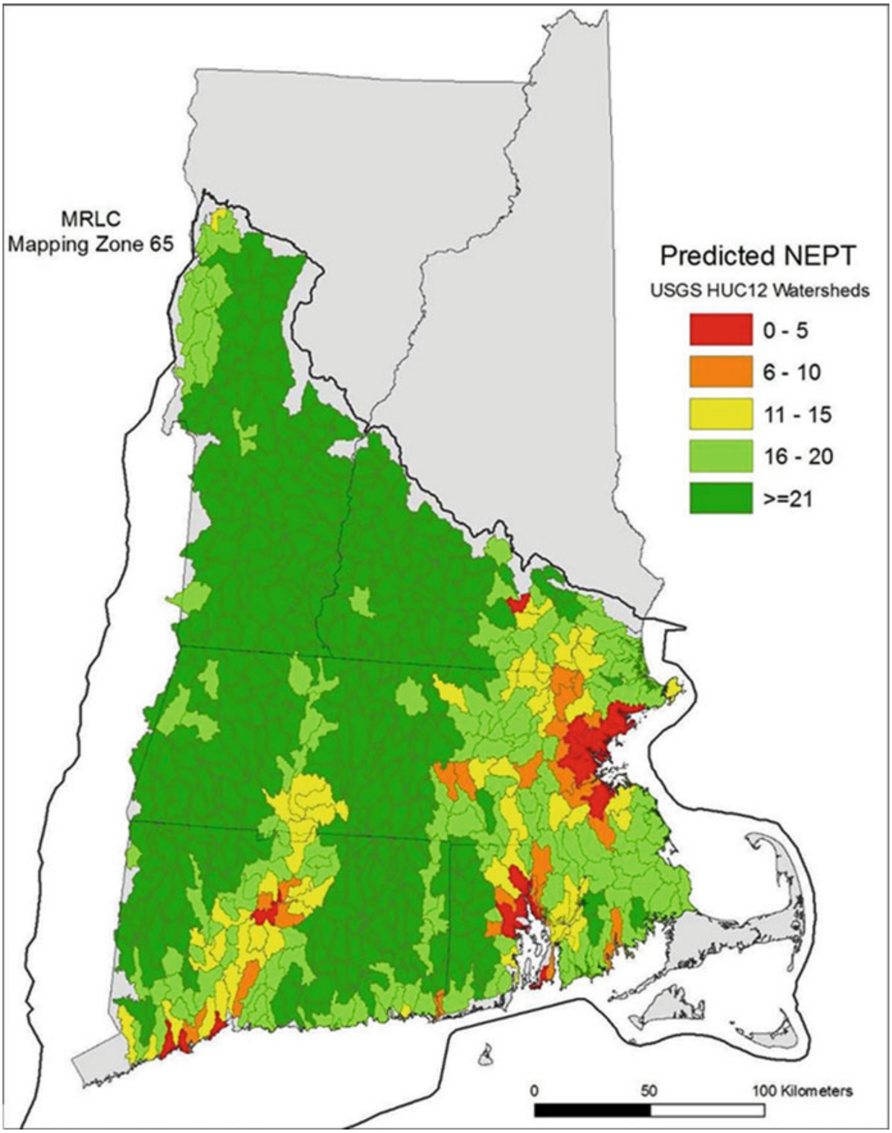

Fig. 4.5 A map showing the predicted number of EPT individuals for HUC12 watersheds in southern New England (MRLC mapping zone 65). The area within this region has a relatively uniform lithology. These results are from an MLR model that did not utilize landscape weighting of the land cover variables (see Fig. 4.4)

was used to predict nEPT in catchments of the Upper Delaware (UPDE) scenic river watershed to the west of the New England study area described in this chapter (Fig. 4.6).

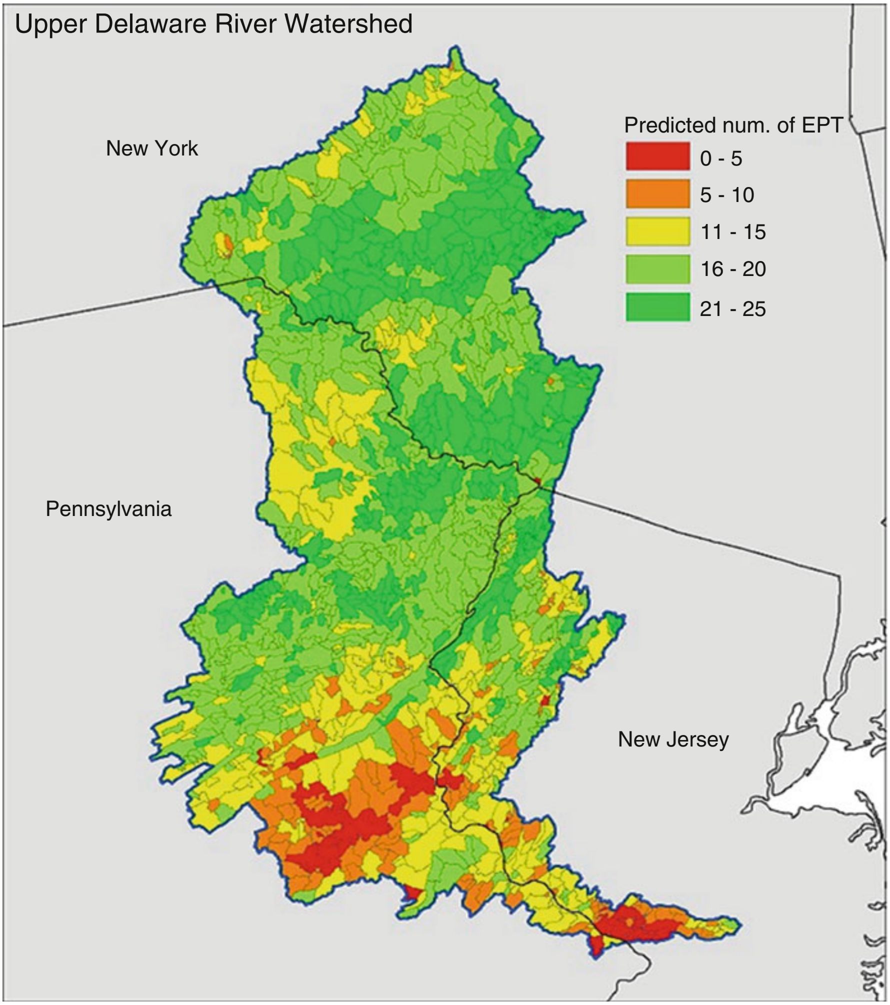

Fig. 4.6 A map showing the predicted number of EPT individuals for watersheds in the Upper Delaware river basin, using the same model as that noted in Fig. 4.5

4.5 Discussion

The GAM and MLR model results were similar in terms of the selection of predictor variables, although the GAMS tended to select fewer variables and performed consistently better in terms of variance explained. This finding may reflect the relative advantage of GAMs over linear models in that GAMs require fewer assumptions of data distributions and error structures, assuming only that functions are additive and components can be smoothed by local fitting to subsets of the data. Smoothing parameters were automatically selected based on the effective degrees of freedom and generalized cross validation based on use of default criteria. As such, the GAMs may have effectively already accounted for much of the variance explained and inclusion of additional variables added little in terms of additional model significance. Moreover, differences between the GAMs and MLR models, although not large, typically added some 5–15 % in terms of variance explained, which was a statistically significant improvement over the MLR models ($0.01 > p < 0.05$). In one case with landscape weighted variables, 76 % of variation in EPT abundance was explained by a GAM using just a single predictor variable - the amount of impervious cover within watersheds (Tables 4.1 and 4.2).

Watershed size was not often selected as a significant predictor of the biotic metrics in any of the model formulations, despite the area encompassed by the watersheds ranging substantially (from 2 to 146,000 ha). Related, although there were not many more cases in the catchment than in the aggregated watershed scenarios, predictions at the catchment scale were consistently better than those based on aggregating the watersheds. This finding suggests that the greater number of smaller watersheds in the case of the catchment scenarios reflected greater sensitivity of the biotic metrics to the land cover variables, even though the sample sizes were only slightly greater (32 versus 27 cases).

Models of EPT abundance and richness performed consistently better than those of the HBI metric, which is consistent with EPT representing sensitive taxa that are better indicators of watershed impacts associated with urbanization than HBI or other integrated indices of biotic integrity. Perhaps surprisingly, landscape weighting did not consistently improve model predictions, and in some cases actually reduced the variance explained by the different models. This finding is consistent with the results of some of our previous analyses in the mid-Atlantic region and may be due, in part, to the fact that impervious cover, which is consistently selected as the most important predictor variable, is often directly connected to the stream channel via storm drainage networks. In such cases, deep-rooted forest cover, or other vegetation cover (grasslands or shrublands), may be bypassed and landscape influences, in terms of buffering runoff volume and pollutant contents, effectively minimized or obviated. Nonetheless, the MLR models of EPT for the catchment scenarios selected tree cover as the primarily predictor variable, despite impervious cover being consistently selected as the primary predictor in nearly every other model formulation.

Only after landscape weighting did the amount of impervious cover get selected as a significant predictor in these cases, which indicates that the weighting did in fact effectively capture the buffering capacity of the landscape. Less variance was explained in the models with landscape weighting, but this is because tree cover was used in the weighting scheme and thus the relative importance of tree cover as a predictor variable dropped out since its effects were already accounted for in the landscape weighting scheme. Related, the HBI metrics showed some sensitivity to landscape weighting in terms of changes in the selection of predictor variables, although impervious cover remained the most important predictor. These findings are consistent with EPT taxa richness and abundance being sensitive indicators of urbanization impacts associated with impervious cover.

The basis of our comparison relies on date-matching the stream IBI and land cover data and that all of our samples were part of one homogenous physiographic province. The reality is that a mismatch in time is possible between our land cover data and stream biotic samples, thus these typs of analysis (given adequate data) should be stratified by state or, even better, well defined physiographic region. Likewise, sample timing and seasonality can also decouple the connection between invertebrate health/activity and land cover metrics.

The predictions of nEPT for an entirely different watershed, the upper Delaware (Fig. 4.6), appear consistent with our results for the New England watersheds, despite differences in topography and, to a lesser extent, in geological substrate. This watershed is experiencing rapid changes in land use via expanding residential development and associated exurbanization, which implications for stream biota. The streams of this watershed are just beginning to be systematically monitored for aquatic biota, including nEPT, by the National Park Service. Predicted maps of this sort, based on land cover variables, provide a baseline against which in situ stream measurements can be compared and assessed as the program develops.

It is known from previous work (e.g. Bolstad and Swank 1997; Booth and Jackson 1997), that management practices, storm water routing, point source pollution (sewage treatment plants, poultry plants, etc.), and other factors, can influence the relationships between land cover and stream biota. Moreover, impacts on stream health and water quality are not threshold responses, but more closely approximate a gradient in which even rural areas with reduced tree cover may display impairments comparable to more urbanized reaches (Booth et al. 2002; Moglen et al. 2004; Goetz and Fiske 2008). Nonetheless, the results presented here indicate that land cover metrics explain the majority or variation in stream biotic metrics in southern New England watersheds, and as such can be used as helpful indicators of stream impairment that can, in turn, be used to focus monitoring, restoration and protection management objectives. Moreover, these results support increasing evidence that reducing impervious cover in new residential and commercial development, or reducing the impacts of impervious areas through mitigation measures such as riparian buffers and overall tree cover within a watershed, is beneficial to stream water quality and associated biotic health.

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Chapter 5
Land Use Influence on the Quantity and Quality of Runoff Along Israel's Coastal Strip

Naftaly Goldshlger, Lior Asaf, and Alon Maor

Abstract This study presents an analysis of the quantity and quality of urban runoff from various land uses by remote sensing and GIS technology coupled with hydrological and chemical monitoring. The study areas were located in the cities of Herzliya and Ra'anana, in Israel's coastal plain, where extensive urbanization has taken place over the last 30 years. Within the research framework, land use in urban basins were analyzed, rain and runoff were measured and sampled at measurement stations for different land uses (residential, industrial, commercial, roads, gas station). The research purposes were to analyze land uses by different remote sensing techniques, to evaluate the quality and quantity of urban storm water from various land uses, and to verify a method for predicting the impact of urban land uses on quantity and quality of urban storm water. The quality of urban storm water from residential areas was very high, and the water is suitable for reuse or direct recharge into the local aquifer.

Keywords Remote sensing • GIS • Urban storm water • Monitoring

5.1 Introduction

The State of Israel has been undergoing an intensive process of urbanization since the end of the 1950s (Mazor 1993). Many open areas and agricultural lands have been turned into residential neighborhoods, urban commerce and industrial areas, with the major urban development taking place along the coastal strip of Israel.

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The increasing of impervious areas and the addition of pollution sources from the urban domain, have a negative effect on water resources.

Combining land-use/land-cover data from remote sensing and GIS with quantity and quality information from urban catchments may help to bridge this gap and generalize relationships between fundamental hydrological and land-use parameters. Increased impervious surface area is a consequence of urbanization, with correspondent and significant effects on the hydrologic cycle (Zheng and Baetz 1999; Shuster et al. 2005; Goldschlager et al. 2009). Carmon and Shamir (1997) estimated that the built-up areas above the coastal aquifer would double by 2020, in comparison to the extent of built-up areas in 1990, and would reach about 500 km^2. These areas would cover approximately 26% of the coastal plain with an impermeable covering, a fact that would affect the ability of the coastal aquifer to continue to be a major source of water for Israel's. Most of the expected increase noted will be in residential neighborhoods (331 km^2, compared with 162.7 km^2), together with a decrease of two-thirds of the cultivated farm land of the coastal plain (from 929 to 361.8 km^2).

Various research studies in Israel and around the world point to the fact that urbanization activities lead to immediate occurrence of some processes effect the water cycle. Urbanization of rural areas is known to directly affect drainage basin hydrology (e.g. Dunne and Leopold 1978; Hollis 1988; Lazaro 1990). Paving the landscape with impervious materials means that a much larger proportion of any rainfall forms immediate runoff. In general, after major urban development in a drainage basin: (1) a higher proportion of rainfall appears as surface runoff, (2) the total volume of discharge increases, (3) for a specific rain event, the response of the watershed is accelerated with a steeper rising limb in a hydrograph, (4) lag time and time to peak are reduced, (5) flood peak magnitude is increased, (6) higher erosion rate of river beds and channels passing through urban areas and (7) water quality in streams and aquifers draining urban centers is typically degraded (Wolman and Schick 1967; Dunne and Leopold 1978; Marsalek and Torno 1993; Kang et al. 1998; Asaf et al. 2004; Bormil et al. 2003; Nativ et al. 2001; Goldschlager et al. 2005, 2009). Human activity in urban areas increases the load of dust, sand, nutritional materials, decomposed organic materials, toxic organic compounds, heavy metals and bacteria on land surface. Consequently, surface water is likely to get contaminated (Flores-Rodriguez et al. 1994). As urban runoff is comprised of many individual flow components draining various areas, the "mix" at the outlet depends on the characteristics of those areas, pollutant wash off potentials and the features of the specific rain event (Pitt et al. 1999).

Urban areas have been classified in the literature into main roads (including parking lots and airports), roofs, residential areas, commercial areas, industrial areas, parks and lawns, and open, undeveloped areas, all of which generate stormwater of different quality. Roads, parking lots and gas stations have been known to contribute a large variety of contaminants, directly related to vehicles (hydrocarbons, oxides of nitrogen, sulfur and lead) or salt de-icing (halite) (Bannerman et al. 1993; Hermann et al. 1994; Smith et al. 2000). The high level of pollution found on major arterial roads in urban areas and highways has been correlated to traffic density (Shinya et al. 2000).

The quality of stormwater from industrial areas is highly dependent upon the type of industry and the conditions at the specific site. The variety of contaminants (some of which can be related to atmospheric deposition) is large and its concentrations can be very high. Whereas in areas of light industry stormwater quality may be similar to that in commercial areas, in dense, heavy-industrial areas, stormwater can be highly polluted with heavy metals and organic compounds (Mikkelsen et al. 1994). Residential areas usually produce high-quality stormwater (Remmler and Hutter 1997). However some contaminants, including detergents, plant-related nutritional materials and fertilizers, herbicides and insecticides, often characterize it (Pitt et al. 1999).

5.2 Materials and Methods

5.2.1 Research Area

The area chosen for the research is located in the urban areas of Herzliya and Ra’anana in the southern Sharon region located in the coastal plain of Israel (Fig. 5.1). The study sites contains number of urban basins with various land uses (e.g. residential areas, industrial areas and major roads), as well variable sizes ranging from (0.2 to 4.4 km^2). The soil in the area is loam, sandstone and sand; the topography is generally gentle, with a number of sandstone ridges. We have

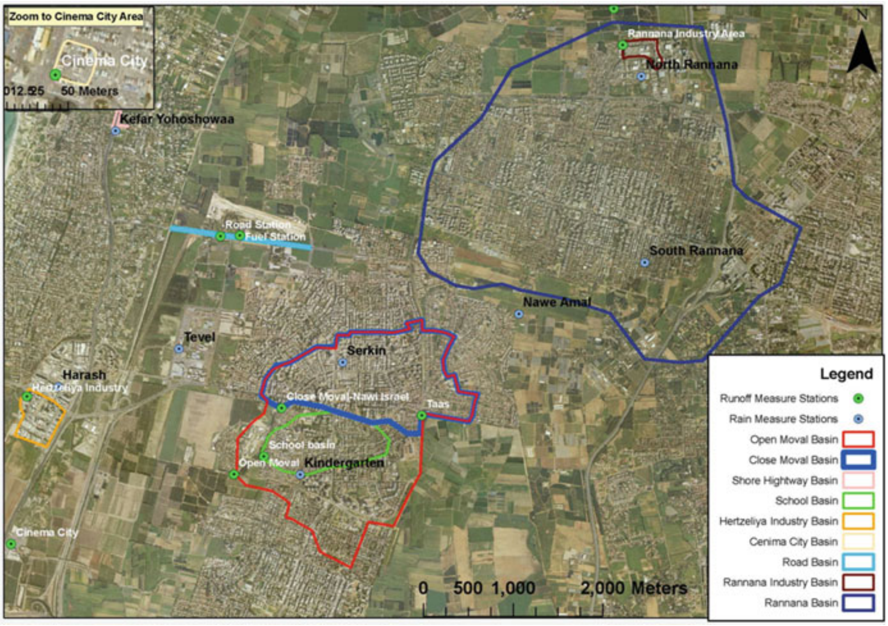


Fig. 5.1 Drainage basins and sampling stations in the Herzliya and Ra’anana area

added data on quantity and quality of urban storm water from the city of Ashdod (Asaf et al. 2004) and Rishone Letzion (un published data), characterized by similar topography and land uses for compressing.

5.2.2 *Sampling Sites*

A number of sampling points were located based on characterize land use and on the urban drainage network structure. The stations were installed at the outlet of the municipal drainage systems. Emphasis was placed on locating the stations at specific land uses known from the literature as having the diverse influence on the quality of urban runoff (e.g. residential, industrial, and main roads). Within the framework of the research, water quality sampling stations were built to enable automatic sampling during rainstorms. During the years of the study, 2006–2008, seven measuring points were defined and established: five measuring points in the Herzliya area and two in the Ra'anana area (Fig. 5.1).

5.2.3 *Land Use Classifications by Remote-Sensing and GIS*

This study used remote-sensing methods with three different spectral and spatial imaging resolutions:

1. Digital aerial photographs (RGB) of high spatial resolution (less than 1 m^2), covering the entire area.
2. Multispectral satellite imagery of intermediate spatial resolution (ATER)—multispectral imaging with nine spectral bands and a low spatial resolution averaging 15 m, covering the entire area.
3. Hyperspectral satellite imagery (AISA) of high spatial resolution (1.6 m) and spectral resolution (198 bands), covering selected spots in the study area.

The processing methodologies were developed in different ways, according to the information content of each source, and they are therefore described separately.

5.2.4 *Classification of the Aerial Orthophotograph*

Initial processing was done on the color orthophotograph of Herzliya and Ra'anana using photo processing techniques: unguided automatic classification and guided classification with the Mahalanobis Distance Method, using ENVI 4.4. The road layer of the GIS was integrated into the results of the classification of all the digital orthophotographs using Arcgis 9.3. The initial classification included 12 classes departments, of which 4 final classes were defined, composed of built-up areas, plant cover, open areas and roads (Fig. 5.2).

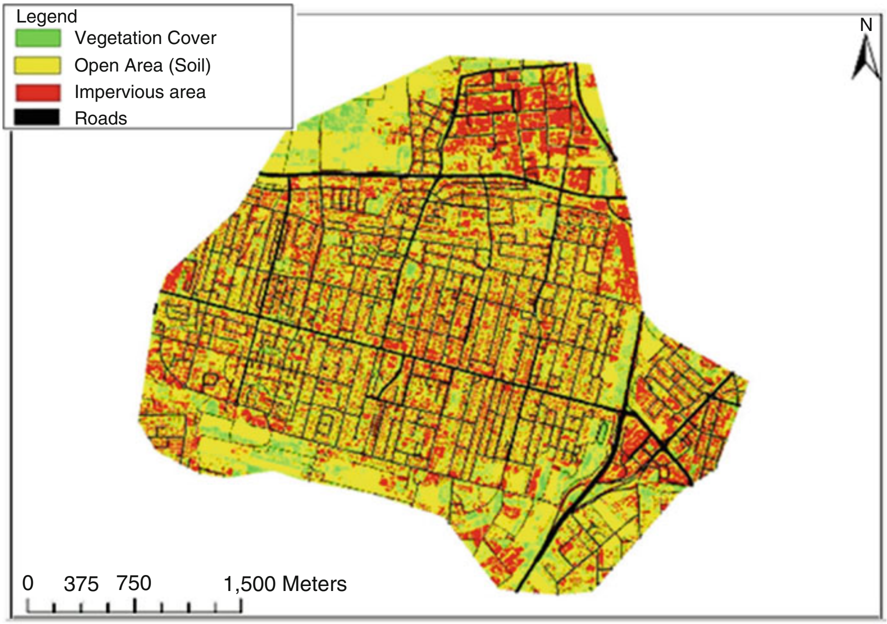


Fig. 5.2 RGB un supervise and supervise classification

Guided classification of the nine-channel multi-spectral images make it possible for characterizing land use by means of spectral signatures identification of the principal classification categories. Since the pixel area in the sampling reaches 225 m^2. it is not possible to calculate the exact area and extent of the land use as in the guided classification of the orthophotograph and hyperspectral sampling. Therefore the classification will be a source for comparison with the results of other classifications such as guided classification according to the orthophotograph (Fig. 5.3).

5.2.5 Hyperspectral Classification

A guided classification of 198-channel hyperspectral images (AISA) provides a great deal of precision in the characterization of land use and their distribution into categories and subcategories; the classification makes it possible to find the extent and size of the land useland use in the imaging process. Since the hyperspectral imaging is limited to the narrow area of the study, it is not possible to carry out a guided classification based on the hyperspectral imaging for the study entire area (Fig. 5.4). The buildings, roads, drainage net, were taken from the national Israeli GIS system. These data were also integrated in analyzing the land-use classification comparison and verification.

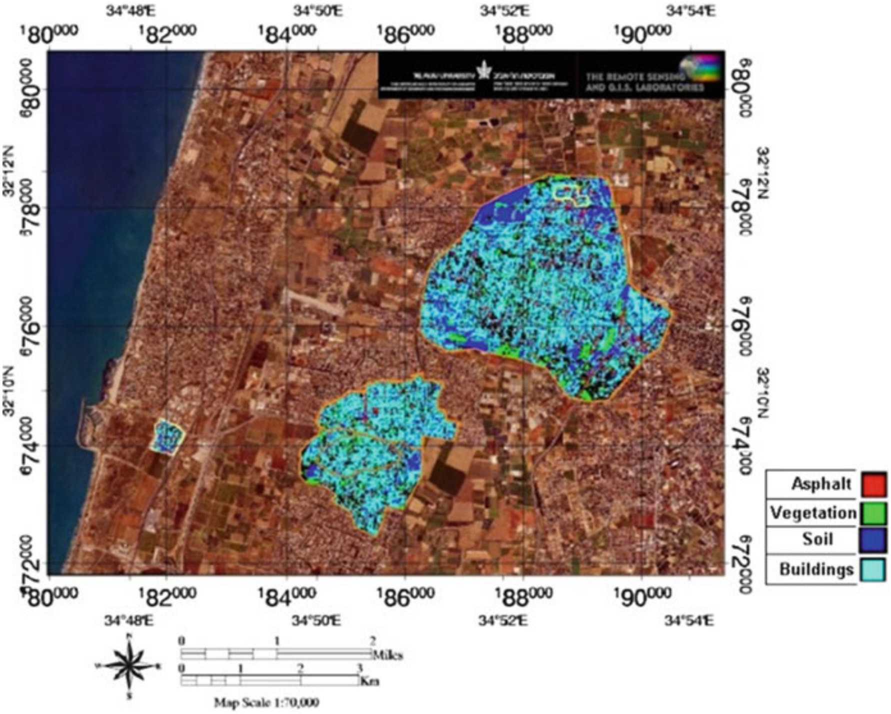


Fig. 5.3 Multi spectral supervise classification

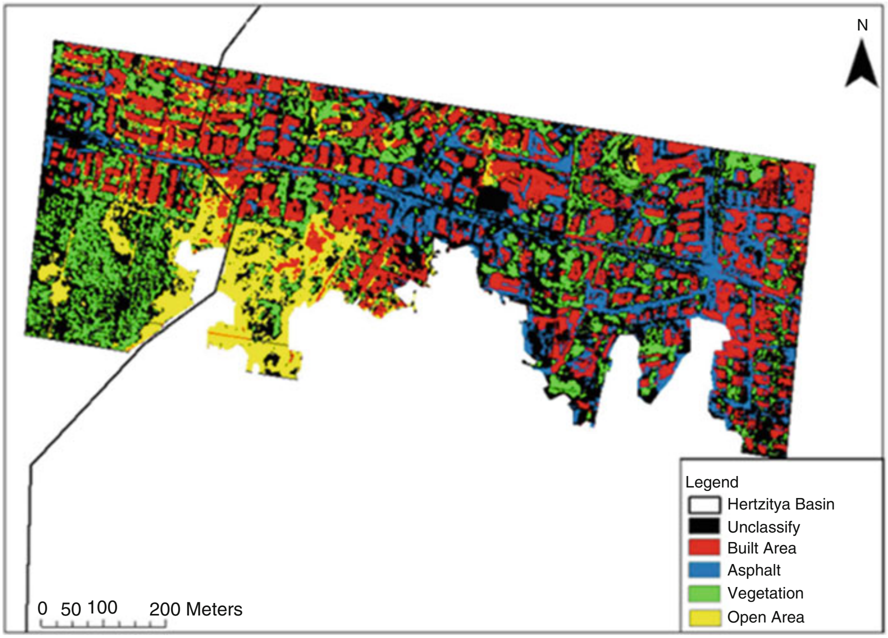


Fig. 5.4 Hyperspectral supervise classification

5.3 Hydrological Measurement

5.3.1 Rain Measurements

Rainfall data were taken from the Meteorological Service measurement station and the Erosion Research Stations for the years 2006–2009. Automatic tipping-bucket rainfall recorders with a resolution of 0.1 mm were installed at three stations (Fig. 5.1) to accurately represent the spatial and temporal distribution of precipitation in the city. For each rain event, the starting and ending times were defined on the basis of hydrograph (the overall rain from near the start of the flow event until the flow ended was taken into account). The calculations of the rain intensity was made for 10 min interval and shown in mm/h units for the various stations. During the first year the quantities of rain were calculated by averaging the values of the rain volume from a number of stations. During the last year, due to mishaps and damage to the measurement instruments from extraneous causes, data was taken from outside the city as well.

5.3.2 Runoff Measurements

Five runoff stations were installed at the outlets of five stormwater drains (four in Herzliya and one in Ra'anana). In 2007/2008, one station was moved from a school basin to a road basin (Fig. 5.1).

Each station included a pressure transducer (Diver with a resolution of 10 mm and data logger) to rescored water head in the channel. The velocities and storm discharges were calculated by using the Manning formula for open channel flow. The area draining into each of the stations was estimated using an ESRI GIS (ArcInfo 9) aerial Ortho-photo map, topographic and infrastructure data and drainage network provided by the local municipalities. Because the drains channeled water from areas of different sizes and land uses, the impact of these characteristics on the quantity and quality of storm water could be evaluated.

5.3.3 Water Sampling

Storm water samples were collected both manually and automatically. Automated samplers were installed next to the storm water gauges at the three stations draining relatively large areas (Fig. 5.1), whereas samples were collected manually from the other drains. The runoff gauges provided information about the discharge and cumulative runoff that could be matched for each sample. The sampler was programmed to start sampling at the beginning of each flow event, then at 10-min intervals during the first hour, followed by 30-min sampling intervals thereafter. Water samples for analysis of major ions were collected in a 0.5 l pre washed plastic bottle and kept under refrigeration. Water samples for trace element analysis were collected in 20 ml plastic bottles after being passed through a 45 μ filter and acidified with HNO_3.

Samples for organic compounds were collected manually from all drains in preheated (400°C) borosilicate bottles, stored on ice and treated in the laboratory within 5 days of sampling, to minimize volatilization. Samples collected for microbiological indicators (general count, coliform bacteria and fecal coliform bacteria) in 300 mm sterile tube were transferred to analysis within 6 h and treated in the laboratory on the day of sampling to avoid bacterial growth.

5.3.4 Analyses of Water Samples

The analyses were carried out at authorized laboratories of the Israel Water Commission, in accordance with the standard methods for chemical and biological analysis. Major ions were examined using a sealed absorption apparatus, and trace elements using the ICP-AES (Intunnelively Coupled Plasma-Atomic Emission Spectrometer) after calibration according to specific standards. The testing of semi-volatile organic compounds was done according to the EPA method 8270, using the Solid-Phase Extraction process and GC/MS analysis. The samples were passed through a 0.5 μ glass filter before extraction. During the analysis, 1 μl of the sample was injected into the MS/GC Varian Saturn 2000, connected to a computer and printer; the quantifying of substances characterized as specific pollutants was done using (Authentic standards). Additional substances discovered in the samples for which we have no authentic standard were quantified by estimation (a crude estimate) on the basis of the response of the substance in the GC/MC device in comparison with that of the internal standards. The microbial analysis to establish the overall numbers, fecal e-coli and coli forms was carried out according to standard incubation methods on Petri dishes and counting of microbe colonies (cfc/100 ml)in various dilutions.

5.4 Results

5.4.1 Land Use Analysis in Herzliya and Ra'anana

According to the results of the land-use analysis, the impervious area reached 30–40% in the residential areas and 60–75% in the industrial areas. The road fractions in residential areas reached 13–18%, in the industrial areas only 8% are roads (Table 5.1). The area was made up of several sub basins:

The Herzliya industrial basin – consists primarily of light industry, hi-tech, office buildings as well as garages and commercial areas. The site is made up of many impervious areas connected directly to the central drainage system. Flows are characterized by a rapid runoff of rainwater and the creation of short, separate high-water waves which respond rapidly to each wave of rain.

The closed tunnel residential basin – The basin characterizes residential areas with a percentage of built-up areas of approx. 40% (Table 5.1).

This basin is a part of the larger basin called the open tunnel.

Table 5.1 Land use classification in Herzliya and Ra’anana residential basins

Close	Close tunnel		Open tunnel		School	
Land use characteristics	Area in km^2	Percentages	Area in km^2	Percentages	Area in km^2	Percentages
Impervious area	1.62	39.2	0.73	40.9	0.27	38.3
Plant covered	0.79	19	0.37	20.7	0.16	22.7
Open area	1.09	26.4	0.41	22.9	0.16	22.4
Roads	0.64	15.4	0.28	15.5	0.12	16.6
Total	4.14	100	1.78	100	0.71	100
Herzliya industrial basin			Shore road			
Impervious area	0.14	63.8	0.0002	1		
Plant covered	0.02	9.6	0.0009	6		
Open area	0.04	18.8	0.0007	4		
Roads	0.02	7.8	0.014	89		
Total	0.22	100	0.015	100		

The open tunnel residential basin – This basin consists mainly of areas of high-rise urban construction as well as low-rise construction. The percentage of built-up area in this basin is approx. 40%.

The school residential basin – This basin consists primarily of areas of low-rise urban construction, road areas reaching approximately 18% and built-up areas reaching 38%.

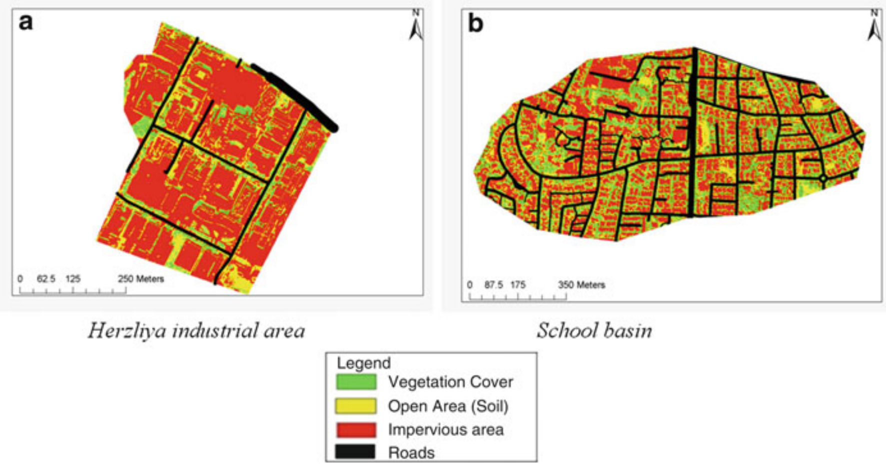
Main highway – A station was set up in the drainage pipe next to the Herzliya landing field, which characterizes a busy city highway.

Ra’anana industrial basin – The Ra’anana industrial basin drains an area of approx. 100 dunams. The basin is small and is characterized by a very high percentage of impervious areas (buildings, commercial areas, shops and roads), reaching 70% of the total area.

Figure 5.5 shows an example of a land use analysis after processing of the aerial photography data using ENVI guided and unguided classifications in a representative area, a residential area (the closed tunnel) and in an industrial area of. It can be seen that in the industrial area there are more impervious areas.

5.4.2 *Storm Rain-Runoff Ratios*

The runoff calculations were based on an evaluation of the runoff measurements from field measurements carried out during the present study as well as on studies of urban storm runoff rain ratios that were carried out previously (Goldschlager et al. 2005; Asaf et al. 2002). A summary of the average values for various basins in Herzliya and Ra’anana are shown in Table 5.2. Overall as expected, the more the impermeable ground cover increases, the more the runoff coefficient rises (Goldschlager et al. 2005); Moreover, in industrial and commercial land use, the percentage of impermeable area rises due to the number of stores and asphalt surfaces, and there is a higher linkage between the areas and the drainage systems. In the industrial land uses maximum values have been observed reaching above 0.80 (Table 5.2).



Herzliya industrial area

School basin

Fig. 5.5 Examples of unsupervised classification in Herzliya basins. (**a**) Herzliya industrial area, (**b**) School residential basin

Table 5.2 Storm runoff coefficients in residential and industrial areas on the coastal plain

Area use	Basin	Basin area (km^2)	Period of observation (years)	Storm runoff coefficient
Residential	Ra’anana	10	3	0.26
	Ashdod – Tel Ashdod	4	3	0.30
	Ashdod average	12	3	0.3
	Herzliya open tunnel	4.2	3	0.32
	Herzliya closed tunnel	1.4	2	0.46
Industrial	Ra’anana industrial	0.086	2	0.86
	Ashdod industrial	3	3	0.3
	Herzliya industrial	0.22	2	0.68

Note: Ashdod’s industrial area is made up of old styled buildings and is significantly different in its percentages of impermeable areas

For the residential areas, it can be seen from Table 5.2 that except for Herzliya’s closed tunnel, the storm runoff coefficients are very similar in the order of 0.30. This is to note that the ratio of runoff rain was observed for only a few years, which did not necessarily include years of abundant rainfall. At this stage, it is the authors’ opinion that for the purpose of estimating water resources from urban residential areas along the coastal plain, the average runoff differential of 0.33 can be used. As expected, the runoff coefficient in the Ra’anana and Herzliya industrial areas is much higher (0.84–0.68), which is why it is suggested to use the average runoff coefficient as a very rough estimate of runoff quantities from industrial areas.

It should be pointed out that these coefficients are average values for each of the sub-basin in the urban area. No distinction was made between areas contributing high quantities of runoff such as buildings, sidewalks, parking lots and roads and areas where the runoff is lower, such as yards, gardens, public areas, parks and open areas.

Based on the area of the watershed, runoff coefficient result and long time average of rain data, we been able to estimate the total potential of urban storm water. Over a number of years, the average urban runoff potential has been approximately 1.5 MCM (million cubic meters) and 2.0 MCM for Herzliya and Ra'anana respectively. In practice, the quantity available for use is much smaller and can reach only several hundred thousand cubic metre, since not all the drainage systems are connected to one outlet or there are local limitations. Therefore the entire quantity of potential urban runoff cannot be captured directly by means of engineering installations. Rather each case must be examined separately in accordance with the draining of the various basins.

5.5 Urban Storm Water Quality from Various Land Uses

5.5.1 Major Ions, Nitrates, BOD (Biological Oxygen Demand) and Total Suspended Sediments (TSS)

The range, mean concentration and standard deviation of urban storm water from the various land uses are presented in Table 5.3. The sulfate concentrations were found to be similar in industrial areas to the concentration observed at the residential area. Concentrations of BOD were higher in the industrial land uses areas than in the residential areas. Salt concentrations on the road and parking lot were the lowest – and in the authors' opinion – demonstrate the short length of the flow path (less than 200 m), and not the nature of the land use. Despite the fact that in the industrial areas the concentrations of BOD does not surpass the standard, the values found were very close to it.

The mean concentration of Chloride and Nitrate in urban storm water from residential area is very low (22.3 and 3.6 mg/L respectively). The chloride and nitrate values were significantly lower than the values in the local aquifer water (253 and 53 mg/L respectively for chloride and nitrite). It is reasonable to suppose, therefore, that the recharge of this water would improve the quality of the local aquifer were. Similar observations regarding saline concentrations in urban runoff water were found in Ashdod and Rishon Lezion (Maniv, unpublished Water quality data).

5.5.2 Heavy Metals

Figure 5.6 shows a comparison of the heavy metal concentration values observed in the residential areas, industrial areas, and major roads. It can be seen from this data that overall at residential areas storm water contained low concentrations of trace metal. It should be pointed out that the larger portion of is expected to be in the adsorbed phase due to the natural partition under aerobic condition. Higher

Table 5.3 Major ions, nitrates, BOD (biological oxygen demand) and total suspended sediments (TSS)

TSS	BOD	chloride	Nitrate	Ammonium	Sulfate	Phosphate	Stormwater concentration (mg/l)	
27	**26**	**31**	**31**	**27**	**20**	**3**	**Samples No.**	**Land Use**
MQL	**3**	**8.6**	**0.8**	**MQL**	**4.81**		Minimum	**Residential**
538	**13**	**50.4**	**6.4**	**0.42**	**15.9**		Maximum	
163.0	**7.6**	**22.3**	**3.6**	**0.2**	**9.6**	**0.7**	Mean	
156.0	**2.6**	**11**	**1.2**	**0.1**	**2.7**		Standard deviation	
27	**27**	**31**	**31**	**27**	**23**		**Samples No.**	
7	**3**	**12**	**0.9**	**MQL**	**9.9**		Minimum	**Industrial**
784	**110**	**77.4**	**10.5**	**4.46**	**84.8**		Maximum	
150.4	**16.3**	**50.7**	**7.5**	**6.4**	**16.7**	**1.4**	Mean	
207.5	**23.4**	**81.3**	**8.3**	**10.2**	**17.7**		Standard deviation	
14	**14**	**18**	**18**	**14**	**12**	**3**	**Samples No.**	
MQL	**1**	**9.2**	**0.79**	**MQL**	**5.29**	**0.27**	Minimum	**Major roads**
815	**25**	**35.6**	**5.0**	**2.87**	**11.6**	**0.38**	Maximum	
182.9	**6.8**	**25.1**	**3.0**	**0.4**	**9.1**	**0.3**	Mean	
205.8	**6.1**	**11.8**	**1.6**	**0.8**	**2.4**		Standard deviation	
5	**5**	**5**	**5**	**5**	**5**	**2**	**Samples No.**	
MQL	**2.5**	**9.46**	**3.3**	**0.15**	**5.8**	**0.74**	Minimum	**Parking**
23	**9**	**114**	**5.4**	**0.5**	**19.6**	**1.06**	Maximum	
173.75	**4.3**	**33.232**	**4.388**	**0.36**	**9.632**	**0.9**	Mean	
	^{1}**20**	^{2}**250**	^{2}**70**	^{1}**1.5**	^{2}**250**	^{1}**1.0**	**Israeli water standards** **1. Stream water** **2. Drinking water**	

Chloride and nitrate concentrations observed in the residential neighborhoods and major roads were lower than concentrations observed in the industrial area

concentrations were observed in the storm water in the industrial areas, above drinking water standards for iron and zinc (1.14 and 2.08 mg/L respectively). Generally, lower concentrations of zinc were found in residential areas than were observed in industrial areas and roads.

A comparison was made between the average concentrations of heavy metals in storm water from residential area at Herzlia to other cities in Israel (Rishon Le-Zion unpublished data) (Fig. 5.7). The observations received from all the cities is similar, runoff water in residential areas contains low concentrations of heavy metals and does not constitute an environmental problem. Heavy metal concentrations in urban storm water were generally higher in Rishon Le-Zion and Herzliya than in Ashdod. The cause may be the higher traffic loads in these cities (Fig. 5.7).

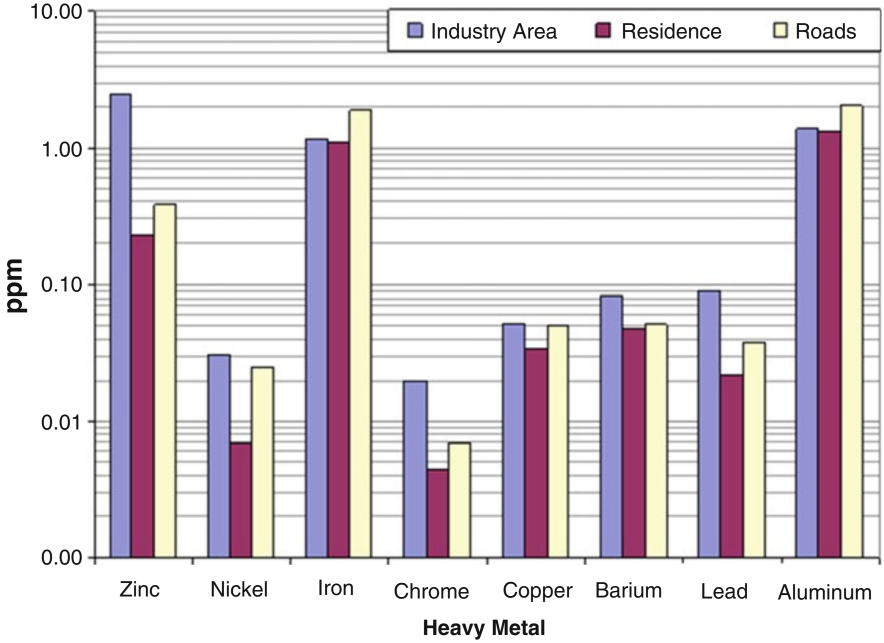


Fig. 5.6 Heavy metal concentrations in urban storm water (mg/L) from various land uses

5.5.3 Calculation of Mass Pollutant Loads from Various Land Uses

Figure 5.8 shows the flax loads calculated in mass/unit of area/year in the various basins. In this calculation the appropriate runoff coefficient was taken into account for each basin and the average concentrations representing all the rainstorms sampled. This calculation makes it possible to compare values received from various land uses per unit of area. It can be seen that in this case there is greater significance in the different loads received from industrial areas as compared with residential areas. There difference in order of magnitudes for some of the elements such as potassium zinc, chloride and magnesium. From the calculation of the loads it can be seen that the Ra'anana industrial basin contributes more salts and metals per unit of area than the Herzliya industrial basin. In the industrial areas, the runoff coefficients were higher, as were the average concentrations, and therefore, there was a more significant contribution from these watersheds per unit areas. These coefficients can give threshold values for the contribution of pollutants from urban areas in Israel and can be used for a preliminary calculation of the loads reaching streams or the sea from urban areas along the coastal plain of Israel.

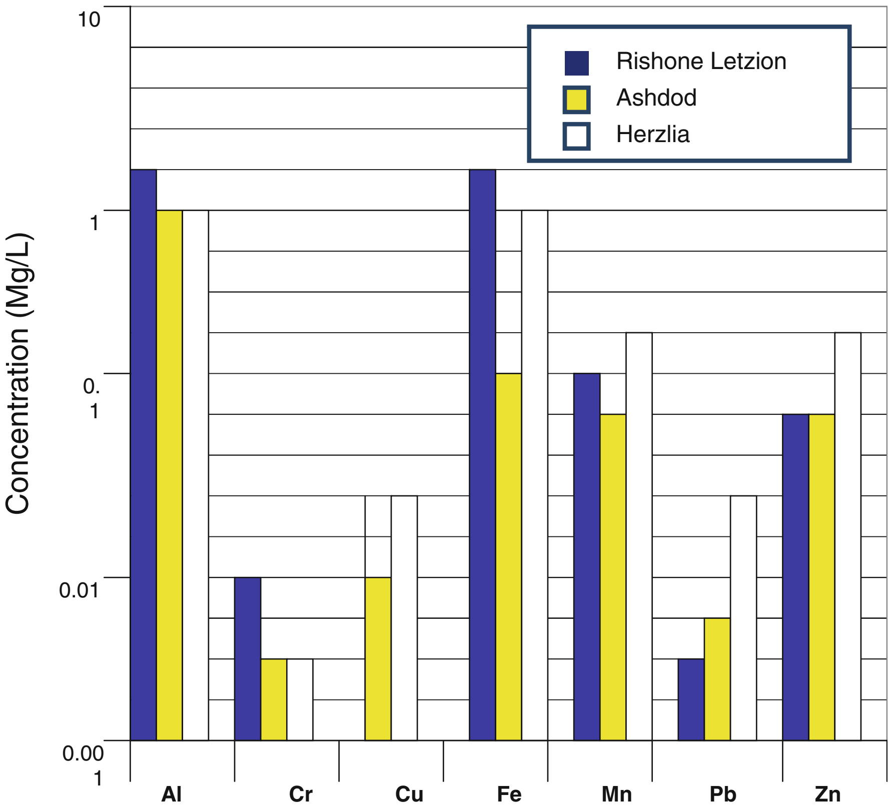


Fig. 5.7 Heavy metal concentrations in urban stormwater from residential areas in Herzliya, Rishon Le-zion and Ashdod municipalities

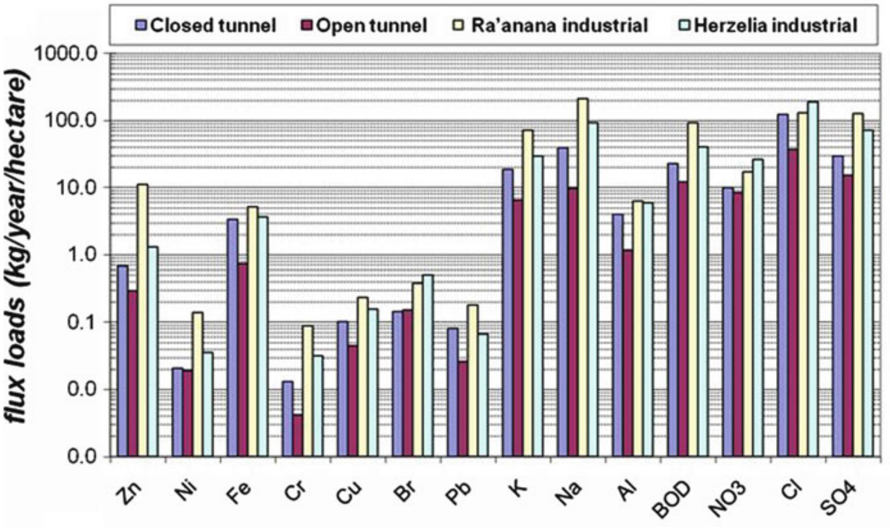


Fig. 5.8 Pollutant loads from various land uses in Herzliya and Ra'anana – 2006–2009

Table 5.4 General count (cfu/100 ml) of microbes (coliforms, *E. coli*) in the runoff from different land uses

General court Cfu/1 ml	*Escherichia coli* MGG Cfu/100 ml	*Escherichia coli* Cfu/100 ml	Coliforms Cfu/ 100 ml	Examination date
57,000	Covered plate	Covered plate	Covered plate	14/3/2007
222,000	ND	32,000	81,000	15/3/2007
450,000	ND	65	83,000	15/3/2007
60,000	ND	<1,000	5,000	15/3/2007
130,000	ND	<1,000	3,000	15/3/2007
590,000	ND	Covered plate	Covered plate	15/3/2007
240,000	ND	28,000	Covered plate	15/3/2007
150,000	ND	3,000	4,000	15/3/2007
60,000	ND	2,000	4,000	15/3/2007
480,000	ND	Covered plate	Covered plate	15/3/2007
290,000	ND	9,700	Covered plate	15/3/2007

5.5.4 Microbial Pollution

Sampling and analyzing microbial pollution was performed during the first 2 years of the study. High concentrations of microbes, fecal e-coli and coli forms were found in runoff water from all land uses (Table 5.4). Fecal coliform concentrations were observed in runoff water at values of tens up to hundreds of thousands (cfc/ 100 ml). Similar values were observed in runoff water in Ashdod (Nativ et al. 2001). Water polluted with microbes, whose source was from sewage leaks from the drainage system and from animal and pet feces, was found in many locations in the urban domain**.** These finding requires initial water treatment before any reuse of the urban stormwater.

5.5.5 Semi-Volatile and Volatile Organic Compounds

Organic compounds have been found in all land uses. The quantification of these substances was done by means of authentic standards (substances for which precise values appear in the table of results). The quantification of fuel substances was done on the basis of aliphatic compounds alone; therefore some of the results appear as an imprecise value. Additional substances found in the samples for which the laboratory did not have authentic standards were semi quantified (crude estimate) on the basis of the response of the substance in the GC/MS in comparison with that of the standard in the literature.

In the runoff water from the industrial area the highest number of organic compounds was observed. In addition, higher concentrations of compounds coming from fuels, pesticides and various industrial compounds were also found. Maximum rates of fuels and Mathlyene pesticide, which is used to control mosquitoes and as an insect exterminator, were found on the roads of the airport and in the industrial area. Generally, concentrations in runoff water in residential areas were characterized by lower concentrations than in industrial areas.

Concentrations of fuels and hydrocarbons were significantly higher in the petrol station and on the roads than in residential areas. Concentrations of pesticides were higher in industrial areas, but in residential areas as well concentrations close to the standard for methylene and simazine. In the 2008–2009 sampling year, an abnormal quantity of simazine was found in the residential area, higher than the standard in one isolated instance.

In a sampling done in 2007 on runoff water for volatile organic compounds (VOC), all the compounds measured by the Water Authority laboratory were found to be under the discovery threshold. The exception was Methyl Tertiary Butyl Ether (MTBE), a fuel additive found in concentrations of 2.11 and 11.33 ppb in two samples in the Herzliya industrial area. MTBE was not found in the other land uses.

5.6 Summary and Conclusions

Storm runoff rain ratios in urban basins of Ra'anana and Herzliya were examined in the years 2007–2009. On the basis of the incorporation of the results of this study with previous studies carried out on this topic, it was found that the regressive coefficient of these connections (runoff coefficients) to residential areas on the coastal plain is 0.26–0.46. In most of the basins, the runoff coefficient varies within narrower boundaries, and at the present stage, an average runoff coefficient of approximately 0.30 may be used. For the first time, an estimate of the urban runoff coefficient in a modern industrial area has been established and found to be approximately 0.70. These average values represent the total urban area. The sites chosen well represent various urban land uses: residential, industrial, roads.

Land uses were characterized and established by use of tools and work methods of ground and aerial remote sensors and use of information layers of the GIS. Use was made of active remote sensing methods. The use of color aerial photography was found to be useful and very inexpensive for mapping and characterizing land uses for estimating water resources from urban areas.

For the purpose of making a rough estimate of water resources in coastal plain basins with a large urban area component, a model was developed which makes it possible to establish urban runoff thickness at various probabilities on the basis of information on multi-annual average rain thickness. It was found that a square kilometer of urban area creates a 50% probability (close to the multi-annual average) of 157,000 m^3 runoff water per year.

The separation between industrial areas and residential areas made it possible to better estimate runoff which may be used due to problems of water quality characterizing urban runoff, from industrial areas in particular.

The quality of runoff water is affected by land use. The best quality of runoff was found in residential areas, which represent most of the urban area. The quality of water from industrial areas, roads and areas of petrol stations is lower. An analysis of the quality of urban water in samples taken from various study sites show that high concentrations of microbes, fecal e-coli and coliforms were found in runoff water from all land uses. This finding obligates treatment of the water before it is reused. These pollutants may result from sewage entering the urban drainage system. The concentrations of salts and major ions were lower than the standard for drinking water. Lower concentrations were observed in residential areas. The chloride and nitrate values in the runoff water were found to be lower than the values in the local aquifer.

The heavy metal concentrations and the loads calculated per unit of area were higher in the industrial areas than in the residential areas, and were similar to concentrations observed in Ashdod and Rishon Le-zion. The similarity in metal concentrations at the study sites and the sites of studies carried out in the area of Rishon Le-zion and Ashdod enable use of this data in characterizing the quality of water from urban areas along the coastal plain.

A number of organic compounds and compounds coming from fuels at high concentrations, pesticides and various industrial compounds were observed in runoff in industrial areas. Higher concentrations of hydrocarbons were observed at the petrol station, in the industrial areas and roads than in residential areas. The highest concentrations of salts and metals were observed generally during the first part of the storm.

In light of the findings of this study and a comparison with water quality data from Rishon Le-Zion and the city of Ashdod, it appears that the quality of runoff water from residential areas is good. It was found that the quality of runoff water at most of the sites examined was better than the standards for drinking water. The standards for penetration to underground water are lower and it is therefore clear that the potential penetration of runoff water in this area is high.

Urban water constitutes an unutilized resource in urban areas in the State of Israel and can be used as a source of additional water if exploited wisely, both by its penetrating directly into the aquifer and by using it for irrigation of gardens and lawns.

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Chapter 6
Modeling Distribution of Point and Nonpoint Sources Pollution Loadings in the Saginaw Bay Watersheds, Michigan

Chansheng He, Carlo DeMarchi, Weichun Tao, and Thomas H. Johengen

Abstract This study involves developing a physically based, spatially-distributed water quality model to simulate spatial and temporal distributions of point and nonpoint sources in the Saginaw Bay Basin, Michigan. Databases of point sources including combined sewer overflows (CSOs) were acquired from the governmental agencies to map the occurrences and magnitude of the CSOs. Multiple databases of meteorology, land use, topography, hydrography, soils, and agricultural statistics were used to estimate nonpoint source loading potential in the study watersheds. Results indicate that point sources from municipalities, industrial sectors and business entities contribute approximately 25 % of the total phosphorous load to Saginaw Bay. While total amount of nutrients (N and P) from animal manure and fertilizer applications and atmospheric deposition declined in the Saginaw Bay Basin, fertilizer applications in non-farmland increased significantly.

Keywords Point and nonpoint source pollution • Distributed large basin runoff model • Saginaw Bay Watersheds

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6.1 Introduction

Pollutants from agriculture, contaminated sediments, urban runoff and combined sewer overflows (CSOs) are the primary impairment contributors of Great Lakes shoreline waters and their tributaries, causing increased levels of nitrogen, phosphorus, and toxic substances in both surface water and groundwater, eutrophication in receiving lakes, and harmful algal blooms (HABs) and beach closings due to viral and bacterial and/or toxin delivery to affected sites (U. S. Environmental Protection Agency, U.S. EPA 2002; He and He 2008). Management of these problems and rehabilitation of the impaired waters to a fishable and swimmable state require identifying the impaired waters and tracking both point and nonpoint source material through a watershed by hydrologic processes. During the past decades, a number of simulation models have also been developed to track the production and transport of both point and nonpoint source materials through a watershed by hydrologic processes. Examples of the models include ANSWERS (Areal Nonpoint Source Watershed Environment Simulation), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), AGNPS (Agricultural Nonpoint Source Pollution Model), EPIC (Erosion Productivity Impact Calculator), BASINS (Better Assessment Science Integrating point and Nonpoint Sources), HSPF (Hydrologic Simulation Program in FORTRAN), and SWAT (Soil and Water Assessment Tool) , to name a few (He and DeMarchi 2010).

While models like these have been quite useful in addressing some watershed issues, however, there are still some key unanswered science questions that are bottleneck problems for an effective restoration of the Great Lakes and prevention of water pollutions. For example, where does the sediment or nutrient come from and how is it being transported downstream to the watershed outlet and nearshore waters of Great Lakes? What and where should best management practices (BMPs) be implemented to produce the maximum effects in the restoration of watersheds? Answering these questions requires an integrated, spatially distributed, physically-based watershed-scale hydrologic water quality modeling system to link the land use and management practices to the movement of materials (sediments, animal and human manures, agricultural chemicals, nutrients, etc.) in both surface and subsurface waters within a watershed (Bouraoui and Grizzetti 2007; Croley and He 2006, 2008; He and Croley 2007a, b, 2008; He and DeMarchi 2010). To meet this need, the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory (GLERL), Western Michigan University, and Case Western Reserve University are jointly developing a spatially distributed, physically based watershed-scale water quality model to estimate movement of materials through both point and nonpoint sources in both surface and subsurface waters to the Great Lakes watersheds (Croley and He 2005, 2006; He and Croley 2007a, b; He and DeMarchi 2010).

This paper describes procedures for estimating potential loadings of nutrients from fertilizers and livestock manure and combined sewer overflows (CSOs) into surface water and groundwater from multiple databases of land use/cover, animal production, fertilizers, and CSOs. It first gives a brief description of the distributed large basin runoff model (DLBRM) and then discusses procedures for processing and deriving nutrient loadings from both point and nonpoint sources. These loading estimates are then used as input to the water quality model to quantify the transportation of combined loadings of livestock manure and fertilizers and CSOs to storages of upper soil zone, lower soil zone, groundwater, and surface water in the Saginaw Bay Basin and to enable management agencies to target critical areas for implementation of water quality programs.

6.2 The Study Area

The study area of this research is the Saginaw Bay Basin with a drainage area of about 23,300 km^2, subdivided into four sub-watersheds: the Saginaw River (16,680 km^2) west of the bay, the AuGres-Rifle (2,777 km^2) to the North, Kawkawlin-Pine (1,409 km^2) in the center, and Pigeon-Wiscoggin (2,425 km^2) to the East (Fig. 6.1). The Saginaw Bay Basin, covering portions of 22 counties, and hosts a number of cities such as Bay City, Flint, Midland, and Saginaw, etc. It is an important base for industrial supply, food production, warm water fishing, and navigation, with agriculture and forests being the two major land uses. Soils in the watershed consist mainly of loamy and silty clays and sands, and are poorly drained in much of the area. Major crops in the watershed include corn, soybeans,

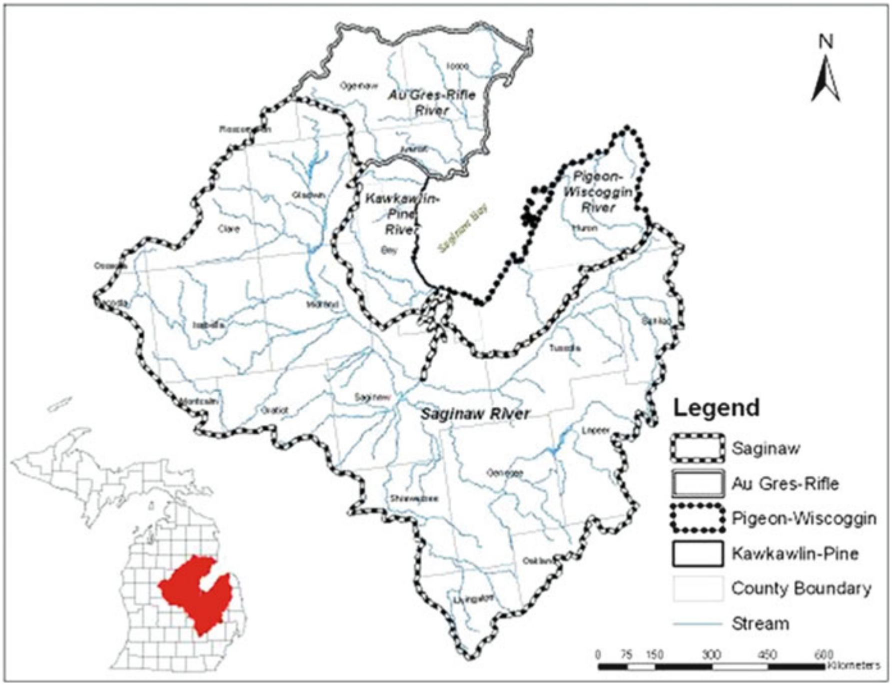

Fig. 6.1 Boundary of the Saginaw Bay Basin and subwatersheds

dry beans, and sugar beets. Over the years, primarily agricultural and urban runoff, improper manure management, CSOs, and industrial pollution have led to high sediment and nutrient loadings, eutrophication in the bay, toxic contamination of fish, restrictions on fish consumption, loss of fish and wildlife habitat, and beach closures in the basin (He et al. 1993; He and Croley 2006, 2008; Michigan Department of Natural Resources 1988). To address the eutrophication problem, the Great Lakes Water Quality Agreement between the United States and Canada has established a target Total Phosphorus (TP) load of 440 metric tons/year for Saginaw Bay (Tao et al. 2010). Achievement of this goal requires estimation of spatial and temporal distribution of nutrients from both point and nonpoint sources. This paper applies the DLBRM to the Saginaw Bay Basin to help ecological researchers and resource managers better understand the dynamics of nutrients for comprehensively managing the pollution problems on a regional scale (He and DeMarchi 2010).

6.3 Watershed Model

The watershed quality model under development evolves from GLERL's DLBRM (Croley and He 2005, 2006; He and Croley 2007a). The DLBRM subdivides a watershed into a 1-km^2 grid network and simulates hydrologic processes for the entire watershed sequentially. Each 1-km^2 "cell" of the watershed is composed of moisture storages of upper soil zone, lower soil zone, groundwater zone, and surface, which are arranged as a serial and parallel cascade of "tanks" to coincide with the perceived basin storage structure. Water enters the snow pack, which supplies the basin surface (degree-day snowmelt) (Fig. 6.2). Infiltration is proportional to this supply and to saturation of the upper soil zone (partial-area infiltration). Excess supply is surface runoff. Flows from all tanks are proportional to their amounts (linear-reservoir flows). Mass conservation applies for the snow pack and tanks; energy conservation applies to evapotranspiration.

The model computes potential evapotranspiration from a heat balance, indexed by daily air temperature, and calculates actual evapotranspiration as proportional to both the potential and storage. It allows surface and subsurface flows to interact both with each other and with adjacent-cell surface and subsurface storages. The model has been applied extensively to nearly 40 watersheds draining into the Laurentian Great Lakes for use in both simulation and forecasting (Croley and He 2005, 2006, 2008; Croley et al. 2005; He and Croley 2006, 2007a). The unique features of the DLBRM include: (1) it uses readily available climatological, topographical, hydrologic, soil and land use databases; (2) it is applicable to large watersheds; (3) mass continuity equations are used to govern the hydrologic processes and solved analytically, thus, making model solution analytically tractable (Croley and He 2005, 2006). Currently, the model is being modified to add materials runoff through each of the storage tanks routing from upstream to downstream. The movement of pollutants through storages in a watershed is

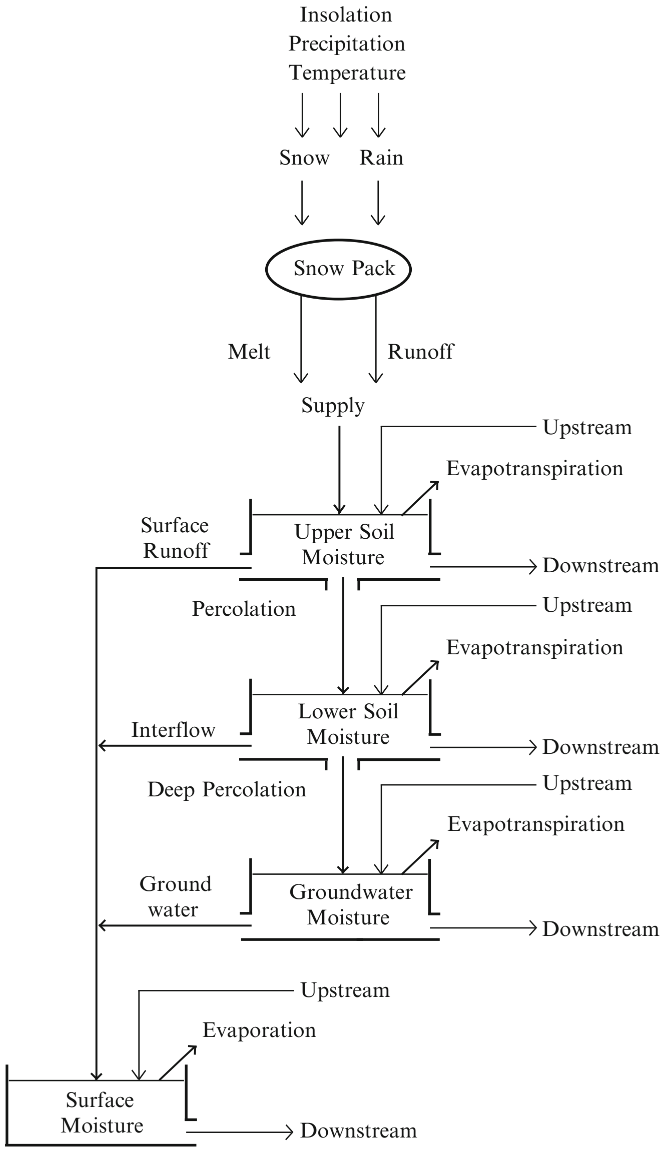

Fig. 6.2 Scheme of the model

governed by continuity equations with linear loss/transformation coefficients (mathematical equations are not shown here due to space limits; for details, see Croley and He 2005, 2006).

The DLBRM hydrology component requires 16 input variables for each of the cells (Tables 6.1 and 6.2). The model output includes: for every cell in the watershed grid, basin outflow, surface runoff, evapotranspiration, infiltration,

Table 6.1 Input variables derived by the AVDLBRM interface

Variables	Databases
Elevation	USGS digital elevation model (DEM)[a]
Flow direction	USGS DEM
Slope	USGS DEM
Land use	USGS land use database[b]
Depth of upper soil zone (USZ)	USDA STATSGO[c]
Depth of lower soil zone (LSZ)	USDA STATSGO
Available water capacity (%) of USZ	USDA STATSGO
Available water capacity of LSZ	USDA STATSGO
Permeability of USZ	USDA STATSGO
Permeability of LSZ	USDA STATSGO
Soil texture	USDA STATSGO
Manning's coefficient value	Land use, slope, and soil texture

[a] U. S. Geological Survey National Elevation Dataset (NED) http://seamless.usgs.gov/

[b] U. S. Geological Survey National Landcover Characterization Dataset (NLCD) 1992, http://seamless.usgs.gov/

[c] U. S. Department of Agriculture 1994. http://soils.usda.gov

Table 6.2 Time series meteorological and flow variables

Variables	Databases
Daily precipitation	National Weather Service climate databases
Daily air temperature	National Weather Service climate databases
Daily solar isolation	National Weather Service climate atlas
Daily flows	USGS discharge database

interflow, percolation, deep percolation, USZ and LSZ moisture storages, groundwater storage, and lateral flows between adjacent USZ, LSZ, and groundwater (Croley and He 2005).

The DLBRM hydrology component was calibrated for the period 1950–1964, applied to the period 1999–2006, and recalibrated for this last period to reproduce the observed daily flow. Performances (Table 6.3) indicate that the model reproduces the flow of the Saginaw River and AuGres-Rifle Rivers well and with sufficient robustness for nutrients load assessment. Performances for the Kawkawlin-Pine and Pigeon-Wiscoggin are less satisfying, probably due to the very small portion of these watersheds contributing to the flow measured at the USGS gages (He and DeMarchi 2010).

6.4 GIS-Model Interface

Since the DLBRM was designed for hydrologic modeling of large scale ($>10^3$ km^2) watersheds, development of the input variables for each grid cell from multiple databases over large watersheds is a challenge. To facilitate the input and output processing for the DLBRM, an ArcView-DLBRM (AVDLBRM) interface program

Table 6.3 Hydrologic simulation performances for the Saginaw Bay tributaries

Basin	Size (km^2)	Period	Calib. Param.	Bias (%)	Corr.	Avg flow (cm/d)	RMSE/ Flow (%)	Nash Sutcliffe
Saginaw	16,680	011950–121964	011950–121964	−5.0	0.90	0.056	61.4	0.77
		011999–092006	011950–121964	−2.4	0.80	0.062	71.8	0.63
		011999–092006	011999–092006	0.1	0.84	0.062	60.0	0.48
AuGres-Rifle	2,777	011950–121964	011950–121964	−1.7	0.86	0.079	54.5	0.66
		011999–122006	011950–121964	−0.8	0.85	0.088	42.6	0.70
		011999–122006	011999–122006	−1.7	0.89	0.088	36.6	0.72
*Kawkawlin-Pine	1,409	011950–121964	011950–121964	9.7	0.79	0.048	147.9	0.25
*Pigeon-Wiscoggin	2,425	011986–121993	011986–121993	6.9	0.79	0.072	125.0	0.30

*Flow for 1999–2006 was not available for Kawkawlin-Pine and Pigeon-Wiscoggin has been developed to assist with the model implementation. The AVDLBRM interface was written in ArcView Avenue scripts by modifying the ArcView Nonpoint Source Modeling interface by He et al. (2001) and He (2003). It consists of six modules: (1) Soil Processor, (2) DLBRM Utility, (3) Parameter Generator, (4) Output Visualizer, (5) Statistical Analyzer, and (6) Land Use Simulator. Databases required for the DLBRM include meteorological data, soil, digital elevation model (DEM), land use/cover, and hydrology and hydrography (Tables 6.1 and 6.2). The databases identified in Table 6.1 are used by the interface and those in Tables 6.1 and 6.2 are used to derive the DLBRM input variables and visualize the simulation results (He and Croley 2007a, c; He et al. 2008; He and DeMarchi 2010).

6.5 Estimating Nonpoint Sources Loading Potential

Nutrients (N and P_2O_5) loading potential from livestock manure and fertilizer applications was estimated at the 5-digit zip code and county scales respectively. The livestock manure loading potential within a county was estimated by using the five-digit zip code from the Census of Agriculture for the periods of 1987, 1992, 1997, and 2002 (http://www.nass.usda.gov/Census_of_Agriculture/index.asp). The census data were tabulated farm counts of animal units by five-digit zip code in three classes: 0–49, 50–199 and 200 (i.e. number of farms with animal units up to 49, between 50 and 199, or 200 or more per zip code) for 1987 and 1992. But those classes were not available for the 1997 and 2002 census data. To be consistent in determining the number of animals per farm, the weighted mean number of animals per farm was computed for each type of animal according to the percentage of three classes of animals for the 1987 and 1992 census data The mean values of 25, 100, and 200 were used for each of the three classes of the animal units in the computation. The weighted mean number of animals per farm in the study area were computed as: 57 cattle and calves, 84 hogs and swine, 18 lamb and sheep, 2,650 chicken, and 6 horses for the census years of 1987, 1992, 1997, and 2002. These were the only data available to estimate number of animals per zip code area and discrepancies between the actual animal number and these estimates should be well noted when using those results for water resources planning (He and Shi 1998; USDA Agricultural Statistic Service 2004).

The computed numbers of livestock per zip code were matched with the five-digit zip code boundary file (http://www.census.gov/geo/www/cob/z52000.html#shp) and multiplied by animal manure production coefficients to estimate animal manure loading potential (tons/year) by zip code. The coefficients from the Livestock Waste Facilities Handbook MWPS-18 (Midwest Plan Service 1985) were used in this study. For example, a 1,000 lb. dairy cow produces 13 metric tons of manure in a year (20–25 % solids content and 75–80 % moisture content) with 150 lbs. of nitrogen and 60 lbs. of phosphate; a 150 lb. pig produces 1.6 metric tons of manure in a year with 25 lbs. of nitrogen and 18 lbs. of phosphate. As animal manure was likely applied to agricultural land, the loading potential was combined with agricultural land in the Geographic Information System to derive the animal loading potential in metric tons per hectare of agricultural land within each watershed. The results indicate that total amounts of nitrogen (N) and phosphate (P_2O_5) produced from animal manure ranges from 23,000 to 27,000, and from 10,000 to 11,400 metric tons, respectively, for the periods of 1987, 1992, 1997, and 2002. These nutrients, if applied uniformly to all cropland (around 1.31 million ha) in the region, would average around 17–21 kg/ha for nitrogen, and 8–9 kg/ha for phosphate (Table 6.4). These amounts seem quite small on a per unit area basis. However, animal production facilities are concentrated in certain locations in the region and the manure produced from those facilities are often either applied to the adjacent cropland or disposed of locally to reduce transportation and labor cost.

As shown in Fig. 6.3, the amount of phosphate produced from manure ranges from 3 to 114 kg/ha in the northeast and northwest portion of the Saginaw Bay Basin, and in certain locations, it amounts up to 114 kg/ha. Consequently, these locations can be targeted for implementation of manure management programs for minimizing the pollution potential to the surface and subsurface waters. This also indicates that agricultural statistics data at a finer scale (below county level) would reveal more useful information than would the county level data in animal manure management. Large livestock operations, difficulty to identify at the county level, could be more easily identified at the 5-digit zip code level for manure management (He and Shi 1998; He and Croley 2007b; He et al. 2008; He and DeMarchi 2010).

Large quantities of fertilizers are applied to both farmland and non-farmland (residential lawns, parks, and golf courses, etc.) each year. If improperly applied, these chemicals also represent a potential threat to both surface and groundwater. Estimating loading potential of fertilizers , however, is challenging because no fertilizer information is collected at county level on an annual basis (U.S. Geological Survey 2000; U. S. EPA 2004; He and DeMarchi 2010). U.S. Geological Survey estimated the county level manure and fertilizer application rates for the period of 1982–2001 based on the state level fertilizer sales data and agricultural statistics data (Alexander and Smith 1990; Ruddy et al. 2006). The results show that approximately 92,000–110,000 metric tons of nitrogen (N) fertilizer and 32,200–11,400 metric tons of phosphate were applied to cropland in the study area each year, averaging about 70–83 kg/ha/year for N fertilizer, and 25–62 kg/ha/year for P_2O_5 fertilizer (Table 6.4). These estimates only show amounts of fertilizers applied to the study area each year and do not consider uptake of the fertilizer by crops. Lack of soil testing, plant uptake of nutrients, and mineralization and volatilization information makes it very difficult and speculative to estimate nutrient budget and excessive nutrients remaining in the soil each year. Thus no attempt was made to estimate excessive nutrients in the soil each year. Instead, only fertilizer loading potential was estimated in the study area (He and DeMarchi 2010).

Table 6.4 shows that total nitrogen and phosphate applications had declined for the period of 1987–2002 in the study area. This was attributable to the implementation of best management practices for reduction of nutrient loadings to the rivers and bay (U. S. EPA 2002; He and DeMarchi 2010). However, nonfarm applications

Table 6.4 Estimated nutrient loading (ton/year) in the Saginaw Bay Basin

	N (Ton) from					P_2O_5 (Ton) from			
		Fertilizer application (F)		Atmosphere (At)	Total N		Fertilizer application		Total
Year	Manure (M)	Total	Nonfarm		M + F + At	Manure	Total	Nonfarm	M + F
1987	26,644	97,908	5,429	13,950	138,502	11,390	81,496	2,526	92,886
1992	25,754	100,534	6,894	14,355	140,643	11,210	42,229	2,323	53,439
1997	24,847	108,662	9,036	14,208	147,717	10,142	43,163	2,868	53,305
2002	23,257	91,883	10,188	14,104	129,244	10,174	32,186	2,949	42,360

Notes:

About 1.31 million ha of cropland (3.24 million acres) is available in the Saginaw Bay Basin

Estimated total amounts of nitrogen and phosphate from animal manure were based on the Census of Agriculture Data of 1987, 1992, 1997, and 2002

Atmospheric deposition of N was based on the U.S. Geological Survey estimates (Ruddy et al. 2006)

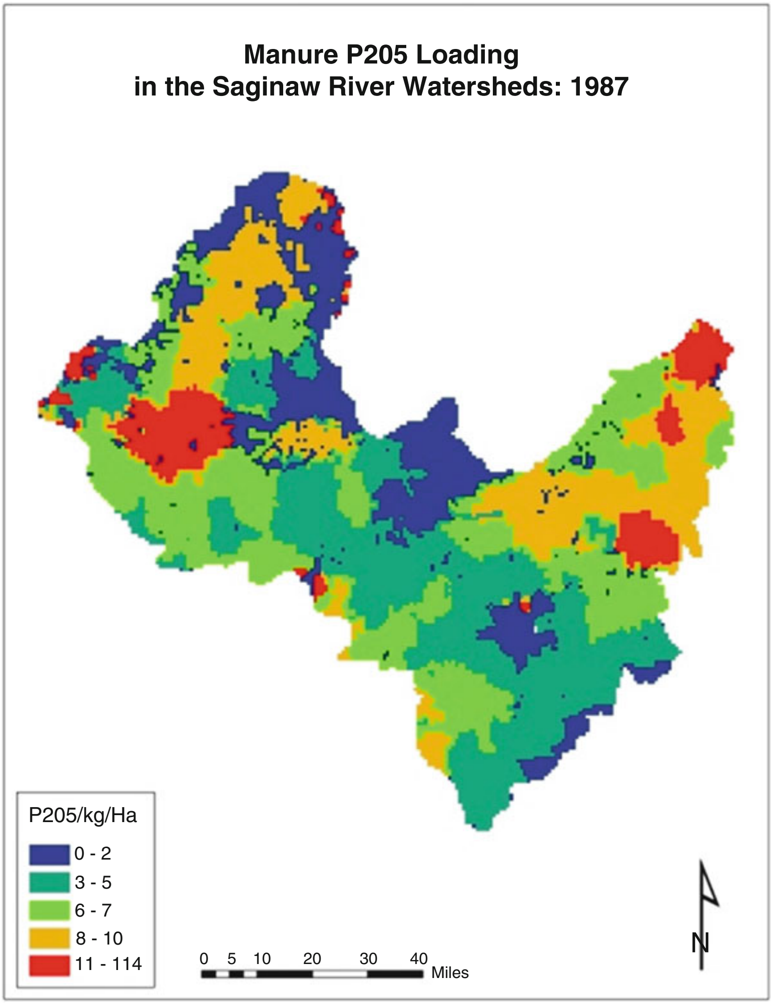

Fig. 6.3 The manure applications

of both nitrogen and phosphate had steadily increased during the same period. These applications, while accounting for only 3–8 % of total applied nutrients, concentrated in urban areas including residential lawns, recreational parks, and golf courses, were characterized by high intensity and frequency, and often combined with irrigations. If not improperly managed, these non-farmland applications of nutrients present a high contamination potential to both surface water and groundwater. Thus, implementing best management practices in non-farmland nutrient applications is also crucial for reducing the pollution potential in the study area (He and Shi 1998; He and Croley 2007b; He et al. 2008; He and DeMarchi 2010).

6.6 Point Source Pollution

Pollutants loads generated by municipal and industrial wastewater treatment plants (WWTP) and by combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) have been estimated from the National Pollutant Discharge Elimination System permits and verified with the management of some of the sources (U.S. EPA 2004). Besides nutrients, CSOs and SSOs also contain microbial pathogens (e.g. fecal coliform), oxygen depleting substances, total suspended solids, toxics, and floatables. These pollutants lead to the impairments of surface waters, beach closures, contamination of drinking water supplies, and threat to human health. Data on CSOs events for the period of 200–2006 were acquired from the Michigan Department of Environmental Quality (MDEQ), processed and spatially referenced. Figure 6.4 shows the locations of the CSOs events in the study

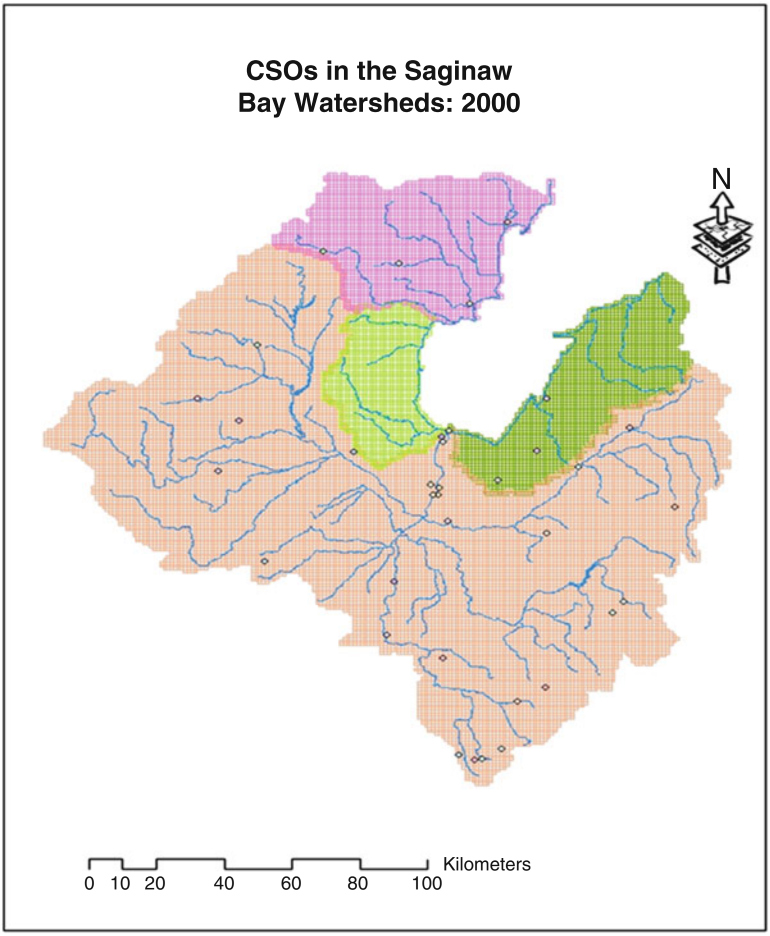

Fig. 6.4 Locations of combined sewer overflows (CSOs)

Table 6.5 Estimated total phosphorous load exported by the Saginaw River and load generated by point sources

	CSO/SSO est. (met. ton)	WWTP (met. ton.)	Total load[a] (met. ton)	CSO fraction of load (%)	WWTP fraction of load (%)
2001	2.43	–	642	0.38	–
2002	3.02	–	513	0.59	–
2003	0.59	–	345	0.17	–
2004	2.98	116	724	0.41	16.0
2005	–	110	288	–	38.2

[a] MDEQ (2003, 2004, 2005, 2006)

area. The processed data were to be used in the DLRBM to estimate the frequency and magnitude of the CSOs in the study area. However, the phosphorous load generated by point sources accounts for ~20 % of the total load exported by the Saginaw River during wet years and ~40 % of the load during dry years (Table 6.5), and CSO's contribution to the total phosphorous load entering the bay is negligible, indicating CSO's impacts are more localized. Consequently, CSOs were not modeled at least initially. Loads from other municipal and industrial sources will vary only at the monthly scale (He and DeMarchi 2010).

As addition of water quality components to the DLRBM is undergoing, a suite of regression models were first developed to relate total phosphorous (TP) concentration to the river discharge using concentration data reported by the MDEQ (2003, 2004, 2005, 2006) and river discharge data for the watersheds shown in Fig. 6.1 (He and DeMarchi 2010; Tao et al. 2010). Point sources in Saginaw/Bay contribute almost one quarter of the TP load reaching the Bay (Table 6.5). The estimated annual TP loads by different watersheds are shown in Fig. 6.5. The more rural Tittabawasse River Watershed (the largest tributary to the Saginaw River), Cass River, and Shiawassee River contributed about 31 %, 12 %, and 7 % of the TP load entering the bay, respectively, and that most of these loads are of agricultural origin. The two urbanized Saginaw River and Flint River Watersheds contributed 23 % and 20 % of the TP load, respectively (Tao et al. 2010). On per square kilometer basis, both the Saginaw and Flint Rivers showed a TP load four times higher than the average level of all other sub-watersheds, indicating significant contributions from urban sources as cities of Saginaw and Bay City, and Flint are located in the two watersheds respectively. A notable importance appears the role of the National Wildlife Refuge (NWR), an area of wetlands and swamps upstream the city of Saginaw, which acts as a sink for almost 10 % of the load coming from the upper part of the watershed (He and DeMarchi 2010).

6.7 Critical Nonpoint Source Pollution Areas

The Great Lakes Water Quality Agreement sets target total phosphorus (TP) load of 440 metric tons/year for Saginaw Bay. However, as shown in Fig. 6.6, the TP load estimates from the Saginaw River Watersheds (not including Au Gres-Riffle,

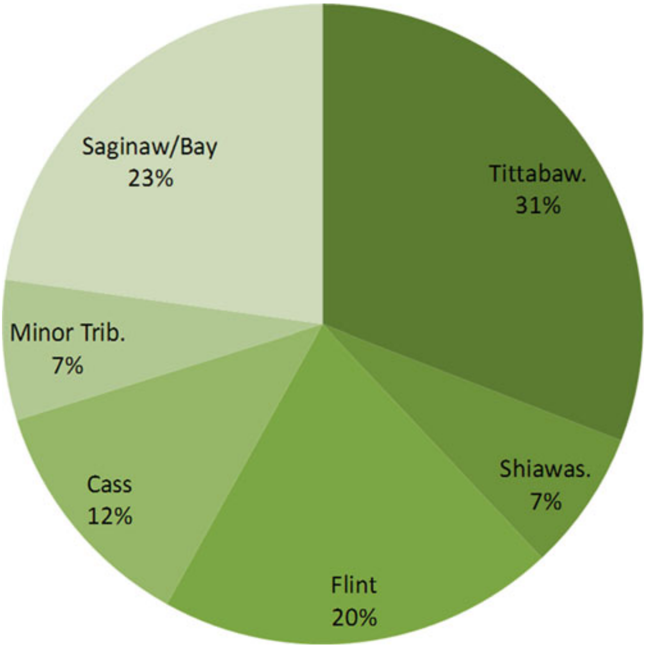

Fig. 6.5 Average contribution of sub-watersheds to the total load of Saginaw River in 1997–2008

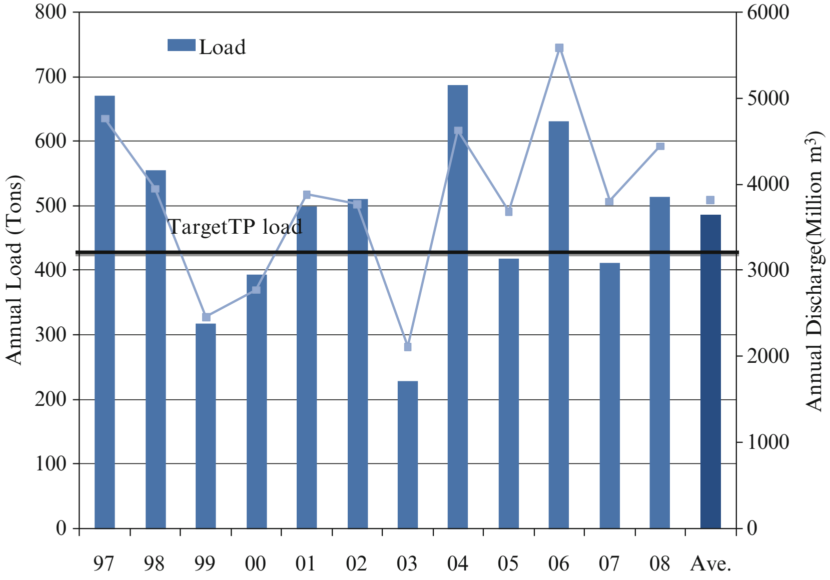

Fig. 6.6 Saginaw River's annual TP load estimates

Kawkawlin-Pine, and Pigeon-Wiscoggin Rivers) had often exceeded the targeted TP load for the period of 1997–2008 except the dries years (Tao et al. 2010). Thus, it is imperative that the BMPs be expanded not only in farmland but also in non-farmland, particularly in the critical NPS areas. Currently, the loading potentials of nutrients (N and P_2O_5 from manure and fertilizers) have been assigned to each 1-km^2 cell of the watershed study area (the watersheds were divided into 1-km^2 grid cells) by using the AVDLBRM interface (Croley and He 2005, 2006; He and Croley 2006, 2007b; He et al. 2008; He and DeMarchi 2010). These data layers will be used with other input variables to simulate transportation of the nutrients in the storages of upper soil zone, lower soil zone, groundwater, and surface water. Additionally, soil erosion and sedimentation will be estimated by adapting the Revised Universal Soil Loss Equation methodology to daily simulation. Eventually, the DLBRM will simulate loading potential and transport of nutrients, pesticides, and soil erosion and sedimentation in the Saginaw Bay Basin and other watersheds.

6.8 Summary

The NOAA's Great Lakes Environmental Research Laboratory, Western Michigan University, and Case Western Reserve University are developing a spatially distributed, physically-based watershed-scale water quality model to estimate movement of materials through point and nonpoint sources in both surface and subsurface waters to the Great Lakes watersheds. This paper, through a case study of the Saginaw Bay Basin, estimates loading potential of nutrients from animal manure and fertilizers and point sources. Annually, about 140,000 tons of N are applied in the Saginaw Bay Basin, with livestock manure and fertilizer applications and atmospheric deposition accounting for about 20 %, 70 %, and 10 %, respectively. Livestock manure and fertilizers contribute approximately 20 % and 80 % of the total phosphate applications (53,000 tons) per year.

While total fertilizer applications declined during the period of 1987 and 2002, fertilizer applications on non-farmland increased significantly during the same period. Point sources contribute about 25 % of the TP load entering the bay, indicating municipalities, industrial and business entities as a large contributor of the TP loading. Thus expansion and enhancement of the current water quality programs in both farmland and urban areas is essential for achieving the targeted nutrient load in the bay. Current efforts are focusing on the refinement of the distributed large basin runoff water quality model for simulating pollutant transport in both surface and subsurface water in the Saginaw Bay Watersheds to help management agencies and ecosystem researchers for identifying critical pollution areas to target implementation of the water quality control programs.

Long term, comprehensive water quality databases with adequate spatial and temporal coverage are critical for both modeling point and nonpoint source pollutions and assessing the effectiveness of water quality programs. A coordinated network should be established among governmental agencies, research institutions, and private organizations to collect and tabulate relevant agricultural chemical application data at finer scale (the township or zip code level) and to monitor water quality with adequate spatial and temporal resolution to aid water resources planning and management.

Acknowledgements Partial support for this research is provided from the NOAA Center for Sponsored Coastal Ocean Research.

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Chapter 7
GIS Based Decision-Making Model for the Identification of High Priority Wetland and Stream Restoration Sites

Mark Eiseman, Patrick L. Lawrence, Tim Walters, Hugh Crowell, and John Kusnier

Abstract This chapter provides a comprehensive and chronological review of the procedures that were used to identify suitable sites for wetland and stream restoration in the Swan Creek and Tenmile Creek/Ottawa River watersheds within northwest Ohio. It includes an explanation of the datasets that were used to generate aerial photographic base mapping, evaluation of existing conditions within the two watersheds and the development of the GIS predictive model that was utilized to identify potential wetland and stream restoration sites and that were used to select the final 26 sites for the development of conceptual wetland and/or stream restoration plans.

Keywords GIS • Restoration • Watersheds • Wetlands • Streams

7.1 Introduction

In 2007 Partners for Clean Streams Inc. obtained funding from the Joyce Foundation to develop a wetland and riparian inventory and restoration plan for the Swan Creek and Ottawa River watersheds located in Northwest Ohio

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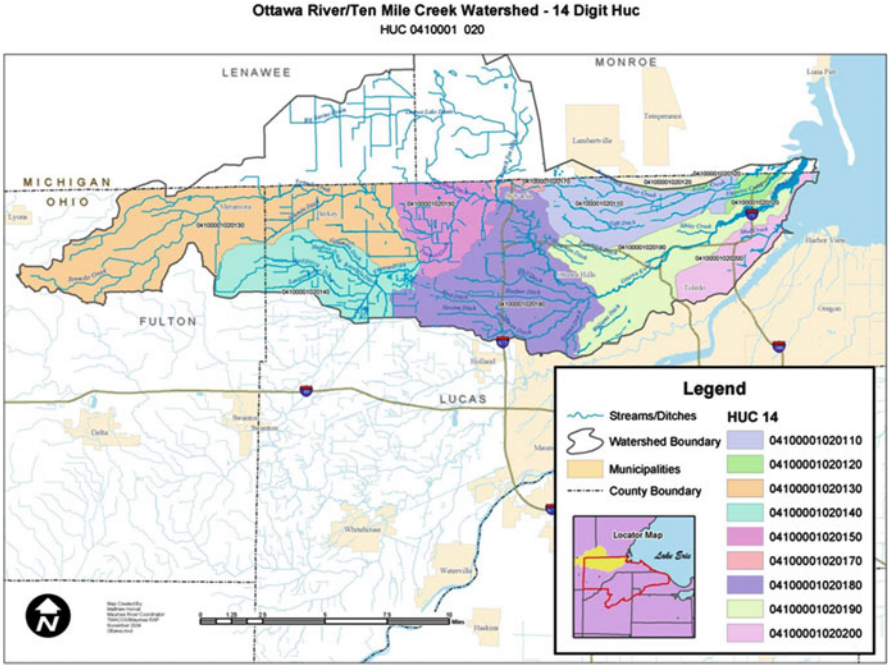

Fig. 7.1 Ottawa River/Tenmile Creek watershed, Ohio

(www.partnersforcleanstreams.org). These watersheds are within the Maumee Area of Concern designated by the International Joint Commission and US Environmental Protection Area in 1987 as a priority area to address serious and persistent water quality concerns (MRAC 1990). The desire to complete this inventory arose from the realization that the conversion of land to agriculture, residential, commercial and industrial development has negatively impacted the physical, chemical and biological properties of the aquatic ecosystems within the two watersheds (Mannik and Smith and Hull Associates 2009). The identification of priority wetland, riparian and stream restoration sites within these watersheds will allow for improvements to habitat conditions, ecosystem health, and related water quality through the implementation of standard restoration techniques for such ecosystems following approaches developed by NRCS (2003), ODNR (no date), and ODNR (2008).

The Ottawa River/Tenmile Creek watershed encompasses approximately 221 square miles in portions of Lucas and Fulton Counties, Ohio and Lenawee and Monroe Counties, Michigan (Fig. 7.1). Its average gradient is 4 ft per mile and many miles of smaller streams and ditches drain into the main stem rivers within this watershed. More prominent tributaries include, from downstream to upstream, Sibley Creek, Heldman Ditch, Hill Ditch, North Tenmile Creek, Prairie Ditch, Zinc Ditch, Wiregrass Ditch, Roberts Ditch and Schmitz Ditch

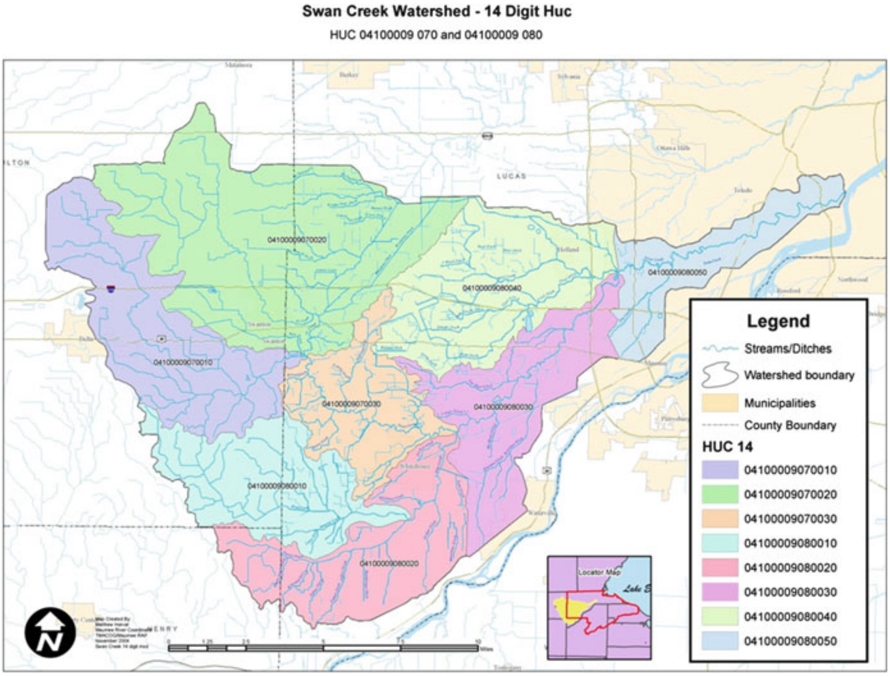

Fig. 7.2 Swan Creek Watershed, Ohio

(MRAC 2006). The Swan Creek Watershed occupies approximately 204 square miles in portions of Henry, Fulton and Lucas Counties, Ohio (Fig. 7.2). Over 200 miles of creeks and ditches drain this watershed (MRAC 2006). The main stem of Swan Creek is only about 40 miles long. More prominent tributaries within this watershed, from downstream to upstream, include Wolf Creek, Cairl Creek, Blue Creek, Gail Run and Ai Creek. It should be noted that both Wiregrass and Prairie Ditches, which are included as tributaries in the Tenmile Creek/Ottawa River watershed, also have the ability to drain into the Swan Creek watershed (MRAC 2006).

Both watersheds contain three rather distinct subregions, based on general patterns of land use and predominant soil associations. All of the headwater areas in the Tenmile Creek/Ottawa River watershed, and a portion of the Swan Creek Watershed, exists in a predominantly agricultural area of eastern Fulton County and northwestern Lucas County. Here soils consist predominantly of Hoytville-Nappanee-Mermill Association, which is described as a level to gently sloping very poorly drained and somewhat poorly drained soils that formed in glacial lake sediment (Mack 2007). Tributaries within this portion of both watersheds tend to be low gradient systems that have historically been within this subregion channelized and subsequently maintained to promote agricultural drainage. Riparian corridors tend to lack natural woody vegetation. As a result, the streams tend to be fully exposed to sunlight and the majority of wetlands in this area have been eliminated for agricultural purposes (Mack 2007).

Downstream of the agricultural subregion, a narrow portion of the Tenmile Creek/Ottawa River watershed and a much larger portion of the Swan Creek watershed flow through the Oak Openings Region of Northwest Ohio, one of the most ecologically unique regions of the Midwest United States. Here, soils consist predominantly of a wide band of the Granby-Ottokee-Tedrow association, characterized by level to gently sloping, poorly drained, moderately well drained and somewhat poorly drained soils that formed in sandy material. Agriculture is still present in this subregion, but to a lesser extent due to the lower fertility of the sandy soils.

After leaving the Oak Openings subregion, both streams and their tributaries flow through the urbanized, densely populated area of eastern Lucas County. Here soils consist of the following soil associations: The Urban Land Association is most prevalent in the urban subregion, followed by the Bixler-Dixboro Association and then the Del Rey-Lenawee Association. Within this subregion, the Granby-Ottokee-Tedrow Association is limited to the northwest corner of the Ottawa River watershed (Mack 2007). Agriculture is for the most part absent in the urban subregion of the Tenmile Creek/Ottawa River and Swan Creek watersheds, being replaced by residential, commercial and industrial development. Within this subregion, the Tenmile Creek/Ottawa River passes through the City of Sylvania, the Camp Miakonda Boy Scout Camp, Wildwood Metropark, the Village of Ottawa Hills, The University of Toledo, Ottawa and Jermain Parks and then an industrial corridor that contains numerous capped and abandoned landfills (MRAC 2006). At its most downstream end, east of Interstate 75, the river widens and is bordered by private properties, public marinas, yacht clubs and restaurants before emptying into the Maumee Bay and the western basin of Lake Erie.

Swan Creek passes through the Village of Whitehouse and Monclova Township, where it winds its way through Brandywine Country Club. Once it crosses I-475/US 23, the creek passes residential and commercial areas before flowing through Swan Creek Metropark. After leaving the metropark, the river continues through residential areas of increasing density, until entering the urban core of the City of Toledo where the creek continues past numerous businesses and warehouses, until it empties into the Maumee River (MRAC 2006).

Over the years, the Tenmile Creek/Ottawa River and Swan Creek watersheds have experienced numerous alterations that have impacted the physical, chemical and biological properties of the rivers and their numerous tributaries. The ditching and tiling of agricultural land in the upper reaches of both streams, combined with increased development in the middle and lower reaches of both watersheds have caused the flow regimes to become more erratic in both watersheds (MRAC 1990). This has caused increased erosion along the banks of the main channels, which in turn has caused increases in turbidity and embeddedness of substrate within the stream channels. Removal of streamside vegetation has contributed to the problem of increased erosion, and also caused an increase in the temperature of waters and reduced oxygen concentrations. Together, these changes have selected for species of aquatic macroinvertebrates and fish that are more tolerant to these types of environmental conditions.

7.2 Project Goals and Objectives

The objective of this study was to identify specific sites and develop conceptual plans for wetland and riparian restoration within the watersheds that, once implemented, would have measurable positive impacts on the following Beneficial Use Impairments (BUIs) as identified within these two watersheds which are part of the Great Lakes Area of Concern for the lower Maumee River basin: degradation of fish and wildlife populations; degradation of benthos; and loss of fish and wildlife habitats (MRAC 2006). Ohio EPA has identified these BUIs as priorities to address within Great Lakes Areas of Concern (including the Maumee AOC where these two watersheds are located) and has provided guidance as to targeted goals to achieve through restoration (OEPA 2005).

As a secondary goal, this study is also intended to provide wetland and stream restoration opportunities for permit applicants who are required to mitigate lost wetlands and stream habitat and functions under Sections 404 and 401 of the Clean Water Act and the State of Ohio's Isolated Wetlands Law. Past experiences have shown that with no local mitigation opportunities readily available, wetland mitigation has oftentimes been accomplished outside of the watersheds where the impacts have occurred, either by restoring wetland habitat on project specific sites, or by purchasing wetland mitigation credits from a wetland mitigation bank that has been approved to service an area that encompasses several watersheds. While such mitigation projects meet the mitigation requirements under Sections 404 and 401 of the Clean Water Act, without the replacement of wetland and stream functions within the watershed where the impacts occur, the identified BUIs may continue to decline in the Swan Creek and Tenmile Creek/Ottawa River watersheds as more wetland and stream impacts occur (MRAC 2006).

7.3 Methods

In order to develop the necessary mapping to assist in the evaluation of existing conditions and the development of conceptual wetland and/or stream restoration plans, GIS shape files and other electronic data were gathered that were available for the two watersheds (Table 7.1). Using these data sources, the

Table 7.1 Databases used in GIS Mapping

Orthographic
Lucas County 2002 GIS\ReferenceData\State\OH\Lucas\Orthos\Lucas_Co_2002\Lucas.sid
Lucas County 2003 GIS\ReferenceData\State\OH\Lucas\Orthos\Lucas_Co_2003\LC_IA_2003.sid
NAIP 2005 – Lucas/Fulton County GIS\ReferenceData\State\OH\Lucas\Orthos\NAIP_2006\naip_1-1_2n_s_oh095_2006_1.sid
OSIP 2006 – Lucas/Fulton County GIS\ReferenceData\State\OH\Lucas\Orthos\OSIP_2006\Lucas.sid
Raster
Digital Elevation Model GIS\ReferenceData\State\OH\Lucas\Shape\Lucas.sid
GIS\ReferenceData\State\OH_NWI\berkey 1977AP.tif
GIS\ReferenceData\State\OH_NWI\sylvania 1977AP.tif
GIS\ReferenceData\State\OH_NWI\toledo 1977AP.tif
GIS\ReferenceData\State\OH_NWI\oregon 1977AP.tif
GIS\ReferenceData\State\OH_NWI\genoa 1966AP.tif
GIS\ReferenceData\State\OH_NWI\wallbridge 1977AP.tif
GIS\ReferenceData\State\OH_NWI\grand rapids 1971AP.tif
GIS\ReferenceData\State\OH_NWI\whitehouse 1977AP.tif
GIS\ReferenceData\State\OH_NWI\reno beach 1977AP.tif
GIS\ReferenceData\State\OH_NWI\Maumee 1977AP.tif
NWI Maps (non-digital)
GIS\ReferenceData\State\OH_NWI\rossford 1977AP.tif
Shapefiles
Rivers & Streams GIS\ReferenceData\State\OH_Statewide\SurfaceWater\oh_hydro_lines.shp
Ohio Wetland Inventory GIS\ReferenceData\State\OH_Statewide\OWI\stateowi_sps83.shp
Soils GIS\ReferenceData\State\OH\Lucas\Shape\oh095_a.shp
Streets GIS\ReferenceData\State\OH\Lucas\Shape\streets.shp
Ohio DNR Lands GIS\ReferenceData\State\OH_Statewide\Ohio_State.gdb\Conservation\OH_DNRLand
NLCD – impervious
NLCD – Canopy
NLCD – Land Cover
ODNR – Detailed Watersheds
ODNR – Land Use/Land Cover
ODNR – groundwater resources
Database Files:
Parcels GIS\ReferenceData\State\OH\Lucas\AREIS_GDB.mdb\Parcels
Ohio Watershed Boundaries
NHD
IMS:
University of Toledo: wetlands University of Toledo: wetlands

a working base map was prepared with superimposed geographic datasets that included surface water networks, wetlands data from multiple local and regional sources, land use/land cover, canopy and riparian data, the Oak Openings Region boundaries, conservation and recreation lands in programs, and agricultural lands.

7.3.1 Preliminary Evaluation of GIS-Based Mapping

The initial GIS mapping was reviewed to determine how it could be utilized to select areas for possible wetlands and/or stream restoration/enhancement sites. Four general restoration categories were developed based on this evaluation:

1. Stream Restoration/Enhancement Sites – This designation included stream segments that were found to be in the “restorable warmwater” habitat quality range, i.e. having a Qualitative Habitat Evaluation Index (QHEI) = 45–60, with a very narrow 100-year floodplain – indicative of channelization or natural incision – and very little forest cover within 200 ft of the channel (for more background on QHEI scoring the reader is referred to OEPA (1989) and Rankin (2006)).
2. Wetland Restoration/Enhancement Sites – This category was developed to identify hydrologically isolated, generally topographically flat hydric areas containing hydric soils that were currently farmed or were recently abandoned agricultural fields.
3. Streams with Adjacent Wetlands – This category was developed to identify those streams in the ‘restorable warmwater’ habitat quality range (QHEI = 45–60), with a wider 100-year floodplain (indicating minimal channelization or natural incision), the presence of topographically flat hydric soils or nonhydric soils with hydric inclusions, and very little forest cover within 500 ft of the stream channel. These areas were considered to be prime candidates for non-isolated, floodplain wetland restoration where, once restored, the wetlands habitat would have the potential to positively impact BUI’s through shading, sediment deposition and filtering, reducing erosion, and increasing and extending baseflow. There may also be some in-channel work associated with this category.
4. Urban Restoration/Enhancement Areas – In addition to the above categories, the project team also considered an urban restoration/enhancement restoration/category, where there are floodplain encroachments and impervious surfaces limiting lateral expansion of the stream cross section. Here, the only option in urban situations might be multi-stage channel construction to restore some channel morphology and increase bank stability.

The GIS mapping was refined to ensure that the data obtained from the various sources would be useful in developing a predictive model that would identify sites that fell within the four categories listed above with varying degrees of restoration/enhancement potential. The most currently available aerial base mapping was also added to the GIS mapping, so that existing land use could be better assessed before going into the field for data verification. The result was a preliminary map based on ranking the potential restoration sites from high to low (Fig. 7.3).

7.3.2 Initial Field Verification of GIS Mapping

The preliminary ranking map was then examined in order to further identify the best areas for restoration opportunities. Forty potential wetland and/or stream restoration/enhancement sites were then selected from the preliminary GIS data analysis

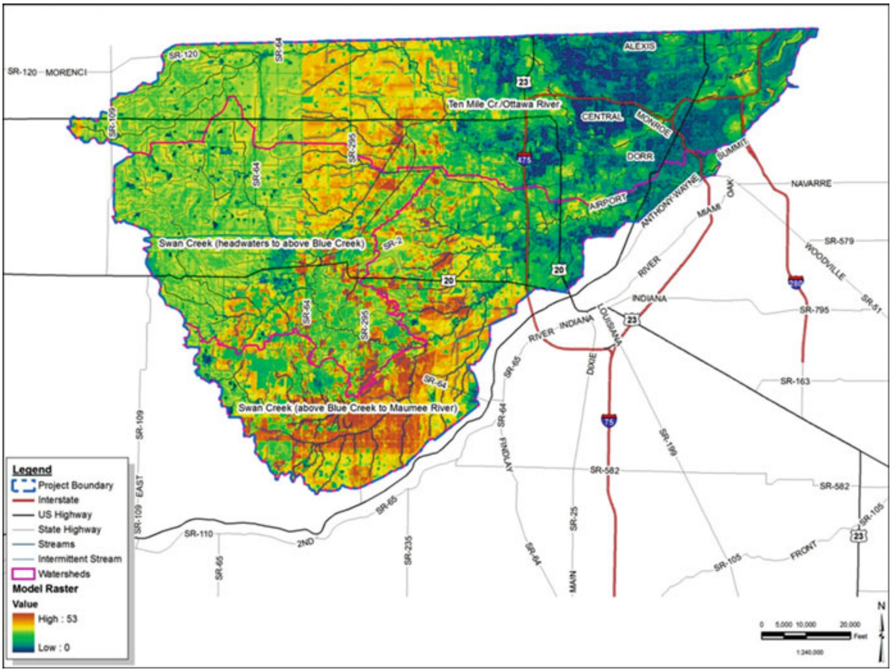

Fig. 7.3 Initial evaluation of potential restoration sites based on GIS data layers

for field verification. Sites were selected based on their proximity to existing stream corridors, the presence of hydric soils, land use/land cover type and proximity to currently established conservation areas. The forty sites were also distributed more or less evenly over the entire study area. After examining ten sites that were scattered throughout the study area, field personnel were able to verify that the GIS data that had been plotted for land use/land cover type, stream locations, riparian buffer condition and the approximate location of floodplain boundaries were accurate. Based on these results, it was determined that no further field verification would be necessary at this time and efforts could be refocused on field verifying the preliminary outcome of the GIS-based predictive model.

7.3.3 Development of the GIS Predictive Model

The data gathered to date was reviewed leading to the development of weighting schemes for the GIS-based predictive model. The intent of the model was to identify sites for the restoration and enhancement of habitat in the following areas:

- In the stream channel;
- Along stream corridors, between 500 and 1000 ft away from the top of bank of the existing stream, channel (a.k.a., isolated wetlands); and
- Along stream corridors, between 0 and 500 ft from the top of bank of the stream (non-isolated wetlands and adjacent stream channels).

Table 7.2 Preliminary weighting for GIS model

		Weighting[a]		
Primary parameter		Streams	Isolated wetlands	Streams w/Wetlands
Distance from stream		0′–50′	500′– 1000′	0′–500′
Proximity to stream		High	High	High
Proximity to 100-yr floodplain		High	0	High
Land use/land cover		Medium	Medium	High
Presence of hydric soils		Low	High	High
Percent canopy cover		Low	High	High
Presence of impervious surface		Medium	High	High
Proximity of wetlands[b]	NWI	Medium	High	High
	319	Medium	High	High
Proximity to rare species		0	Medium	Medium
Slope		High[c]	High[d]	High[d]
Proximity to ODNR sites		0	Medium	Medium
Proximity to metropark lands		0	Medium	Medium
Presence of agricultural land		High	Medium	Medium

[a] High = 5, Medium = 3, Low = 1, no weight = 0

[b] 319 Wetland information supersedes NWI data

[c] For streams, the greater the slope, the higher the weighting

[d] For isolated wetlands and steams w/wetlands, the flatter the slope, the higher the weighting

The preliminary model was developed using the following parameters as primary indicators:

- Proximity to the stream channel
- Proximity to 100-year floodplain
- Land use/land cover type
- Presence/absence of hydric soils
- Percent existing canopy cover
- Presence/absence of impervious cover
- Presence of impervious surface
- Proximity to wetlands, as indicated by National Wetland Inventory Mapping or Section 319 Wetlands
- Proximity to rare species
- Slope
- Proximity to existing Ohio Department of Natural Resource protected lands
- Proximity to Toledo Metropark lands
- Presence of agricultural lands

Each of the primary parameters was then assigned a weighting of high, medium or low, based on its ability to predict the restoration or enhancement potential for one of the three given areas (stream, isolated wetlands or streams with wetlands). The weighting system that was developed is presented in Table 7.2. A number of parameters were then identified as secondary factors that would be used to refine the search for enhancement and restorations sites, after the GIS-based model identified sites based on the primary parameters. These secondary factors included:

- Toledo Metropark Priority Lands: the closer the site to Toledo Metropark Priority Lands the higher the weight;
- Development Pressures: the presence of known or imminent development pressures excluded areas identified as good restoration or enhancement sites based on primary parameters;
- QHEI/HHEI: sites that are located in or adjacent to stream channels areas that have been previously monitored using QHEI or HHEI and have been shown to be of moderate quality (i.e., they have potential for restoration or enhancement) have greater weight than those sites that have been shown to be of low quality and thus are less restorable;
- Parcel Size: sites that occupy fewer, larger parcels will be more desirable than sites that occupy a large number of smaller parcels.

Using the above primary parameters, the GIS-based model was run to identify sites throughout the Tenmile Creek/Ottawa River and Swan Creek watersheds that would be suitable for habitat restoration and/or enhancement. Three versions of the model were generated, one for stream locations, one for isolated wetland locations, and one for streams with adjacent wetlands, based on the weighting of parameters as identified in Table 7.2.

Model outputs were then mapped and evaluated that resulted in the determination that the top 30% of the sites, as defined by the predictive model score, should be mapped throughout the study area, and that those sites with the highest ranking would be selected for ground verification (Fig. 7.4). After reviewing the top 30% of the sites throughout the Swan Creek and Tenmile Creek/Ottawa River watersheds, it became evident that the GIS model identified the largest number of potential restoration and/or enhancement sites in the Oak Openings Subregion of the two watersheds, which occupies the middle third of the study area, This resulted in a disproportionately large number of sites in this region. The next most abundant number of sites was observed in the western third, or Agricultural Subregion, outside of the Oak Openings. However the majority of sites in this region did not score as high as sites in the Oak Openings Subregion. The Urban Subregion was found to contain the fewest number of sites.

Approximate boundaries were identified for the Agricultural, Oak Openings and Urban Subregions, and the model reran to identify the top 30% of sites within each of these three subregions (i.e., as opposed to the top 30% of sites across the entire study area as previously run). As expected, this approach identified a greater number of sites in the Urban Subregion, although the number of sites in this subregion was still low compared as compared to the number of sites in the other subregions. Figure 7.5 illustrates the identification of the top restoration sites within each subregion of the Tenmile Creek/Ottawa River and Swan Creek study area and by restoration type (stream, wetland, isolated wetland).

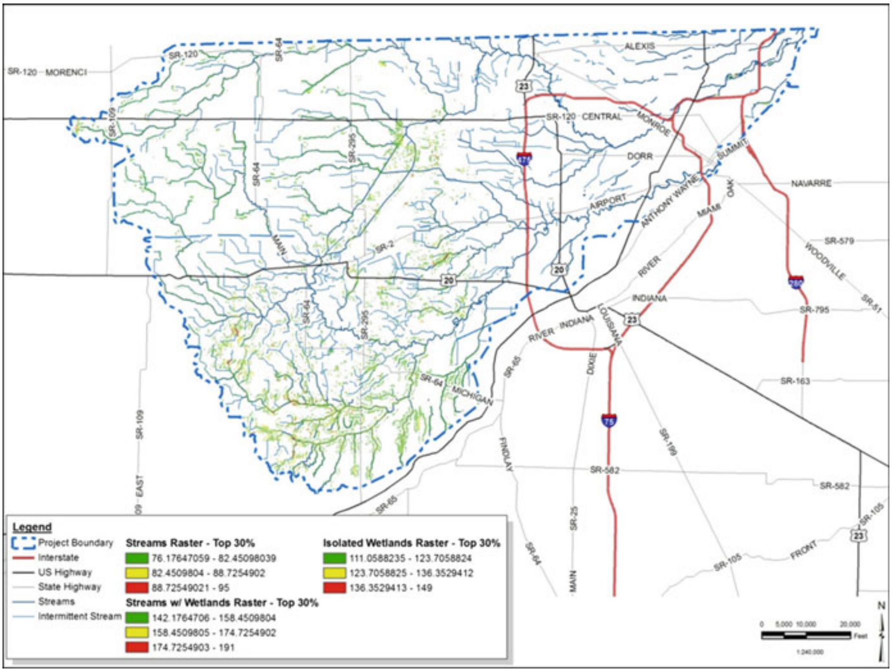

Fig. 7.4 Identification of the top 30% of potential restoration sites

7.4 Field Verification of the GIS Model Output

Model outputs (mapping) for the three scenarios (stream, isolated wetlands and wetlands with streams) within each subregion were taken into the field by aquatic biologists from The Mannik & Smith Group, Inc. (MSG) and Hull & Associates, Inc. (Hull) for field verification. Based on an evaluation of sites in all three subregions of the study area (Oak Openings, Agricultural and Urban), the team determined that the GIS model produced a sufficient number of sites that warranted further evaluation in the Oak Openings and Agricultural Subregions of the study area. However, the model still identified many fewer sites in the Urban Subregion of the two watersheds.

Next, the top 30% of the sites were then classified within each of the three Subregions. This produced approximately 1,300 sites. It was determined that this was too many sites to access. It was also noted that based on the score, sites in the top 10% of the Urban Subregion had a similar score to sites found in the lower 1/3 of the top 30th percent of the Oak Openings Subregion. The 10th percentile of each subregion by type (stream, wetlands with streams or isolated wetlands) was then used for the Oak Opening and Agricultural Subregion. This was to eliminate the extraneous data. Due to the limited number of sites in the Urban Subregion, the top 20% were taken for this region. This selection procedure yielded approximately

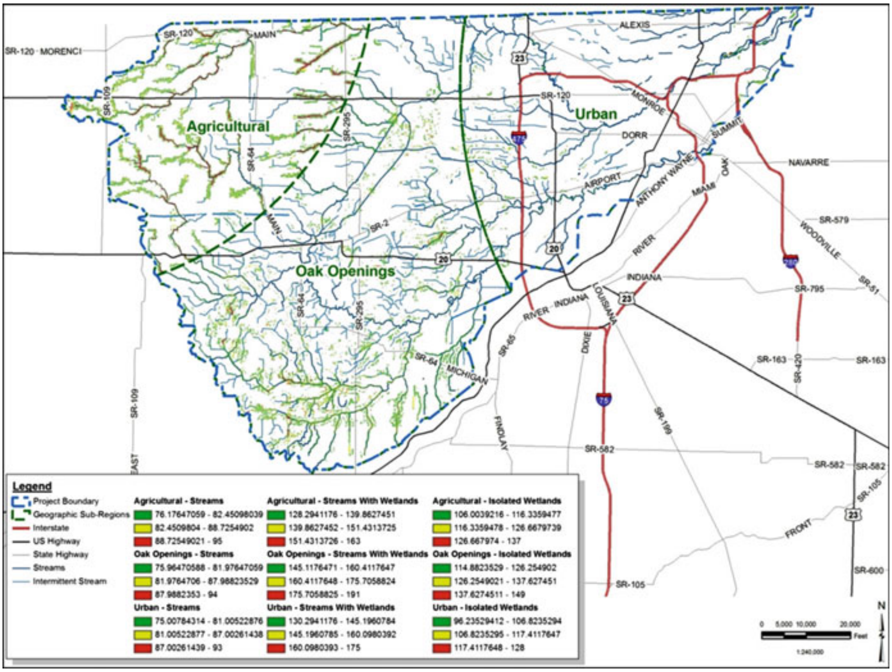

Fig. 7.5 Top 30% priority areas by subregions (Agricultural, Oak Openings, Urban) and by type (Streams, Wetlands, Isolated Wetlands)

900 sites over the entire study area (two watersheds). Using GIS vector/ Hot Spot analysis, the 900 sites were then clustered into groups of adjacent sites and converted to a smaller number of central points or individual centroids. Based on the average score from the combined site ties, each centroid was then assigned a score. The analysis attempted to identify areas of high concentrations of quality locations. This method failed due to the detail of the resolution of the model.

Using an alternative approach, each cell within the top 10% was combined with all of its adjacent cells. These merged clusters were then assigned a score based on their centroid. The cell clusters were then ranked based on these scores. Tables were generated ranking all of the scores by cell cluster. The tables were examined for natural splits between the top several clusters. The top clusters were recorded. At this time, the polygons were renamed based on the rank, type and subregion. This revised nomenclature distinguished which clusters had the highest relative ranking in each of the subregions and by type. For example, the highest ranking isolated wetland in the agricultural subregion was identified as IA1. After reviewing the results of the model output, it was decided that the three different types should be added to the same layer and clusters should include and be influenced by the presence of multiple types. Figure 7.6 shows an example of the output mapping to create grouped polygons.

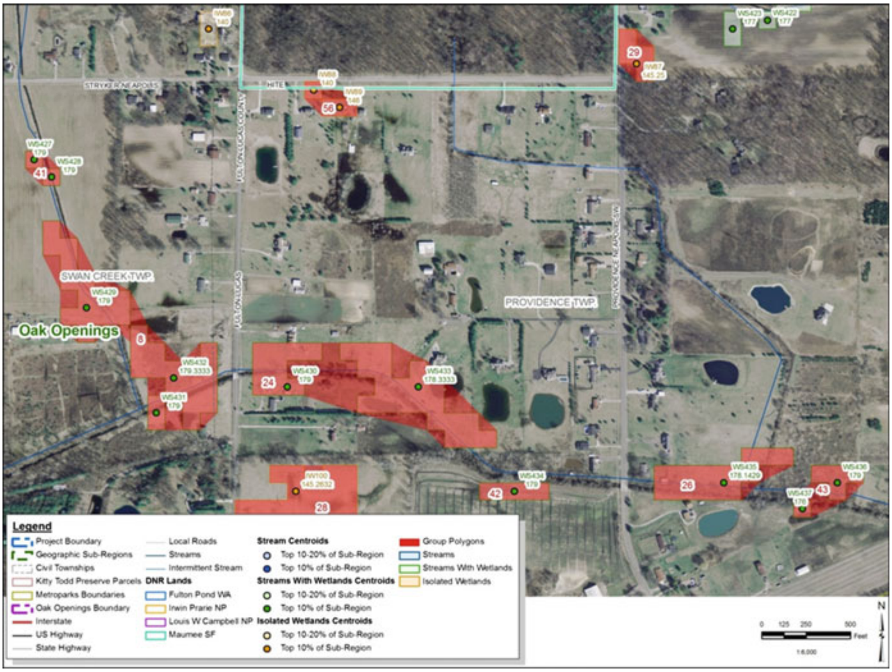

Fig. 7.6 Example of a grouped polygon of selected ranked restoration sites

7.5 Selection of Sites for Detailed Field Studies

The multiple-type polygon groups or areas that had been created through GIS modeling were individually evaluated. Each polygon group was evaluated for practicality and restoration potential following discussions with local professionals with knowledge of the area. Areas were dropped from further study if they were located in a site that had been slated for future development, or if the area was comprised of too many small land parcels. A total of 33 ranked polygons, or sites, were selected for more detailed investigation (Fig. 7.7). The property owners were identified and sent notices requesting permission to access the site for detailed field investigations. After 1 week, property owners were then contacted by telephone to request their permission to enter their property. During the field investigations, biologists from MSG and Hull recorded dominant vegetation, land use/land cover and in-stream (if present) condition. Wetlands were delineated in accordance with the 1987 Corps of Engineers Wetland Delineation Manual and soil types were confirmed. Streams were also evaluated for the possibility of quantitative fish and macroinvertebrate sampling. After the field sampling period, 21 sites were found to be acceptable for the development of stream and/or wetland restoration/ enhancement plans. Of these, eight sites were selected for quantitative fish and macroinvertebrate sampling.

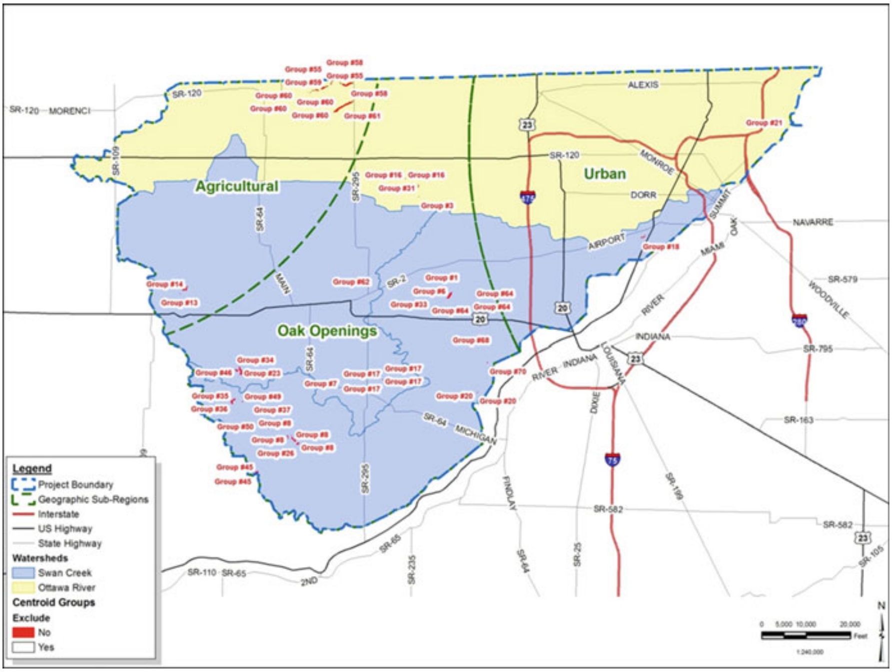

Fig. 7.7 Grouped Polygons representing the top sites for potential restoration

After initial reviews of this site selection, four additional stream/wetland sites in the Tenmile Creek/Ottawa River watershed would be added for detailed field studies. These included: one area at the upstream end of the Tenmile Creek/Ottawa River watershed; the Camp Miakonda Boy Scout Camp, the City of Toledo's Jermain Park, and along Mud Creek, Toledo Ohio. The Camp Miakonda and Jermain Park sites had been selected for an earlier, smaller watershed inventory that was completed for a portion of the main stem of the Ottawa River. Field studies followed the same procedures as those performed on the 22 sites that were selected using the GIS model.

7.6 Discussion and Conclusions

This project provided a readily available inventory of sites with good restoration potential and ecological value. Additional steps in the project included the preparation and ranking of restoration concept plans for each of the final selected priority steps. The identified of the proposed restoration sites will address several of the required Beneficial Use Impairments (BUIs) identified by the International Joint Commission (IJC), U.S. EPA, and Ohio EPA to delist the Maumee Area of

Concern, including the degradation of fish and wildlife populations, degradation of benthos, and the loss of fish and wildlife habitats. The results identify specific sites for wetland and riparian restoration, current and potential wetland or riparian restorability, the ecological value of restoration, habitat function especially in terms of connecting habitat areas to establish corridors, present owners and use, and provide conceptual restoration plans including estimated restoration and maintenance costs. It also evaluates the hydraulics to identify areas that can be restored as wetlands through natural stream flow.

With the development of the resulting wetland and riparian Inventory and restoration plans for Swan Creek and the Tenmile Creek/Ottawa River, four watersheds in the Maumee Area of Concern in northwest Ohio now will have conservation restoration plans ready for implementation; which when implemented will ultimately reduce loadings of sediment, nutrients, and other contaminants into Lake Erie while creating, improving, or protecting habitat and wildlife. A critical measure of the success of the project will be an increase in conservation and restoration projects in these watersheds. This project will allow the region to capitalize on wetland and stream mitigation opportunities. Past experience has indicated several pending or missed mitigation opportunities on the Tenmile Creek/Ottawa River due to a lack of documented restoration sites possibilities. These plans will be provided to contractors, consultants, developers, regulatory agencies, academia, etc.; any entity that might need a place to conduct a mitigation or supplemental environmental project or that might be contacted to recommend a site.

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Chapter 8
GIS and Remote Sensing Applications for Watershed Planning in the Maumee River Basin, Ohio

Kevin Czajkowski and Patrick L. Lawrence

Abstract The Maumee River watershed is the largest drainage basin that discharges into the Great Lakes. Although the watershed is largely a rural landscape, several major urban-industrial cities, including Fort Wayne and Toledo are located along the river. Many water quality concerns are present, especially non-point rural runoff that contributes significant amounts of sediment into the Maumee River. There is an important need to collect, organize and assess the available information on the watershed conditions and to better determine the status of the changes with land uses, crop rotation, and implementation of conservation tillage practices within this watershed. A partnership between the University of Toledo and US Department of Agriculture NRCS lead to several GIS and remote sensing products including annual land cover and crop rotations via remote sensing techniques, establishment of a Maumee Watershed Project Area GIS database, and providing educational and informational outreach with other project partners, resource managers, and the general public.

Keywords GIS • Remote sensing • Watershed planning

8.1 Introduction

The Maumee River watershed is the largest drainage basin that discharges into the Great Lakes. Although the watershed is largely a rural landscape, several major urban-industrial cities, including Fort Wayne and Toledo are located along the river. Many water quality concerns are present, including non-point rural runoff that contributes significant amounts of sediment into the Maumee River. There is an important need to collect, organize and assess the available information and better

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Geotechnologies and the Environment 7, DOI 10.1007/978-94-007-4734-0_8,

determine the status of the changes underway within the watershed. In 2005, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) entered into a five year agreement with the Geographic Information Science and Applied Geography (GISAG) Research Center at the Department of Geography and Planning at the University of Toledo, Ohio.

The work performed assists NRCS in undertaking sub-watershed rapid resource assessments, watershed and area planning, farm conservation planning, and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill. The tasks undertaken with this project consists of: annually determining land cover and crop rotations via remote sensing techniques; combining Ohio, Indiana, and Michigan data layers to establish Maumee Watershed Project Area GIS database; and establishing a Maumee Watershed Project GIS Website to provide educational and informational outreach with other project partners, resource managers, and the general public.

The Western Lake Erie Basin has been identified by NRCS as a major contributor of non-point source pollution into Lake Erie. In 2005, NRCS developed a plan to use Rapid Resource Assessments, Area Wide Planning, and acceleration of USDA Farm Bill programs to address the resource concerns for the Western Basin of Lake Erie, and contributing watersheds including the Maumee, Portage, and Ottawa Rivers. This 10-year study primarily addresses land use/cover changes, conservation tillage practices, and water quality monitoring. A secondary element of this plan is to develop a basin wide GIS (Geographic Information System) to aid in watershed planning projects and public outreach. Nelson and Weschler's (1998) study suggested that the Maumee River watershed might not be ready for basin wide collaboration on watershed planning, but with the implementation of a GIS-based institutional atlas, the local and regional organizations and agencies with interests in watershed planning could be moving in the right direction towards integration.

The watershed management approach has emerged as a holistic and integral way of research, analysis and decision-making at a watershed scale (Montgomery et al. 1995; Perciasepe 1994; Voinov and Costanza 1999). Initially oriented toward the control of water supply and use, it has shifted to include a concern for water quality and the combined effects of land use in the drainage basin, particularly since non-point pollution has overtaken point-source pollution as a primary concern as a cause of impairment (Nelson and Weschler 1998). By relating water quality and land use concerns, a link is created between science and planning, thereby connecting all stakeholders, community leaders, agency administrators, and concerned citizens in the watershed. Basin-wide collaborations can provide the expertise, scientific backing, moral support, and political leadership necessary to implement regional plans. GIS interfaced hydrological models are considered as a major tool for surface water management at a watershed scale because they are capable of presenting the relationship between the spatial and hydrological features of the watershed in an efficient way (Al-Abed et al. 2005).

GIS is a general-purpose technology for handling geographic data in digital form (McKinney and Cai 2002). GIS has the ability to combine physical features, political and administrative jurisdictions, and organizational missions in order to make sound recommendations or decisions for the entire watershed. The advances of GIS have grown beyond simple data management, storage, and mapping. Today, a more sophisticated means of analysis is being utilized by combining various mathematical and computer generated models with spatial data within the GIS. Simulation models are useful tools for analysis of watershed processes and their interactions, and for development and assessment of watershed management scenarios (He 2003). Schreier and Brown (2001) used GIS for analysis of buffer zones, which were delineated and classified from digital aerial photos, which allowed the identification of the type, width and continuity of the buffer zone. Kelsey et al. (2004) used GIS techniques to calculate several "distance or proximity" land-use variables to examine land-use effects on fecal coliform densities.

In October 2005, NRCS entered into a five year memorandum with the Geographic Information Science and Applied Geography (GISAG) Research Center of the Department of Geography and Planning at the University of Toledo as part of the Western Lake Erie Basin Water Resources Protection Plan. The University of Toledo assisted NRCS in implementing the Maumee Watershed project, including sub watershed rapid resource assessments, watershed and area planning, on farm conservation planning and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill. The tasks generally consisted of: annually determining land cover and crop rotations via remote sensing techniques; combining Ohio, Indiana, and Michigan data layers to establish Maumee Watershed Project Area GIS data layers for the project; and establishing and maintaining a Maumee Watershed Project GIS Website to provide educational and informational outreach to share data and information with other project partners, resource managers, and the general public.

Crop type classification for the Maumee River project is being carried out using multitemporal Landsat 5 satellite imagery for each year of the agreement. Images were gathered from several time periods during the growing season to differentiate between the different crops types, in particular corn, soybeans, wheat and pasture. Once collected, the images underwent cloud screening and then were stacked in Erdas IMAGINE remote sensing software package. Training sets of crop type had been collected using a driving survey of the watershed and located with Global Positioning System (GPS) readings. These training sets were used to create spectral signatures in Erdas and then a supervised classification was performed using the Maximum Likelihood classifier.

8.2 Maumee River Basin

The Maumee River basin covers over 4.9 million acres across Ohio, Michigan and Indiana. The Maumee River, the most prominent watershed in the basin, begins in Fort Wayne, Indiana, and extends more than 130 miles to Lake Erie, 105 miles of which are located in Ohio (Fig. 8.1). The Maumee River has the largest drainage area of any Great Lakes river with 8,316 square miles and drains some of the richest farmland in Ohio. The project area for this study will only include the drainage into

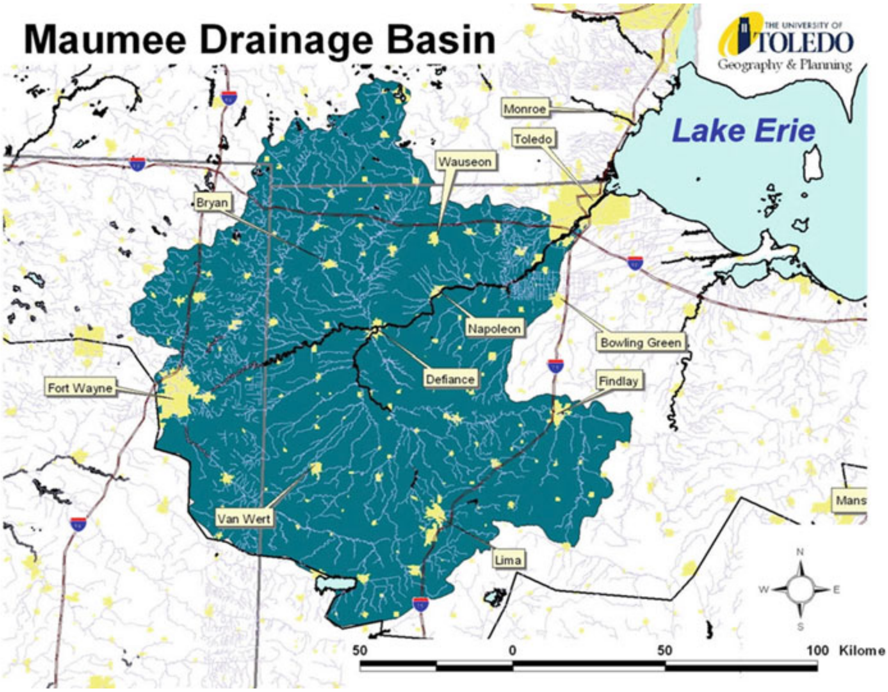


Fig. 8.1 The Maumee Drainage Basin, NW Ohio

Lake Erie south of the Ohio-Michigan state line. The cities of Toledo, Fort Wayne, and Lima constitute the major urban areas. Other smaller towns and cities are scattered throughout. The population of this area totals over 1.2 million people.

Land use is predominantly agriculture covering about 71% of the total basin (NRCS 2005). Urban development and roads represent 10% of the area (NRCS 2005). Soils are naturally poorly drained. Surface ditches and subsurface drains have been implemented to improve drainage. The basin area receives a relatively even distribution of precipitation throughout the year between 33 and 37 in. depending on the location. Soil erosion is a major problem in the basin causing NRCS to track conservation tillage practices in order to reduce the loss of sediment off cropland. Dredging in the Toledo Harbor, at the mouth of the Maumee River, is costing $2.2 million per year due to sediment loading. Tourism and sport fishing are also directly related to water quality and the health of the lake associated with increased sedimentation (NRCS 2005). Several watershed planning efforts have been undertaken with the Maumee Basin, especially in the Maumee Great Lakes Area of Concern (AOC) located in the lower (downstream) portion of the Maumee River and including several other rivers and streams discharging directly into the western basin of Lake Erie (Lawrence 2003; Maumee RAP 2006).

Table 8.1 Main GIS data layers for the Maumee GIS Project

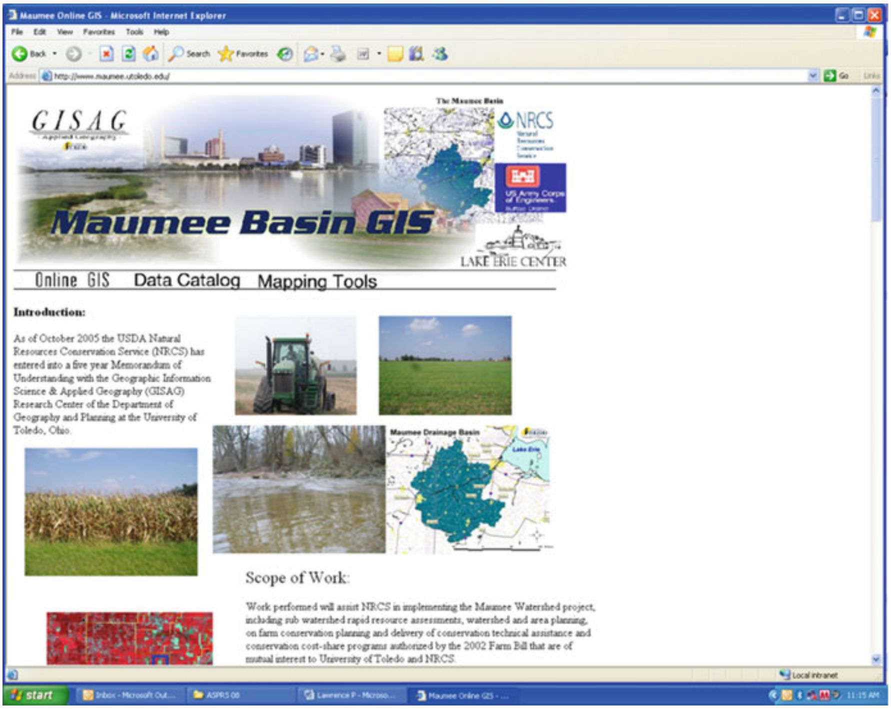
DEM (Digital Elevation Model)
SSURGO soils
Stream network
Land use cover
Watersheds (HUC units)
Quaternary and bedrock geology
Recreational areas and parks
Various boundaries (states, cities, and counties)
Wetlands
Source water protection areas
Groundwater data
100 year floodplains
Climatic zones
Soil drainage
Roads and transportation

8.3 GIS Database Development

Spatial data layers were assembled from numerous sources to assemble and deliver GIS layers that cover the entire Maumee Watershed Project Area (Table 8.1). Some of the websites, where spatial data is freely available, are Soil Data Mart, Data Gateway (NRCS/USDA), Center for Geographic Information in Michigan, ODNR GIMS (Geographic Information Management Systems), Indiana Geological Survey (A GIS Atlas), United States Geological Survey (USGS), and Great Lakes Information Network (GLIN). Once the data was downloaded, it was necessary to evaluate its condition using ESRI ArcGIS software. Datasets for the basin needed to cover Ohio, Michigan, and Indiana. In some cases, there was only Ohio datasets available and therefore were not used. In other cases, there were security issues; therefore the data was not made public. Metadata, which contains descriptions of the spatial data sets, needed to be present because it indicates what has been done to create the data and who created it. The metadata would be updated with the project purpose and contact information. After deciding on datasets, geoprocessing techniques were performed. Clipping, merging, and reprojecting were necessary for datasets for map overlay.

The next step was to establish a GIS website for the Maumee Watershed Project Area linking an ArcIMS site for data viewing. The website located at www.maumee.utoledo.edu contains background information on the project, spatial layers available for download through a password protected ftp site, and the ArcIMS available for viewing these spatial layers (Fig. 8.2). The ability to download the information is a means to share the data with NRCS and project partners for the overall collaboration of the project. Training sessions were held for partners and stakeholders to learn how to use this online system providing them ample opportunity to make suggestions and ask meaningful questions.

ArcIMS provides for the ability to access various layers at various scales of viewing. In this manner it is possible to compile many important spatial data layers into the GIS product and make each layer viewable and active at the appropriate scale.



Introduction:

As of October 2005 the USDA Natural Resources Conservation Service (NRCS) has entered into a five year Memorandum of Understanding with the Geographic Information Science & Applied Geography (GISAG) Research Center of the Department of Geography and Planning at the University of Toledo, Ohio.

Scope of Work:

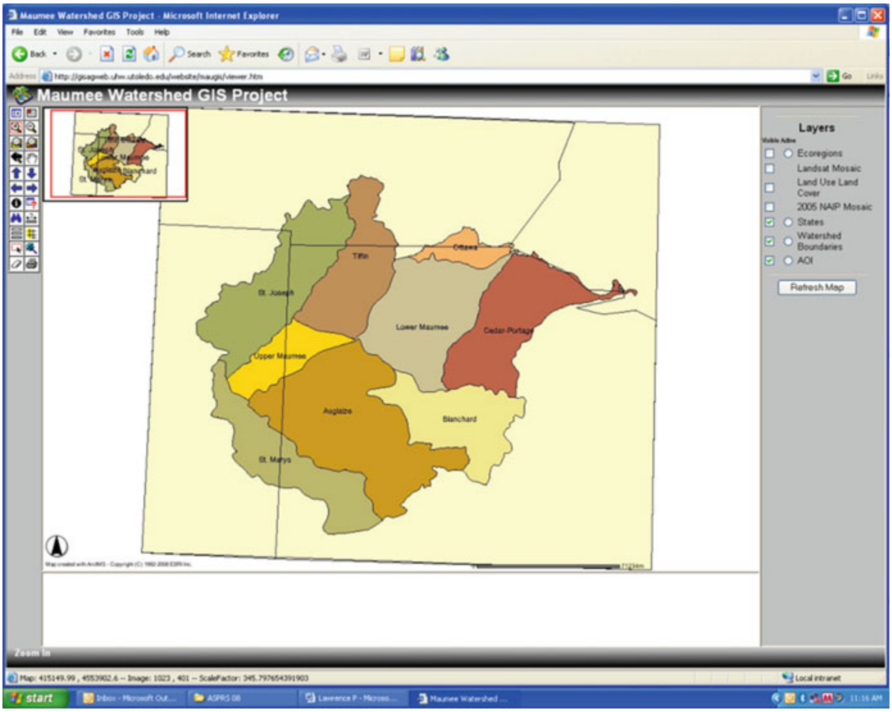
Work performed will assist NRCS in implementing the Maumee Watershed project, including sub watershed rapid resource assessments, watershed and area planning, on farm conservation planning and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill that are of mutual interest to University of Toledo and NRCS.

Fig. 8.2 Maumee GIS project website (at www.maumee.utoledo.edu)

For example, Fig. 8.3 shows the view scale of the entire watershed area highlighting the individual river basins located within the watershed with additional layers including land use/land cover, 2005 NIAP imagery, ecoregions and state boundaries. Figure 8.4 illustrates a view at the scale of one river basin with display of the Land Capability Class and additional layers that include counties, zip codes, annual precipitation, farmland class and many others. Figure 8.5 displays the view at the local community scale highlighting SSURGO soil types and also can include Census blocks, streets, and several other additional data layers. ArcIMS also provides numerous data tools to assist with spatial analysis including query functions, distance calculations, and area measurements – all of which can be useful to potential users of the datasets.

8.4 Remote Sensing

Land cover and land use can be classified for a watershed region by utilizing a satellite image which covers a large area. Landsat Thematic Mapper can be used at the regional level with its 30 m spatial resolution (Oetter et al. 2000; Jensen 2005;



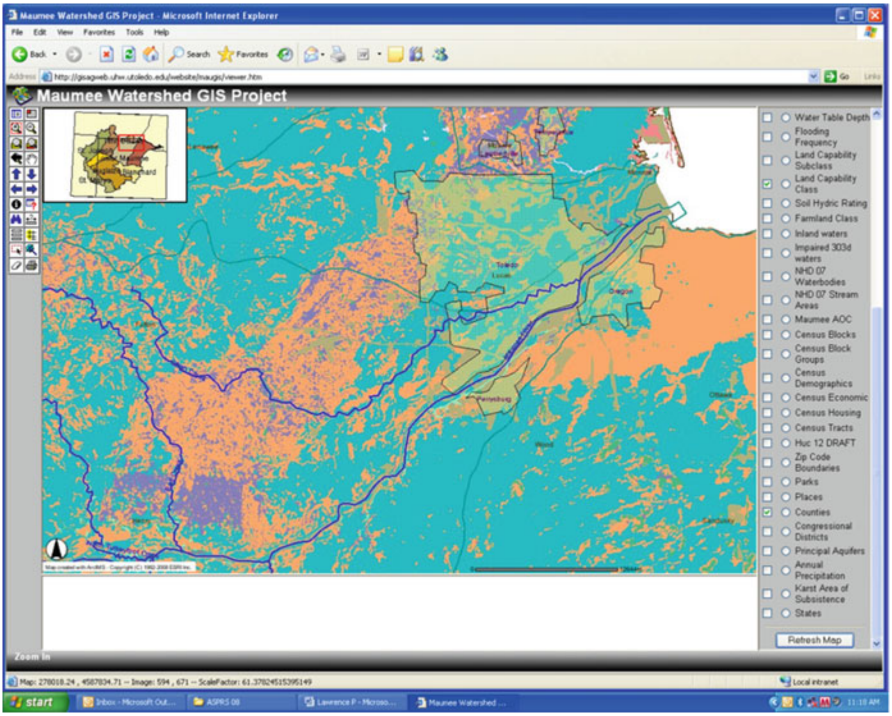
☐ ○ Ecoregions
☐ Landsat Mosaic
☐ Land Use Land Cover
☐ 2005 NAIP Mosaic
☑ ○ States
☑ ○ Watershed Boundaries
☑ ○ AOI

Map: 415149.99 , 4553902.6 -- Image: 1023 , 401 -- ScaleFactor: 345.797654391903

Fig. 8.3 Screenshot of Maumee Watershed layer showing all river basin units

Woodcock et al. 2001). The point of classification with remote sensing is to categorize every pixel in the image into themes or classes based on the reference spectral response of a band. Normally, multispectral data is applied since categories which can be separated in a channel are very limited. A commonly used method is the supervised classification technique which requires a prior knowledge of the study area, and pixels are classified based on the user-defined reference spectral data set. A maximum likelihood is used to categorize the pixels into defined classes as it takes into account a variance and a covariance to the computation and classifies pixels into a class to which the pixel has the highest probability of belonging (Jensen 2005).

Many times a good classification of land cover types can result from applying a single image. However, when land use types such as crop types are classified, it is useful to use multiple images wherein the dates are different. In the case of crop identification, the images include pre-growing season and growing season so that different spectral information can be extracted from the images which discriminate objects in the study area. For instance, winter wheat may be indistinguishable from bare soil in late fall when it is just planted and from alfalfa in spring due to a similar spectral response. However, by using two images, winter wheat can be identified by having a unique set of responses to bare soil in fall and alfalfa in spring (Lillesand et al. 2004). Therefore, it is important to know the study area to take advantage of the multi-temporal classification.



☐ ○ Water Table Depth
☐ ○ Flooding Frequency
☐ ○ Land Capability Subclass
☑ ○ Land Capability Class
☐ ○ Soil Hydric Rating
☐ ○ Farmland Class
☐ ○ Inland waters
☐ ○ Impaired 303d waters
☐ ○ NHD 07 Waterbodies
☐ ○ NHD 07 Stream Areas
☐ ○ Maumee AOC
☐ ○ Census Blocks
☐ ○ Census Block Groups
☐ ○ Census Demographics
☐ ○ Census Economic
☐ ○ Census Housing
☐ ○ Census Tracts
☐ ○ Huc 12 DRAFT
☐ ○ Zip Code Boundaries
☐ ○ Parks
☐ ○ Places
☑ ○ Counties
☐ ○ Congressional Districts
☐ ○ Principal Aquifers
☐ ○ Annual Precipitation
☐ ○ Karst Area of Subsistence
☐ ○ States

Fig. 8.4 Screenshot of Maumee GIS ArcIMS product as viewing one river basin and highlighting the land capability classification layer

A land use and land cover layer was created for this study. Throughout the creation of the classified map, ERDAS IMAGINE 9.1 was utilized unless otherwise noted. Ground truth points were collected at selected transits along roadways within the watershed resulting in over 300 points annually for analysis. Landsat TM images of path 20/row 31 were used for the classification which were downloaded from the OhioView website. Clouds and shadows in the images were removed by visual assessment. Removal of the urban area was also conducted by visual assessment using an urban area shapefile downloaded from the ESRI Census Watch website (http://www.esri.com/censuswatch). The images were then stacked to perform the multi-temporal classification. For example in 2005 images were used from May 4th, August 8th, and November 12th in order to cover the complete growing season for the primary crops: corn, soybeans and wheat.

The identification of crop types within farm fields was also checked by USDA personnel at the county level within the watershed on an annual basis via "windshield surveys" that would generate 8,775 observation points. Among these crop type observations, 78% were either corn or soybean. At total of 150 points per class for the entire Maumee watershed were randomly selected as reference points, and the others were used as training samples. Out of the 150 points, 75 points per class

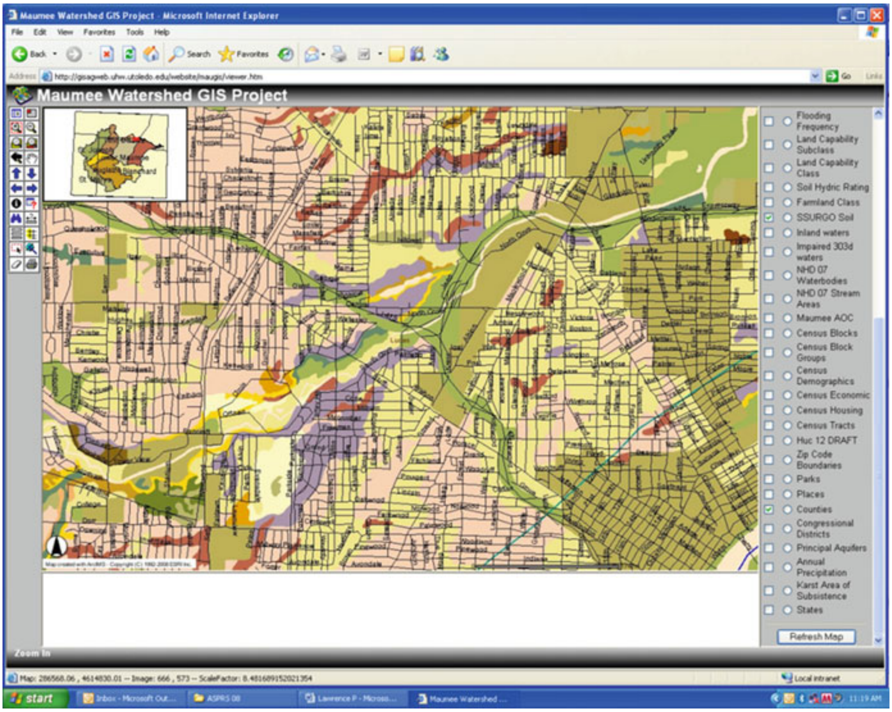


Fig. 8.5 Screen shot of Maumee GIS ArcIMS product as viewing at the community scale and highlighting the SSURGO soils layer

fall into the study area and were used for accuracy assessment of the supervised classification for the study area. Normally, a minimum of 50 samples for each class is good enough for the accuracy assessment. However, when a study area is larger than one million hectare, the minimum number of the sample should be increased to 75 or 100, thus for this study, 75 samples were used.

To perform a maximum likelihood supervised classification, a training set for each class of corn, soybean, hay, and wheat was created. By using the training samples, pixels were selected by using an Area of Interest (AOI) tool for each class. The training samples were visualized in different colors in terms of cardinal directions to consume less effort and time in collecting pixels. For each class, about 100 fields of pixels were collected. Those pixels were the reference for the computer to classify the entire image. For the forest and water classes, pixels were collected visually. Water is obvious in a satellite image by its shape and color of navy to light blue with bands 4, 3, and 2 as red, green, and blue in color composite. Forest is also visible and easily identifiable in an image by its texture and color of red with the same condition of the color composite as that used for the water.

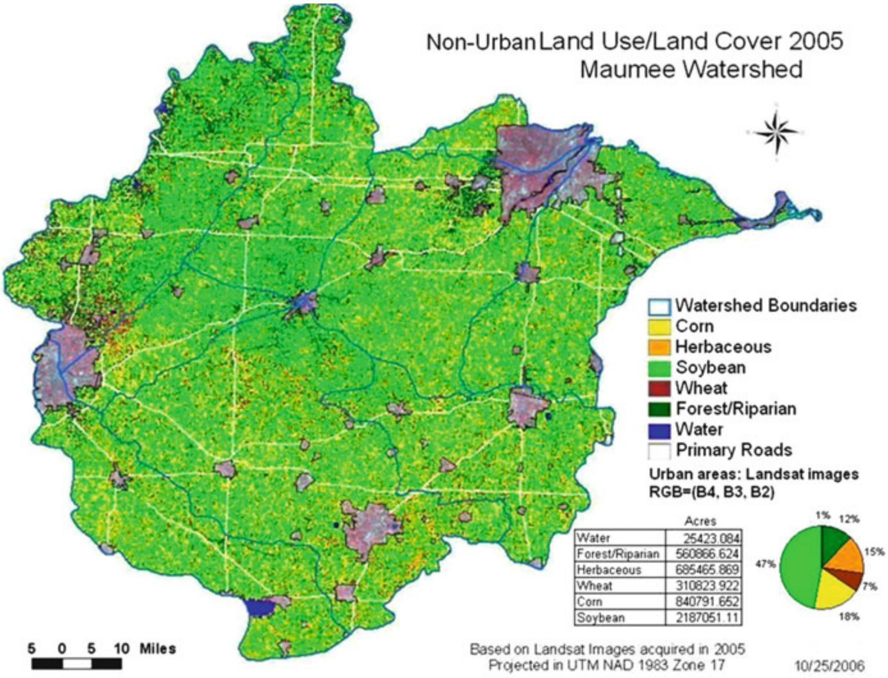
After running the supervised classification, sieve and clump functions of ENVI were applied to the classified image except for the water and forest classes to smooth isolated pixels. The sieve function identifies an isolated pixel, and the clump function classifies the isolated pixel into the class which has the highest occurrence of its surrounding pixels. Some water bodies such as a river and some forest which are represented by a pixel or line of pixels were likely to be removed by the sieve-clump process, therefore the original water and forest classes were reserved.

Finally, an accuracy assessment was conducted for the classified image by using the reference points, which were separated from the training sample at the beginning. The reference points were compared with the classified map to check to see if the reference field was classified correctly or not in ArcMap with the cardinal directions of the reference point visualized in a different color. This information was typed into Excel, which has columns of reference point numbers and classified classes. For the forest and water class, random points were created by an accuracy assessment function, and they were visually assessed by using the satellite image with the color composition used for the creation of the training set described earlier in this section.

An error matrix with columns of reference classes and rows of classified classes was created. By using the matrix, overall accuracy was estimated by dividing the total amount of diagonal pixels by the total amount of all of the pixels used for the accuracy assessment. An accuracy of 85% or more overall accuracy is considered acceptable. The accuracy of each class was estimated. A producer's accuracy or an omission was calculated by dividing the total number of the correctly classified pixels in a certain class by the total number of pixels of that class derived from the reference data. A user's accuracy or commission errors is calculated by dividing the total number of correctly classified pixels in a certain class by the total number of pixels of that class derived from the classified data and tells how much the classified pixels match with the actual validation points. A further assessment was performed by conducting a kappa analysis, which indicates the accuracy between the classified map and the reference data and if accuracy was derived from an actual agreement between the two data or by chance. Actual agreement would be strong with a kappa value of more than 0.80, fair with a value between 0.80 and 0.40, and poor with a value below 0.40.

An example of an annual land cover/land use and crop type classification (from 2005) is shown in Fig. 8.6, with farmland with planted crops the most common land cover/land use. Soybean (47%) and corn (18%) crops are the most common rural land use/land cover types. Forest cover was found to represent 17% of the land area. The reference points of hay and wheat were small due to the limited amount of the ground truth points. Overall accuracy of the classification was 87.96% and the Kappa value was 0.82.

Tillage classification was conducted in the same way as the crop types were classified. For example the tillage classification in 2006 used a Landsat TM image of path 20/row 31 acquired on May 23, 2006 and obtained from the OhioView website. The classes created for the map were traditional tillage (<30 %), mulch-till (30–90 %), no-till (<90 %), forest, and water. Tillage systems within the Maumee watershed were documented at 8,927 farmfield data points that were checked by USDA personnel at the county level. Approximately ½ of the farm field points were



	Acres
Water	25423.084
Forest/Riparian	560866.624
Herbaceous	685465.869
Wheat	310823.922
Corn	840791.652
Soybean	2187051.11

Fig. 8.6 Land cover/land use classification with crop types, 2005

found to represent no-till agriculture in the watershed. An accuracy assessment was also conducted, and an error matrix was created. The resulting image of the supervised classification conducted for the tillage systems in 2006 is shown in Fig. 8.7. The accuracy was 81.33% and did not reach the acceptable guideline. However, it was the best result which was performed, and the technique was utilized for the remaining annual classification and mapping of tillage with similar results. The Kappa value was 0.77, with the agreement between the classification map and the reference data fair enough and close to a strong relationship, and the accuracy of the classification was less likely to happen by chance.

8.5 Discussion

With the development of the Maumee GIS/Remote Sensing project several data gathering issues have been identified. Data may have been found for only one or two states and not complete for the entire Maumee Basin. Some contacts were not willing to share their data due to copyright or propriety issues. Some data is not being made public because of security reasons such as transportation, pipeline, and other infrastructure. For many of the GIS datasets no metadata attached to data

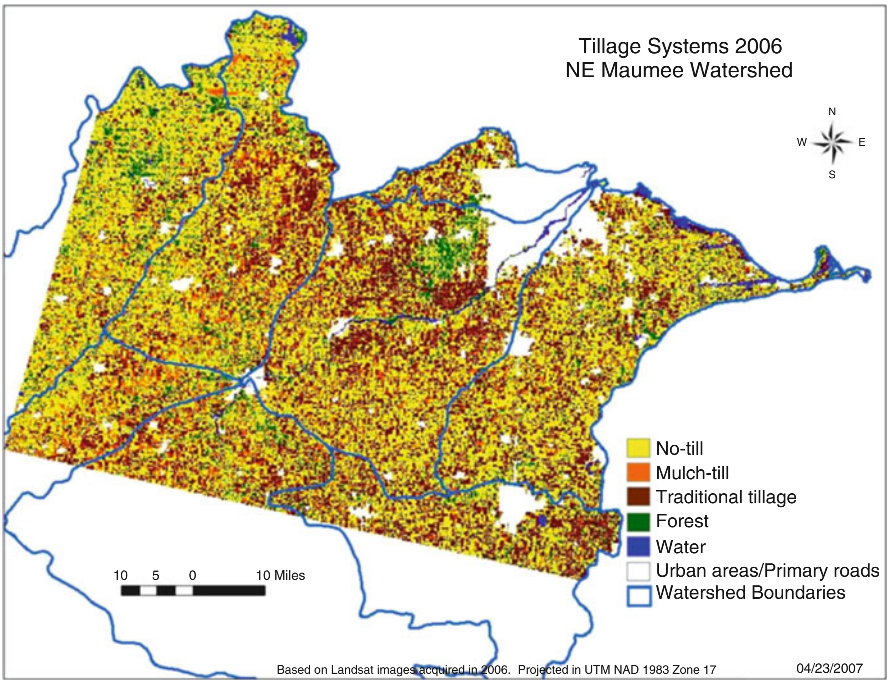


Fig. 8.7 Classification of Tillage Systems in the northeast portion of the Maumee Watershed, 2006

sets making it very difficult to validate and assess the data source and its quality. The development of the spatial database is a continuing process. Feedback from users of the ArcIMS web based viewer is helpful in managing the website in order to make it more user friendly. Efforts continue in the updating of data sets with current information.

In early 2007 a survey was sent to 188 current and potential users of the Maumee Basin GIS/Remote Sensing project website (www.maumee.utoledo.edu) in order to assess the utility of the website and ArcIMS data viewer and to solicit feedback on future additions and improvements (see Rousseau, this volume for more details). A total of 55 individuals responded (29% return rate) with state and federal government agencies and NGOs/Universities having the largest number of responders. Over 41% of respondents indicated that they had been using GIS for more than 5 years. When asked about their use of GIS in watershed planning 60% indicated that they had created maps or data products and the most common sources of GIS data that they used included the Ohio Department of Natural Resources (ODNR) GIMS website, USGS, and NRCS Service Data Gateway. In accessing and using the Maumee Basin GIS/Remote Sensing project website over 90% rated the site as Good to Excellent and suggested improvements, including making more data readily available for download, providing clearer instructions for non GIS users, and providing links to metadata and source citation.

Ongoing searches are underway to secure and post additional new useful data sets and work continues in evaluating current data sets. Additional updates to the data sets during the project included transet data collected annually from 2007 to 2009 on crops types for use as validation/training data for land cover analysis, assembling data sets in response to severe flooding and impacts along the Blanchard River in August 2007, collection of the Landsat imagery for 2007–2009 for the preparation of a series of annual land use, crop type and tillage analysis, acquisition of one foot orthophotos for the watershed, collection of the NAIP and LiDAR imagery available for a portion of the Maumee Basin. Tasks also included compiling the field survey data from 2007 to 2009 for crop type and tillage assessments collected by NRCS county extension staff into a common database, analysis of annual land cover from Landsat (including accuracy assessment and % cover types), development of tile surface creation workflow to assist in creating a bare earth DSM, and to process the LiDAR and NAIP imagery into ArcIMS.

8.6 Conclusions

The Maumee GIS/Remote Sensing Project has created an array of useful products to assist with various watershed planning initiatives underway within the basin including projects undertaken by the Western Lake Erie Basin Partnership, USDA NRCS, and Army Corp of Engineers. The GIS database has been provided on request to various parties to assist with the preparation of watershed studies, rapid assessments, crop inventories, sediment modeling, and in response to flooding events. As further progress is made in determining the critical watershed issues and prioritizing future projects, programs and efforts within the basin, the GIS and remote sensing materials will be of continued importance. The project website, with GIS data layers and the land use/land cover mapping from remote sensing, provides many important opportunities for public outreach, teaching and the creation of unique map based products for a variety of watershed projects within the Maumee Basin. With the ongoing development of watershed based planning within the Maumee Basin by a variety of agencies and organizations these spatial data sources will be increased value in plan development.

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Chapter 9
The Application of GIS in Watershed Planning: The Case of the Western Lake Erie Basin

Kathryn Rousseau and Patrick L. Lawrence

Abstract The Western Lake Erie Basin has been targeted as a major contributor of non-point source pollution into Lake Erie largely due to its predominant land use; agriculture. An increased use of GIS among planners in watershed related issues is needed in order to improve their decision-making capabilities to address the overall health of the watershed. An online GIS system had been created for data sharing and management across the Western Lake Erie Basin. The object of this study was to conduct a survey examining the usage of GIS across the Western Lake Erie Basin in order to advance the knowledge of civic leaders, agency administrators, and planners involved in managing the watershed. Survey participants were asked about their current use of GIS, spatial data resources, data distribution, data sharing, data exchange, and future use of GIS. The survey analysis indicated that while the current online GIS system was a good start, there needed to be more training on how to use GIS among the watershed planning community.

Keywords GIS • Non-point source pollution • Watershed planning

9.1 Introduction

The Western Lake Erie Basin has been targeted by United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) as a major contributor of non-point source pollution into Lake Erie. In 2005, NRCS developed a plan to use Rapid Resource Assessments, Area Wide Planning, and acceleration of USDA Farm Bill programs to address the resource concerns for the Western

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Basin of Lake Erie, and contributing watersheds including the Maumee, Portage, and Ottawa Rivers. This 10-year study primarily addresses land use/cover changes, conservation tillage practices, and water quality monitoring. A secondary element of this plan is to develop a basin wide Geographic Information System (GIS) to aid in watershed planning projects and public outreach.

The watershed management approach has emerged as a holistic and integral way of research, analysis and decision-making at a watershed scale (Montgomery et al. 1995; Perciasepe 1994; Voinov and Costanza 1999). Initially oriented toward the control of water supply and use, it has shifted to include a concern for water quality and the combined effects of land use in the drainage basin, particularly since non-point pollution has overtaken point-source pollution as a primary concern as a cause of impairment (Nelson and Weschler 1998). By relating water quality and land use concerns, a link is created between science and planning, thereby connecting all stakeholders, community leaders, agency administrators, and concerned citizens in the watershed. Basin-wide collaborations can provide the expertise, scientific backing, moral support, and political leadership necessary to implement regional plans. Nelson and Weschler's (1998) study suggested that the Maumee River Watershed might not be ready for this kind of collaboration, but with the implementation of a GIS-based institutional atlas, the organizations could be moving in the right direction towards integration.

GIS is a general-purpose technology for handling geographic data in digital form (McKinney and Cai 2002). GIS has the ability to combine physical features, political and administrative jurisdictions, and organizational missions in order to make sound recommendations or decisions for the entire watershed. The advances of GIS have grown beyond simple data management, storage, and mapping. Today, a more sophisticated means of analysis is being utilized by combining various mathematical and computer generated models with spatial data within the GIS. Simulation models are useful tools for analysis of watershed processes and their interactions, and for development and assessment of watershed management scenarios (He 2003).

Government and academic institutions throughout the United States as well as watershed groups have developed surveys addressing the application and utility of GIS products for watershed planning. The California Watershed Group Information Needs Survey (2004) was conducted to identify information needs to support watershed groups that are involved in developing watershed assessments and related planning documents, and conducting watershed projects. The Bay Area GIS Survey's (2001) purpose was to build the foundation for Geographic Information System data sharing/exchange, as well as metadata awareness and usage in the Bay region.

9.2 Study Site

The Western Lake Erie Basin covers over 4.9 million acres across Ohio, Michigan and Indiana. The Maumee River, the most prominent watershed in the basin, begins in Fort Wayne, Indiana, and extends more than 130 miles to Lake Erie, 105 miles of which are located in Ohio. The Maumee River has the largest drainage area of any Great Lakes river with 8,316 square miles and drains some of the richest farmland

Fig. 9.1 The Western Lake Erie Basin

in Ohio. The project area for this study will only include the drainage into Lake Erie south of the Ohio line (Fig. 9.1). The cities of Toledo, Fort Wayne, and Lima constitute the major urban areas. Other smaller towns and cities are scattered throughout. The population of this area totals over 1.2 million people.

Land use is predominantly agriculture covering about 71% of the total basin with urban development and roads representing only 10% of the area (NRCS 2005). Soils are naturally poorly drained and surface ditches and subsurface drains have been implemented to improve drainage. The basin area receives a relatively even distribution of precipitation throughout the year between 33 and 37 in. depending on the location. Soil erosion is a major problem in the basin causing NRCS to track conservation tillage practices in order to reduce the loss of sediment off cropland. Dredging in the Toledo Harbor, at the mouth of the Maumee River, is costing $2.2 million per year due to sediment loading. Tourism and sport fishing are also directly related to water quality and the health of the lake associated with increased sedimentation (NRCS 2005).

9.3 Project History

In October 2005, NRCS entered into a 5 year memorandum with the Geographic Information Science & Applied Geography (GISAG) Research Center of the Department of Geography and Planning at the University of Toledo as part of the Western Lake Erie Basin Water Resources Protection Plan. The University of Toledo is assisting NRCS in implementing the Maumee Watershed project, including sub watershed rapid resource assessments, watershed and area planning, on farm conservation planning and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill. The tasks generally consist of: annually determining land cover and crop rotations via remote sensing techniques; combining Ohio, Indiana, and Michigan data layers to establish Maumee Watershed Project Area GIS data layers for the project; and establishing and maintaining a Maumee Watershed Project GIS Website to provide educational and informational outreach to share data and information with other project partners, resource managers, and the general public.

Crop type classification for the Maumee River project is being carried out using multitemporal Landsat 5 satellite imagery for each year of the agreement. Images were gathered from several time periods during the growing season to differentiate between the different crops types, in particular corn, soybeans, wheat and pasture. Once collected, the images underwent cloud screening and then were stacked in Erdas IMAGINE remote sensing software package. Training sets of crop type had been collected using a driving survey of the watershed and located with Global Positioning System (GPS) readings. These training sets were used to create spectral signatures in Erdas and then a supervised classification was performed using the Maximum Likelihood classifier (see Chap. 8, this volume).

An online web-based survey was distributed among the watershed planning community in the Western Lake Erie Basin and Maumee River Basin in order to examine their current use of GIS, their spatial data resources, data sharing capabilities, and any future applications.

9.4 Methods

A web-based survey was developed to work on average computers and did not require any GIS software to answer the questions. The goal of the survey was to discover the use of GIS in watershed planning across the Western Lake Erie Basin in order to make recommendations for future uses of GIS and also make suggestions as to collaborations among respondents.

9.4.1 Participants

Participants invited to complete the survey were thought to have some kind of influence or participation in the Western Lake Erie Basin plans or implementation of plans. The sample selected included employees from universities, federal government agencies, state government agencies, county and city governments, townships, villages, non-governmental organizations (NGOs), consulting firms, park systems, engineering firms, watershed organizations, and school districts. The sample of participants was developed and drawn from three sources. The first group consisted of 135 people involved in the Maumee Remedial Action Plan (RAP) partnership. The Maumee RAP is a partnership of citizens, government agencies, businesses and industry working to restore the health of our streams in the Maumee Area of Concern (AOC) (www.partnersforcleanstreams.org). The second group consisted of 25 additional participants drawn from a list of Western Lake Erie Basin Committees provided by NRCS. Since 1935, the Natural Resources Conservation Service (originally called the Soil Conservation Service) has provided leadership in a partnership effort to help America's private land owners and managers conserve their soil, water, and other natural resources (http://www.nrcs.usda.gov). The third group consisted of 28 additional contacts identified through Ohio Watershed Network (http://ohiowatersheds.osu.edu/groups/) of watershed groups in the Western Lake Erie Basin and through response emails from the original survey sent out providing further contacts. The total sample group for the online survey consisted of 188 individuals from the watershed planning community in the Western Lake Erie Basin.

9.4.2 Procedure

Participants were emailed an invitation to be included in this study. The email gave a brief overview of the purpose of the study and included the link to an online survey through a service called SurveyMonkey. SurveyMonkey has a single purpose: to enable anyone to create professional online surveys quickly and easily (http://surveymonkey.com/). This online service also has database capabilities, such as storing data, exporting, summarizing, and tabulating results. After 2 weeks, participants were emailed a reminder to fill out the survey before the close of the study, which was scheduled in two more weeks time.

The survey asked questions in five categories: background information; current use of GIS; spatial data resources; data distribution, data sharing and data exchange; and future use of GIS. Background information included contact information, so to get a sense of the sample that responded to the survey and so participants can be sent a link to the results of the survey. Part of the background information included a question on their current employer. It is important to know the type of participants who are utilizing this survey and their related interests in GIS. The participants were also asked about their watershed concerns in a ranking format.

Participants were asked about their current use of GIS including the length of time spent using GIS, how frequent GIS is used, what GIS data is being used for, and the software being utilized. Open ended questions explored how has GIS use benefited their organization and what improvements would they like to see to their GIS capabilities. This will allow for knowledge as to what the participants are not receiving, as far as training, which they feel they need in order to be better users of GIS.

The next section of the survey explored their spatial data resources. The aim is to know where the participants were gathering their data and the type of data they used. Part of this section led the participants to an "Online GIS" viewer for the Western Lake Erie Partnership GIS program located on a separate webpage at www.maumee.utoledo.edu. The participants were asked to explore the viewer and answer questions about what data and tools they utilized in their exploration. They were also asked to rate the viewer in terms of its relevancy to their work. The fourth section asked a few open ended questions about data distribution, data sharing, and data exchange. The importance of this information is to see how participants are collaborating with other users and to see if they are utilizing GIS user group activities that are currently being offered in their area.

The final group of questions asked about participants' future use of GIS. Are they planning on using the Maumee Basin Online GIS website and online viewer for their watershed planning? How they will use it or why they wouldn't use it? What type of mapping needs does their organization foresee in the future and what other datasets would be useful to have available? These responses will help determine what the overall consensuses of needs are and where they see their group going as far as GIS capabilities.

9.5 Results

The key results of the web-based GIS watershed survey are provided. The invitation to participate in the research attracted 55 responses from 188 people contacted (29 % return rate). Of the 55 respondents 11 were from University or nongovernmental organizations, 10 were from the city government, 9 were from the federal government, 5 were from consultant or contracting companies, 4 were from the county government and 10 were from "other" groups which included the park district, school system, local/township government, volunteer, and retired engineers (Fig. 9.2).

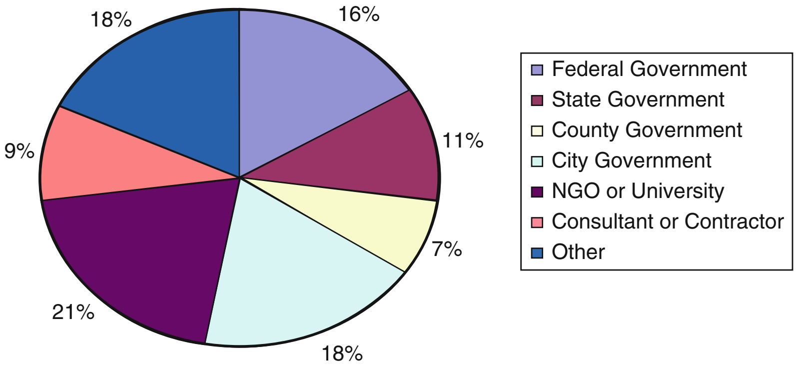


Fig. 9.2 Employment of respondents

9.5.1 Watershed Concerns

When asked about watershed concerns, the participants were asked to rank combined sewer overflows, municipal separate storm sewer systems, urban runoff, rural runoff, nutrient loading, drinking water protection, and sediment transport and deposition in order of concern. Combined sewer overflows ranked first in order of concern with selection by 31 % of respondents as the highest concern. Urban runoff, rural runoff, nutrient loading and drinking water protection fell in the middle of selections. Municipal separate storm sewer systems and sediment transport and deposition were the least concerning. A second question asked the participants to rank funding for implementing watershed plans and/or projects, water quality monitoring, land use planning, sustained long-term funding for operating groups, dumps/landfills/uncontrolled sites/brownfields, and land acquisition/habitat preservation and restoration in order of concern. Funding for watershed planning and projects was the top concern with 39 % of respondents choosing this as their highest concern. Water quality monitoring, land use planning, sustained long-term funding for operating watershed groups, and land acquisition/habitat preservation and restoration were the next highest. The issue of least concern was dumps/landfills/uncontrolled sites/brownfields.

9.5.2 Current Use of GIS

The next set of questions asked participants about GIS at their present place of employment. Forty-six responded to these questions. First, they were asked about the status of GIS use. A majority of respondents stated that their GIS was either growing or mature (Fig. 9.3). Growing was described as making some use of GIS, but needs are growing so quickly that the infrastructure and database management practices are not able to keep up. Mature was described as having GIS as an integral part of the organization and that they have an efficient system for managing the data and users. The next question asked how long the organization has been using GIS. The responses included using GIS less than 1 year (6.5 %), for 3–5 years (26.1 %), 6–10 years (19.6 %), more than 10 years (21.7 %), and N/A (15.2 %). The respondents also indicated that they use GIS software for work frequently or daily with 43.5 % responding in this manner. When asked about using GIS data, the respondents indicated that creating maps or figures (60.9 %) was most common. Previewing data only (56.5 %) and overlaying data to look for relationships (54.3 %) were also common. The survey also indicated that ESRI ArcGIS 8.x or 9.x was the most common software used (54.3 %), while 37 % still using ESRI ArcView 3.x.

Two open ended questions were asked in this section. The first asked how GIS use has benefited the organization. Thirty-four responded to this question. Some of the benefits included displaying and analyzing information, improving planning capabilities, public outreach, research and education projects, identifying potential trends, and being able to see the “big” picture and identify “holes.” The other

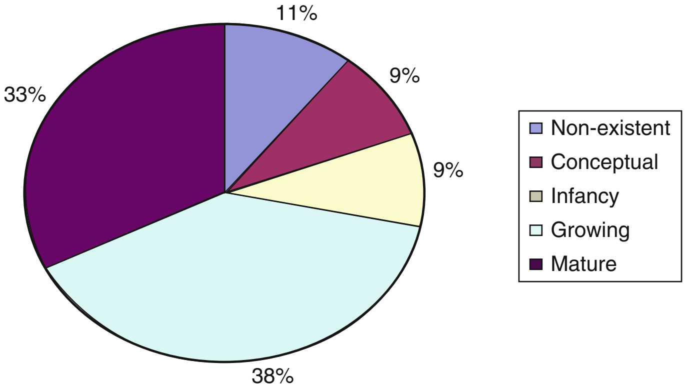


Fig. 9.3 Current use of GIS

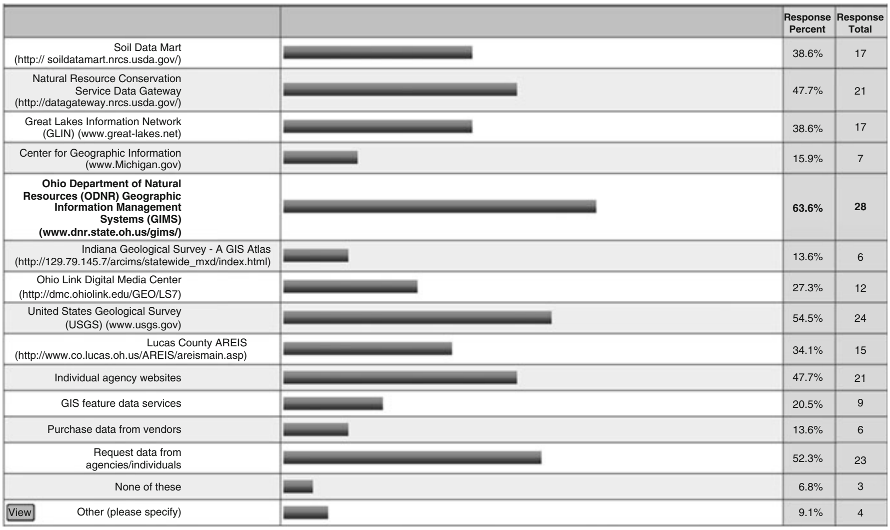
question asked about the improvements they would like to see to their GIS capabilities. Thirty-one responded to this question. Some responses included better hardware, software, and more training, better understanding of what is being created, knowledge behind constructing and using model builder, easier interfaces with spatial statistics, and being able to acquire the most recent data.

9.5.3 Spatial Data Resources

Forty-four individuals responded to two questions on spatial data resources. The first question displayed several websites that can be used to access GIS data. The participants were asked to mark all sites that they have used to acquire data (Fig. 9.4). Twenty-eight respondents (63.6 %) used Ohio Department of Natural Resources (ODNR) Geographic Information Management Systems (GIMS) to access data. Twenty-one respondents (47.7 %) used Natural Resource Conservation Service (NRCS) Data Gateway. Only six respondents admittedly purchased data from vendors. Three responded to not using any of the sites mentioned. The second question presented data themes and asked which themes they used. Three data themes were the most prevalent with each being selected by 32 respondents (72.7 %). These included orthoimagery (aerial photography, satellite images, etc.), hydrography (rivers, streams, lakes, wetlands, watersheds, etc.), and environmental (soils, habitats, etc.). The data theme that was used the least was public safety/public health, which was only used by 29.5 % of respondents.

9.5.4 Maumee Basin Online GIS

The participants were asked to view and manipulate the Online GIS viewer located at www.maumee.utoledo.edu. Thirty-four responded to this set of inquiries. The first



		Response Percent	Response Total
Soil Data Mart (http:// soildatamart.nrcs.usda.gov/)		38.6%	17
Natural Resource Conservation Service Data Gateway (http://datagateway.nrcs.usda.gov/)		47.7%	21
Great Lakes Information Network (GLIN) (www.great-lakes.net)		38.6%	17
Center for Geographic Information (www.Michigan.gov)		15.9%	7
Ohio Department of Natural Resources (ODNR) Geographic Information Management Systems (GIMS) (www.dnr.state.oh.us/gims/)		**63.6%**	**28**
Indiana Geological Survey - A GIS Atlas (http://129.79.145.7/arcims/statewide_mxd/index.html)		13.6%	6
Ohio Link Digital Media Center (http://dmc.ohiolink.edu/GEO/LS7)		27.3%	12
United States Geological Survey (USGS) (www.usgs.gov)		54.5%	24
Lucas County AREIS (http://www.co.lucas.oh.us/AREIS/areismain.asp)		34.1%	15
Individual agency websites		47.7%	21
GIS feature data services		20.5%	9
Purchase data from vendors		13.6%	6
Request data from agencies/individuals		52.3%	23
None of these		6.8%	3
View Other (please specify)		9.1%	4

Fig. 9.4 Spatial data resources

question asked how often they had used the viewer on this site. Many of the respondents indicated that this was their first time (32.4 %), while never (26.5 %) was also a popular response. The participants were then led through a series of question asking about the different data layers they used at various extents. At the full watershed coverage extent, land use land cover and watershed boundaries layers were both used by 21 respondents (61.8 %). When asked which watershed sub-unit they made use of, 16 respondents (47.1 %) had chosen the Lower Maumee, while the Upper Maumee was chosen by 15 respondents (47.1 %). The least used watersheds were the St. Joseph’s and St. Mary’s, which only had 6 respondents (17.6%) utilizing these areas.

Once the participants accessed one of the watersheds, the map zooms to that section and other layers appear. They were asked which layers were utilized at this spatial extent. The most prevalent was the major rivers layer with 21 respondents (61.8 %), and watershed boundaries and counties each having 18 respondents (52.9 %). The least chosen data layer was congressional districts with only 2 respondents (5.9 %) choosing to view this layer. As they zoom in even further to the county/sub-county level even more layers appear. Again, the most utilized layer was major rivers with 19 respondents (55.9 %). Watershed boundaries and stream network were close behind with 52.9 % and 50 % of respondents viewing these layers respectively. The least utilized layers were census blocks, census block groups, census economic, and census housing, which not one respondent viewed or manipulated these layers.

The next question was open ended and asked if the participants were doing any kind of statistical analysis that could make use of the data. Of the 24 respondents, 16 said no and 8 said yes mostly without any explanation. Then, the question about map tools was addressed. Utilizing the zoom in tool (79.4 %) and legend (76.5 %)

gathered the most results in manipulating the viewer. Setting the units proved to be the least utilized tool with only 3 respondents (8.8%). When asked specifically about the utilization of the query tool, participants were asked which data layers they made active in order to perform the function. Fourteen responded to this question with 7 respondents (50%) using the stream network and 7 respondents (50%) using the watershed boundary for their queries.

Participants were then asked to rate the Maumee Basin Online GIS. Of the thirty-four respondents, 24 (70.6%) rated the online viewer as good and 7 (20.6 %) rated as excellent. Two open ended questions concluded this section. The first question asked the participants how the developers can make the Maumee Basin Online GIS more useful for their organizations. Fifteen responses included suggestions such as making the data available for download and having clearer instructions especially for those who do not fully understand GIS. Other suggestions were to provide links to metadata, provide source citation and display scale in the title of the layer. The second question asked participants to provide websites that are useful to them in watershed work. Seven responded to this question, with two respondents providing multiple sites. Several university websites such as Heidelberg College, Bowling Green State University, and University of Texas were suggested as well as websites that provided general watershed information on issues and planning, such as Ohio Department of Natural Resources' website on stream morphology and U.S. Environmental Protection Agency's water science page on basins.

9.5.5 Data Distribution, Data Sharing, and Data Exchange

This group of questions was open-ended. The first asked participants about their participation in GIS user groups or other organizations to coordinate data development, data sharing or application development activities. Twenty-eight of the fifty-five responded to this question. Responses included were split between "yes", they participated in some kind of user group for data exchange, and "no", they didn't know of any groups, or not sure. The second question asked if their organization provided any GIS data online through an ftp site or GIS web server. Of the 26 responses, 14 said they did not, 10 said they did, and 2 were not sure. The final question in this section asked for comments or suggestions related to GIS coordination. Comments included that "it is good to see that a clearing house is being developed for this information" and "we have a long way to go to incorporate this information into our work here." Suggestions included "asking local watershed groups for information and what websites they use" and "would like to see a regional workshop or conference where area GIS users could meet and share ideas."

9.5.6 Future Use of GIS

This last set of open-ended questions asked about utilizing the GIS viewer they had just explored, future mapping needs, and dataset needs. Twenty of the thirty-four respondents (58.8 %) said that they would use the Maumee Basin Online GIS for watershed planning efforts. Some were not sure how they were going to use the site, while others were going to look more closely at the data layers it provides. Other ways of utilizing this resource were for producing maps, public outreach, and teaching. The responses for not using this site were because they aren't directly involved in watershed planning, this doesn't go along with the organization's mission, or they already have their own comprehensive datasets. The type of mapping needs the participants saw in the future ranged from infrastructure, adding certain datasets, personnel and resources, among others. The datasets that the respondents felt would help in watershed planning included more high resolution imagery, underground utilities, and more water quality data.

9.6 Discussion

In analyzing the results of the survey, it became clear that there is a definite need for GIS in watershed planning efforts. Those who responded to the survey represented employees from each category, including working for the federal government or being consultants in a private firm. This supports the fact that watershed planning efforts come from a culmination of people with various skill sets, expertise, and professional responsibilities who are working in the watershed at varying spatial scales and for a range of purposes. With that said their responses to watershed concerns really depended on who they worked for or what projects they were involved with. It wasn't a surprise that funding was a primary issue since every agency or firm seems to be in a budget crunch.

When beginning to ask about GIS, a few respondents dropped out of the survey. It could have been a time constraint issue, but it could also have been that these respondents really didn't know or understand what GIS is. For the most part, the respondents who continued the survey had been working with GIS for at least 1 year and therefore felt comfortable answering this set of questions. The question about how the respondents use GIS data was insightful in the fact that many respondents used the data for statistical analysis. This along with the frequency of using GIS really shows the technical abilities that some of respondents have in this watershed area. The question about improvements to the respondents GIS capabilities really varied and was based on their level of GIS at the time of the survey, with many of them wanting training of some kind.

The spatial data resources section was in part to see what data resources the respondents were currently using, but it was also a way to educate the respondents on other resources they might not have known about by providing the website addresses to these sites. Since most of the Western Lake Erie Basin is in Ohio, it was no surprise that ODNR GIMS site was used by more respondents than the Indiana GIS Atlas. Those responding to requesting data from other agencies or individuals suggest that the data sharing capabilities are there if you know the right people. In response to data themes, it was expected that hydrography and environmental themes were used quite frequently by respondents since these are linked directly to many watershed concerns, but it was a surprise that orthoimagery was used just as much. The ability to download high resolution aerial photography and satellite images at no cost from some of the data resources mentioned, such as Data Gateway and Ohio View, could be a reason that it is used more frequently than believed. This suggests that the respondents are looking at geographic areas and their related ground conditions at specific time periods.

When participants were directed to the Maumee Basin GIS website, they needed to open another window which could have resulted in a lower response rate. If the website had been displayed in another way from the survey site, there may not have been the number of “drop-outs.” Even so, many had never been to this website or used the online GIS viewing system. The website has only been “live” for 2 months before the survey was conducted, so it may have been unknown that the website exists, at least to the extent of those participating in the survey. There had been less than 200 total visits to the Maumee Basin GIS web page prior to the survey.

When manipulating the viewer at the various extents, the data layers that were utilized most were general layers that appear on many base maps. These include major rivers, stream network, watershed boundaries, counties and roads. This response could be biased in the fact that the viewer automatically turns some of these layers on when using the zoom tool to view a smaller extent. Whether or not the participants really utilized these layers is unknown. If the layers had all been turned off, the answers may be more accurate. The census data, however, was rarely utilized, if at all, and the reason could possibly stem from the background or interest of the respondents.

The overall response of the Online GIS viewer from the Maumee Basin webpage was positive with several respondents saying that it is a good start. One suggestion was that clearer instructions were needed. This survey didn’t provide explicit instructions on how to manipulate the viewer (only a suggested link to map tools), which could have limited the overall use by the respondents who were new to looking at these types of GIS viewers, map tools and data layers.

The amount of GIS user group/data sharing activities really depends on how established the organization is. Several respondents said that they didn’t coordinate with anyone or that they didn’t know if they participated in sharing data. This suggests that they haven’t researched the resources that are in their area because it seems there are plenty of user groups or at least people who are willing to share their data out there based on other respondents’ replies.

The survey results propose that the Maumee Basin Online GIS will probably be used by half of these respondents in public outreach, mapping needs, and referencing data. There are no analysis capabilities at this time, so mature GIS users probably won’t need to use this tool given the fact that they have their own software with modelling and spatial analyst functions. Future mapping needs mainly consisted of data needs, funding and personnel. These responses show that some of the respondents are really at the base stages of implementing this kind of work and do feel that it could prove worthy in managing their watershed efforts.

The feedback from all who were emailed the survey was unanimously positive. The only suggestion was to allow respondents more time to fully engage themselves in the viewer. It would be difficult for them to realize all the capabilities of this type of online GIS system, especially if they had never seen a tool such as this, in such a short time. The use of an online survey proved to be cost effective and timely. The outside source, SurveyMonkey, was easy to use and provided the database capabilities that might have taken the author ample time to produce, such as spreadsheets and tallies for every question with percentages, not to mention compiling the open ended response questions. The exporting of results to spreadsheet format in both summary and detailed form provided options for the user when analyzing the responses.

When the initial survey was sent out, there were a few email responses with notices of incorrect email addresses and of councilmen who recently had taken office. This helped in making sure the lists that were given were as accurate as possible and that the number of possible participants were recorded correctly. One respondent sent me a list with the new Board of Trustees with their email addresses. Another respondent replied to the email expressing that he couldn't finish the survey because the answers he wanted to give weren't possible choices. Although he did not complete the survey, he did email asking for any support with another GIS project he was involved with.

Whether or not people responded could be from the fact that they didn't know the author who was sending them the survey. Therefore, the survey could have gone straight to their "junk mail." If the survey had come from another address, one more official than a "hotmail" address, there may have been a better response. Next time, it would be better to use a University of Toledo address sent by a well-known professor who is actively involved in watershed planning efforts in the area.

One idea to expand the survey to those who might not have participated in this study is to link it to the Maumee Basin GIS webpage, so that the project team can receive continuous feedback from people involved in watershed planning, the public and others who are browsing the web page and the viewer. This feedback could give the project team a fresh perspective on what data layers need to be updated to the viewer, what could be added as useful to the site, and what could be changed to the look and functions. Another idea for the survey would be to use it at a kiosk type computer like the AREIS kiosk in the Government Center in downtown Toledo. If it were set up at a statewide GIS conference, watershed planning committee meeting or ESRI User Group session, this would expand the sample into a larger population with a wider range of answers concerning GIS use in watershed planning efforts.

The Maumee Basin GIS project should look at exploring the various additional data sets and websites mentioned by the respondents from the survey. Investigating collaborations for web services and expanding ArcIMS capabilities would aid in the overall usability of the website. A further component to advance the project would be to host or offer training sessions to watershed groups or non-experienced GIS users to show them the capabilities that this kind of system can provide.

Using GIS in watershed planning efforts is still scattered in experience and scope. Every organization or group seems to be working on their own watershed issues and using GIS in different ways. If the Western Lake Erie Basin Partnership and NRCS could set up a system to where each watershed group had at least a basic level online GIS system, data could be collected and compiled in this system at certain times and then given to the watershed coordinator to the basin. The Partnership could then take the GIS databases or shapefiles to persons who have the capabilities to run models and perform statistical analysis for the entire watershed area. If certain projects such as this could be implemented, there wouldn't be the issue of having certain datasets in some areas and not others. Timing for collecting the data would have to be impeccable and micromanaged in order to accomplish this task.

9.7 Conclusions

This study reveals the usability and utility of GIS in watershed planning across the Western Lake Erie Basin. Implementing GIS allows planners to view relationships between variables that might not have been seen otherwise through the use of paper maps or reports. It adds a scientific aspect to planning whether the planner or manager directly uses GIS. As long as there is a connection between the planner and GIS personnel, the planner will be in closer proximity to the data and knowledge of how the underlying science aspects of the watershed relate to each other visually. With increased knowledge of GIS, its functions, and capabilities, the planner has a better chance of predicting future events that may occur in the watershed. Preventative measures against flooding could be implemented more timely with the aid of GIS.

This study also gives exposure to the Maumee Basin GIS Project web page, which provides information on the University of Toledo's involvement in the Western Lake Erie Basin Project. The web page provides an overall general look of the basin area through a GIS viewer. It also gives the users links to other websites that will help them in developing their own spatial databases. The ability to download layers through an ftp server is a great way for data sharing and promotes relationships between the users and the data manager.

In Nelson and Weschler's (1998) study, a GIS that involved stakeholders, political personnel, governmental agencies, watershed organizations, and citizens that spanned the Maumee Watershed was only a vision. With increased awareness of this ongoing project through this survey, collaborations have been suggested that directly tie into the goals and vision of the Western Lake Erie Basin Project. A representative of US Environmental Protection Agency Region 5 has contacted the author by phone and email wanting to know more about the ongoing project in the Maumee Watershed Basin and how they can establish web services between our resources and theirs. This representative and others from the US EPA are already collaborating with numerous other partners, agencies, and universities on the examining and addressing the non-point pollution and sediment aspects of the Maumee watershed and would like to tie in with University of Toledo on data sharing and analyses. By emailing the summary results to those who responded, more collaboration and correspondence among respondents with data user groups beginning with University of Toledo for data sharing and Natural Resource Conservation Service for larger basin-wide projects will occur.

Although there are no potential projects in sight that directly relate to the survey itself, the online GIS viewer presented on the Maumee Basin GIS website is a dynamic entity that will be consistently updated and improved over the next several years. As a future study, this type of survey could be given to a smaller watershed community, such as the Upper Maumee to really dig deep into their GIS related issues and work on resolving them. Another study would be to research all GIS related activities in a specific watershed and find out what data is being collected in order to find the best routes to integrate it all into one database for all users. This GIS study in watershed planning has come to a close, while future avenues for research and investigations have opened.

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Chapter 10
Utilizing Secondary and Public Data to Examine Relationships Between Watershed Land Cover and Biotic Integrity in the Lake Erie Tributaries

Kari A. Gerwin and Patrick L. Lawrence

Abstract Since the late nineteenth century draining of the Great Black Swamp, the watersheds of the Lake Erie Direct Tributaries (the Tribs) in Northwest Ohio have undergone massive agricultural development and patchy residential and urban growth. Landscapes of these watersheds are currently dominated by large plots of homogeneous cultivated land with patches of urban and residential development and minimal amounts of forest. The effects of intensive agricultural land use and drainage modifications are reflected in the Tribs' degraded fish communities and loss of riparian habitat. This study attempted to identify the relationships between fish community quality, habitat quality, and land cover variables using secondary data collected from 1993 to 1996 by the Ohio Environmental Protection Agency (OEPA) and a maximum likelihood land cover classification of Landsat Thematic Mapper (TM) imagery. Multiple regression analyses indicated that agriculture is a significant predictor of fish community quality and habitat quality in the Tribs. However, as this area continues to develop residential and urban land cover types may play a larger role in stream quality.

Keywords Watershed • Fish communities • Habitat quality • Land cover

10.1 Introduction

Present landscapes in developed regions of the world are highly fragmented and dominated by agricultural, urban and residential development. The effects of land development are reflected in the water quality and biotic communities of rivers and streams. Sedimentation, altered temperature regimes, toxicity and nutrient enrichment have had deleterious impacts on overall stream ecosystem health and limit the

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ability of streams to sustain healthy and diverse fish populations. These effects can be seen even in relatively rural landscapes such as the Lake Erie direct tributaries watersheds (the Tribs), within the of the Maumee Area of Concern (AOC) in Northwest Ohio. A 1993–1996 statewide biological and habitat sampling project conducted by Ohio Environmental Protection Agency (OEPA) revealed that all but 2 of the 27 sites sampled in the Tribs had poor to very poor biological integrity according to the Index of Biotic Integrity (IBI) (OEPA 1988). In addition, all of the sites fall below targeted habitat quality as measured by the Qualitative Habitat Evaluation Index (QHEI.) These scores are considerably lower than the targets set by the International Joint Commission (IJC) and the OEPA (OEPA 2005). In fact, biotic integrity and habitat quality scores in the Lake Erie Tributaries are generally lower than the scores for the more urbanized watersheds in the Maumee AOC (MRAP 2006). In an area without historically high levels of industrial use and urbanization, this brings to question the factors driving the poor aquatic health of the Tribs.

Using secondary and public data, this study merged a variety of GIS, database and statistical tools in an attempt to identify the watershed land cover types that influence the biotic integrity of fish communities in the Lake Erie Tribs. IBI is a multi-metric index that assesses a stream's ability to support healthy fish populations. The metric weights fish species collected along various stream reaches according to their pollution tolerance as well as their richness, trophic functions, reproductive functions, abundance and deformities (OEPA 1988). Fish communities can be impacted at the local scale by habitat modification and at a larger scale by activities within the drainage basin that input pollutants (chemicals, nutrients, sediments) and alter temperature regimes. Watershed modifications can cause changes in the trophic structure of a stream (Karr 1981), reduce species diversity (Snyder et al. 2003; Robinson et al. 2002; Roy et al. 2003) and in extreme cases of toxicity may cause a decrease in biomass (Karr 1981). Due to their sensitivity to watershed activities, and because they represent the top of the aquatic food web, fish communities are an ideal subject when attempting to quantify the effects of land use on aquatic systems.

10.2 Study Area

The Lake Erie Tributaries are a collection of four individual creeks located east of the Maumee watershed in northwest Ohio and drain directly into western Lake Erie (Fig. 10.1). Prior to the mid- 1800s, the area was part of the system of wetlands, forests and grasslands known as the Great Black Swamp. Beginning in the mid-nineteenth century the area was extensively channelized and deforested to allow for settlement and crop cultivation. By the early 1900s most of the swampland had been drained with only a handful of remnant forests and wetlands existing today as evidence of the Tribs' rich natural history (Kaatz 1955). The current landscape is dominated by large plots of homogeneous cultivated land with patches of urban and residential development and minimal amounts of forest.

The study area includes first through third order streams Wolf Creek, Cedar Creek, Crane Creek and Turtle Creek and encompasses portions of Lucas, Wood and Ottawa

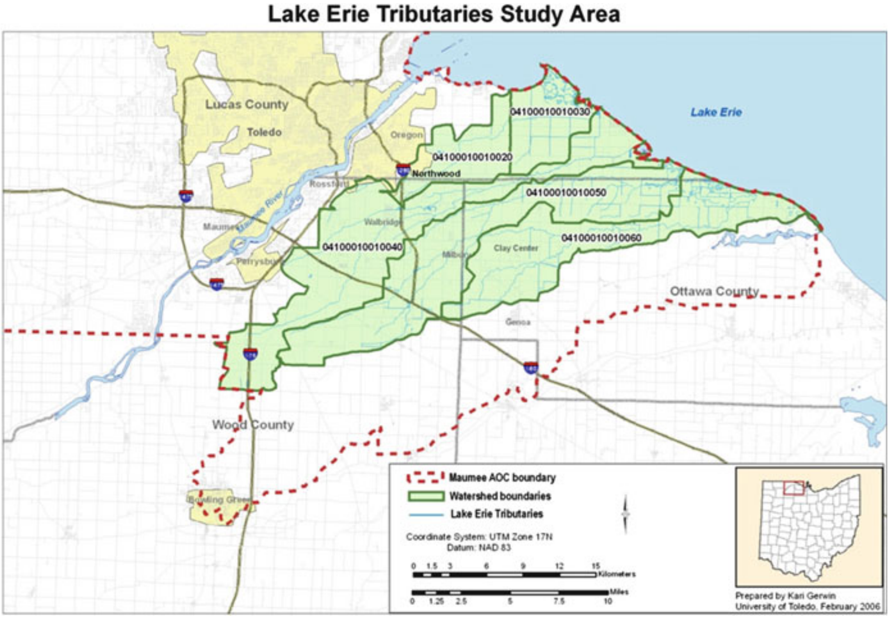


Fig. 10.1 Study area Lake Erie tributaries

Counties. Initial field observations of these streams and their watersheds have revealed pockets of new urban and residential development amidst the extensive agricultural land use. Larger urban areas within the watersheds include portions of the City of Toledo suburbs of Oregon and Northwood with some industrial land uses occurring in some sites outside of Oregon. All streams in the study area exhibit degradation of fish and benthic populations, loss of habitat and degradation of aesthetics, which are a few of many impairments preventing full attainment of beneficial uses in the Maumee AOC (MRAC 2006). The causes of these impairments are due primarily to land modifications and non-point source pollution and include nutrient enrichment, bacterial pathogens, siltation, pesticides, flow alteration and habitat alteration (MRAC 2006).

10.3 Research Approach

Because landscapes exhibit modifications to the natural or native landscape in varying degrees, it is predicted that variation in IBI and QHEI scores across the Tribs is related to the degree and type of landscape modification. Specifically, highly modified landscapes, such as those with >10% impervious surfaces (Booth and Jackson 1997; Snyder et al. 2003; Wang et al. 1997), or >50% agricultural land (Wang et al. 1997), will impact IBI and QHEI scores negatively and those with relatively undisturbed habitat will have a positive impact on scores (OEPA 1988).

Highly modified land cover types exhibit widespread alterations that destroy habitat or promote pollutant loadings (e.g. complete devegetation, surface paving and land cultivation).

Land cover types with moderate alterations are those that may be dramatically different in composition from the undisturbed landscape, but still retain some of the functionality of the original landscape. For example, grass can potentially minimize soil erosion (Beard and Green 1994) but also can input large amounts of dissolved nutrients into waterways with negative effects on aquatic communities. Finally, land cover types with relatively few modifications are compositionally and functionally similar to the original landscape. These areas include estuaries, wetlands, marshes and forested areas. It is assumed that they potentially provide habitat for aquatic life (Robinson et al. 2002), retain sediments, input coarse particulate matter (an essential energy source of many low-level consumers) and provide shade to regulate water temperatures. Overall these areas should have a positive influence on IBI and QHEI scores.

10.3.1 Secondary Data Sources

This study utilized biological and habitat data collected by the Ohio EPA from 1993 to 1996 for the Water Resources Inventory project. While the use of secondary data at times can constrict the scope of a study, they were of great value to this study as resources and time were limited. All original datasets were received as Microsoft Excel spreadsheets and required extensive pre-processing to ensure that all data were in a format that could be used for GIS analysis, database development and statistical analysis. After determining which data were the most relevant to this and future research, a relational database was created containing all Ohio EPA habitat and biological data for the Maumee AOC. All data for the Tribs were exported to a format (.dbf) usable for both GIS and statistical analysis. Correspondence with the Ohio EPA and subsequent ground verification ensured the positional accuracy of all points and allowed for the inclusion of all but one sample into the final dataset. Any data that did not meet quality, scale and spatial/temporal extent requirements were not used in this analysis, but were included in the larger database for use in future research. After eliminating invalid samples, sample sizes were 27 for IBI scores 19 for QHEI scores.

Much larger sample sizes were preferred for multiple regression analysis, but the analyses were conducted with the knowledge that the analyses may produce no significant results. Additionally, even the small samples provided insight into possible trends and relationships between variables. The mean IBI and QHEI scores for the study area are 19.3 and 28.2 respectively. These are both below the mean scores for the entire Maumee AOC (22.4 and 39.8 respectively). This is somewhat surprising considering the urbanization and history of industrial pollution in many Maumee AOC rivers and streams. In fact, both IBI and QHEI scores for the study are well below those of the more urbanized watersheds (Fig. 10.2).

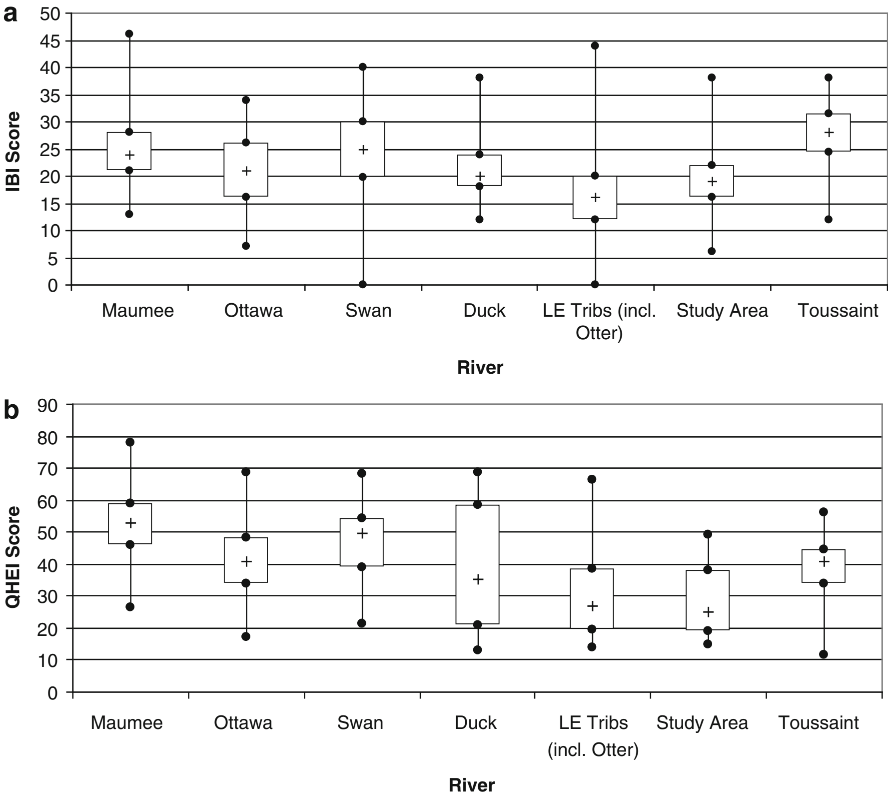


Fig. 10.2 OEPA data 1993–1996 (**a**) Index of Biotic Integrity (IBI) and (**b**) Qualitative Habitat Evaluation Index (QHEI) scores for all 11-digit HUCs in the Maumee AOC:Maumee River (n=144 and n=32 respectively), Ottawa River (n= 88 and n=64) Swan Creek (n= 44 and n=19) Duck Creek (n=21 and n=14) Lake Erie Tribs including Otter Creek (n=57 and n=59) Tribs study area excluding Otter Creek (n=28 and n=30) Toussaint River (n=18 and n=13)

10.3.2 Public Satellite Data

Numerous data repositories freely distribute civilian satellite data to the public. Among these are the University of Maryland Global Land Cover Facility (GLCF) and Ohioview data consortium. Although satellite imagery is widely available for the study area, very few images were available for the early 1990s. After examining all available Landsat datasets from both sources, a May 16, 1992 Landsat 5 Thematic Mapper (TM) dataset (path 20/row31) was downloaded from GLCF. In addition to the TM Imagery, US Geological Survey 7.5 min Digital Ortho Quads (DOQ) were used. These are mosaics with dates ranging from 1994 to 1995 were downloaded from the USDA/NRCS Data Gateway. The 1 m spatial resolution DOQs were the basis of training site selection and were used for collecting post-classification “ground reference points” in the accuracy assessment of the land cover classification.

10.3.3 Pre-Classification Image Processing

Landsat TM data were orthorectified to a planar projection (UTM) by the distributor prior to download. Using ENVI (Research Systems Inc.) image processing software, the seven bands of the data were projected to coordinate system: UTM, Zone: 17 N, Datum: NAD 83. Erdas Imagine "Model Maker" was used to stack the separate bands (minus thermal band 6) to produce one six-band multispectral image. To reduce file size and processing time, the image was subset to a 1 km buffer around the study area. The buffer was used to minimize edge effects in the classification.

Multispectral images can be radiometrically enhanced to correct for atmospheric attenuation effects and allow for greater separability of reflective materials. Although atmospheric correction is critical for detection of subtle differences in land cover classes that have closely related spectral characteristics, land cover types in an Anderson Level I classification are dissimilar enough that radiometric correction is often not necessary for discrimination between classes (Jensen 2005). After visual examination of the Landsat 5 data, it was decided that the negligible amount of visible haze in the image would not influence the separation of the six land cover types. The data were not resampled to correct for atmospheric effects.

10.3.4 Image Analysis

The study area was classified into six land cover types with minor modifications to the seven Anderson Level I classes (Anderson et al. 1976) using standard USGS methods. Considering the unique character of the study area and the objectives of this study, the following classes were chosen for the classification: impervious, grass, agriculture, bare soil, forest and water/wet vegetation. ENVI software was used for all digital image processing and accuracy assessment, with the exception of selected preprocessing techniques that used Erdas Imagine (Leica Geosystems) software.

A common issue with land cover classification in agricultural regions is confusion between agriculture and urban land cover types. Barren agricultural fields are often misclassified as impervious surfaces and vice versa. This is due to the highly reflective nature of dry bare soils, which have similar spectral signatures to that of impervious surfaces. Likewise, grassy agricultural vegetation such as winter wheat has reflectance values similar to those of turf grass commonly used on golf courses and in urban and residential landscaping. Because these misclassifications will ultimately affect the accuracy of the analysis, agricultural land was classified separately from non-agricultural land. This was accomplished by stratifying the data based on agricultural information in GIS parcel data from Lucas, Wood and Ottawa Counties. Using ENVI image processing software, the agricultural parcels were subset from the data based on each parcel's Current Agricultural Use Value (CAUV), a tax credit for agricultural land that has proven to be a good indicator of agricultural use in a previous study (Torbick 2004) CAUV proved to be the most accurate representation of agricultural land use because data were consistent between the counties and within each dataset.

The parcels identified as agriculture were used to apply a mask to the Landsat 5 data. A Maximum Likelihood classification was performed on the nonagricultural data by first selecting 22 training sites representing eight land cover types: impervious, industrial/highly reflective surfaces, forest, shrub, grass, bare soil, water, wet vegetation. The training sites were identified using the DOQ and were selected based on their ability to accurately represent each land cover type. Because collection of training sites is a highly subjective process, accuracy was ensured by (1) selecting only those sites that, upon visual inspection, exhibited land cover agreement between the Landsat data and the DOQ and (2) selecting only homogeneous areas. Based on the training sites, the image was classified using a maximum likelihood algorithm. Industrial and impervious were then combined to produce an impervious class. Forest was combined with shrub to produce a general forest class. Water and wet vegetation were combined into one class as well.

Agriculture land was classified using the above methods. Twenty-seven training sites were selected representing green agriculture (winter wheat), early agriculture (corn or soy), dry bare soil, wet bare soil, forest, wet vegetation, and water. These classes were also combined to produce four general land cover types: agriculture, forest, wet vegetation and water.

10.3.5 Accuracy Assessment

To test the accuracy of a land cover classification, stratified random sample of $\geq$500 validation pixels (30–50 per class for each of the two classifications) was classified and compared against the actual classification. To reduce bias in sampling, these points were collected separately from the original set of training data used for the classification. Each of the random pixels was then systematically inspected within the context of the false color May 1992 Landsat TM image. In many cases, the pixel's corresponding class could be determined based solely on visual interpretation of the Landsat image. However, each validation pixel was cross checked with the 1994–1995 1 m DOQs to ensure the correct assignment of each validation point. The classified validation pixels served as ground-truthed samples and were then compared to the values of the actual classifications within a confusion matrix using ENVI. This test produced results for overall accuracy, kappa coefficient, errors of commission and omission, and producer and user accuracies. Accuracy for both samples was about 88% (Table 10.1).

Table 10.2 shows the proportions of correctly classified pixels and the proportion of misclassified pixels for each class. The most common misclassifications in the agriculture subset were between green agriculture and forest with 20% of green agriculture being classified as forest and 6% of forest classified as green agriculture. Additionally, 8% of bare soil was misclassified as early agriculture. The most significant misclassification in the non-agriculture dataset was between bare soil

Table 10.1 Accuracy of agricultural and nonagriculture land cover classifications

Agricultural		
Overall accuracy	(230/261)	88.1226%
Kappa coefficient	0.8561	N = 261
Nonagriculture		
Overall accuracy	(294/331)	88.8218%
Kappa coefficient	0.8615	N = 331

Table 10.2 Error matrix for agricultural and non-agricultural classifications

Agriculture classification

Class	Bare soil	Green ag	Forest/shrub	Water	Wet veg	Early ag	Total
Bare soil	86.21	0	0	0	0	0	19.16
Green ag	0	79.25	5.56	0	0	11.11	19.16
Forest/shrub	5.17	20.75	94.44	0	0	3.7	19.16
Water	0	0	0	93.75	0	0	11.49
wet veg	0	0	0	6.25	100	0	11.49
Early ag	8.62	0	0	0	0	85.19	19.54
Total	100	100	100	100	100	100	100

Non-agriculture classification

Class	Grass	Wet veg	Forest/shrub	Impervious	Water	Bare soil	Total
Grass	94.17	5.26	2.56	4.88	0	0	30.82
Wet veg	0	76.32	2.56	0	0	0	9.06
Forest/shrub	5.83	18.42	94.87	0	0	0	15.11
Impervious	0	0	0	85.37	0	23.33	14.8
Water	0	0	0	0	100	0	15.11
Bare soil	0	0	0	9.76	0	76.67	15.11
Total	100	100	100	100	100	100	100

and impervious. Bare soil was classified as impervious in 23% of instances and impervious classified as bare soil in about 10% of instances. Confusion between vegetation types (i.e. forest, grass, wet vegetation) accounted for 46% of the error in the nonagriculture classes. This illustrates the necessity for separately classifying agriculture from non agriculture to reduce errors between these classes.

Although the above method for land cover classification produced an accurate classification by remote sensing standards, several errors were evident that would likely affect the accuracy of later analyses. Most misclassifications were traced back to the preprocessing of the data when the raw satellite data was clipped by CAUV status. Although CAUV was a consistent method of defining agriculture across the three counties in the study area (as opposed to zoning status), it did not guarantee that all agriculture parcels were included in the clip. Consequently, the most obvious errors were the misclassification of agricultural fields as non-agricultural bare soil. Any large areas classified as bare soil were examined against the DOQ and misclassifications were reclassified. Errors in the other classes were not as frequent, but when noticed, these were reclassified as well. As reclassification was conducted post-accuracy assessment using high resolution the DOQs the final classification was more accurate than initial accuracy assessments suggest.

10.3.6 Post-Classification Image Processing

After correcting for errors, the classifications were converted from raster data types to vector format by first converting the classification to a grid, then converting the grid to a shapefile in ArcToolbox (ESRI, ArcGIS 8.3). The resulting shapefile contained the spatial and attribute data, and most importantly the land cover values, from the original raster classification. After additional processing was performed to ensure standardized nomenclature between the two datasets, the agriculture and nonagricultural classifications were merged into one vector classification containing six classes: agriculture, forest, impervious, grass, bare soil, water/wet vegetation. Agriculture, early agriculture, and green agriculture were merged into a generalized "agriculture" class. The goal of merging classes was to flatten seasonal trends and variation to give a generalized long term picture of land cover during the study period. Similarly, water and wet vegetation were merged into one class due to short-term and seasonal fluctuations in water levels caused by wind direction, seiche and rainfall. Variability between water and wet vegetation, specifically in estuarine environments, occurs at a finer temporal scale than that of land cover, so distinguishing between these two land cover types based on a single satellite image is not useful to this particular analysis.

10.4 Results

10.4.1 Land Cover

Agriculture is by far the dominant land cover type in the Tribs watersheds (about 67% of the 450 km drainage area) (Fig. 10.3). Of the four watersheds, Crane Creek has the highest proportion of agriculture (about 72%) followed by Turtle, Cedar and Wolf/Berger (69, 64, and 60% respectively) (Table 10.3). All of the watersheds have agricultural land use above the 50% threshold that Wang et al. (1997) found to affect stream biotic integrity. Grass represents the second most dominant (11%) land cover type across all four watersheds. Cedar Creek has the highest percentage of grass (14%) and Turtle had the lowest (7%). Grassy areas represent mainly residential and urban land uses, although a few natural grasses may have been included during image analysis. Forest and impervious surfaces each represent about 8% of the Tribs land cover. The forested portion of each watershed is between 7.03 and 7.61% with the exception of Turtle Creek, which is 11% forested. Cedar creek has the most impervious surfaces (10.83%) and Turtle the least (5.64%) Water/wet vegetation represented just over 4% of the total study area. The majority of water is found at the mouths of the streams and represents estuarine sample sites. Bare ground only represents a minimal proportion (2%) of the land cover.

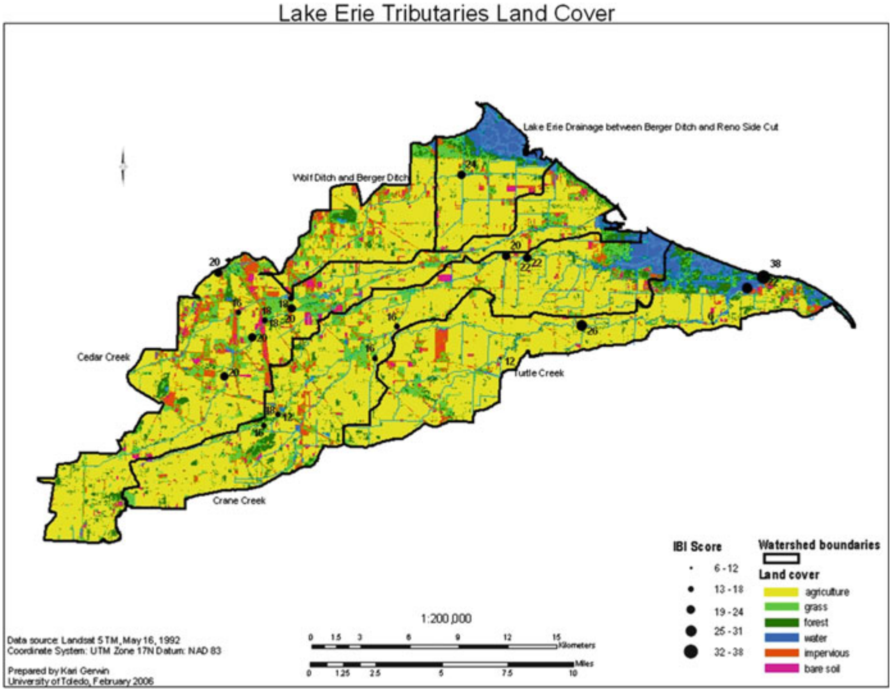


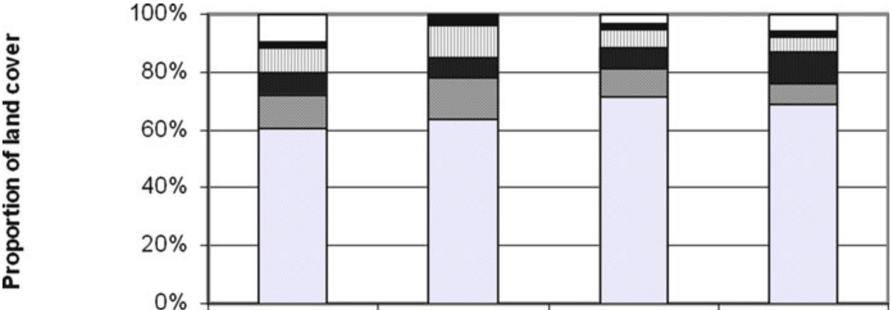
Fig. 10.3 Land cover classification of Lake Erie tributaries study area after reclassification of select areas

10.4.2 Spatial Analysis

ArcGIS 8.3 provides a built-in platform for spatial analysis. However, none of the available tools in ArcGIS were able to directly solve the problem of calculating the proportions of each land cover type within both 100 m and 500 m buffers around each IBI sample point. Alternatively, a hybrid-type method utilized multiple software packages to complete this task. To determine the land use within a distance of each sample point buffers of 100 m and 500 m were created around each IBI and QHEI point feature, producing a new polygon for each buffer. To avoid area measurement problems due to multi-part geometry among spatially disconnected like-attribute features, the “explode multipart feature” function was applied to create discrete features. After this critical step was complete the land cover data layer was clipped to the 100 m and 500 m buffers, which produced two shapefiles of (1) all land cover within 100 m of each sample point and (2) all land cover within 500 m of each sample point. The area of each polygon was calculated and appended to the attribute table of each of the clipped land cover layers using Visual Basic for Applications (VBA) statements in ArcGIS.

Spatial queries were run to join the IBI and QHEI point data to the land cover data. This process assigned the appropriate sample point ID to each land cover

Table 10.3 Proportional land cover of each of the Tribs watersheds as determined by classification of Landsat TM imagery, May 1992



	Wolf/Berger	Cedar	Crane	Turtle
□ Water/wet veg	9.51	0.92	3.54	5.98
■ Bare	2.08	3.23	1.84	1.52
▥ Impervious	8.65	10.83	6.17	5.64
■ Forest	7.61	7.15	7.03	11.07
▨ Grass	11.95	14.07	9.85	7.22
□ Ag	60.20	63.81	71.57	68.57

polygon, which was necessary for further calculations. The proportion of each land cover type within each buffer was calculated using Microsoft Excel. The result was a condensed table with the proportion of each land cover type corresponding to each sample point. These data were then joined to the original IBI and QHEI data in ArcGIS thus assigning an IBI and QHEI score to the proportional land cover composition of each buffered area. These data were imported into SPSS for statistical analysis. After logarithmically transforming all data, multiple regression analyses were conducted to assess the influence of the proportion of each land cover type on IBI scores and QHEI scores.

Nine multiple regression models were run using SPSS 14.0. First, each dependent variable (IBI and QHEI) were analyzed against the land cover data within the 100 m buffer, then the same was analyzed for the 500 m buffer. The datasets were divided and analyzed separately based on the water body type (riverine or estuarine) of the IBI/QHEI sample locations. QHEI and IBI for the 100 and 500 m buffer were analyzed for the divided dataset. Finally, a bivariate linear regression analysis was conducted to determine possible relationships between IBI scores and QHEI scores. All models used the stepwise regression method to eliminate covariant variables and include only those statistically significant ($\alpha \leq 0.05$).

The results of the multiple regression showed that within the 500 m buffer, agriculture, wet vegetation, bare ground and grass together explain 58.4% (adjusted R^2 $=0.584$) of the variance in IBI scores ($p < 0.05$.) Agriculture alone explained 16.2% of variance. Water/wet vegetation explained 13.3%, bare ground 17.7%

and grass 11.2%. Forest and impervious were excluded from the model by SPSS due to colinearity and insignificance of the variables. Although the model shows that the four variables negatively influence IBI scores, the model was skewed by outlying (<0.01%) values of wet vegetation. When the water/wet vegetation class was excluded from the model only agriculture was a significant predictor of IBI score (adjusted R^2=0.162). The results of regression using the dependent variable QHEI show a negative influence of agriculture on QHEI score, with agriculture explaining 22.3% (adjusted R^2) of the variance in QHEI scores. The remaining land cover variables were also excluded from the habitat model due to colinearity and insignificance of the variables. No significant relationships were found for either IBI score or QHEI score within a 100 m buffer of the sample points. Additionally, the bivariate regression analysis of IBI and QHEI scores revealed no relationship between biotic integrity and habitat scores using the Tribs subset of the larger OEPA dataset.

10.5 Discussion

Although multiple regression analysis was largely inconclusive, agricultural land uses do appear to have greatly impacted the health of the Tribs. Larger sample sizes would certainly have yielded more reliable results. Despite the inability of theses analyses to point with certainty toward a particular land use culprit, examination of the summary statistics against land cover proportions gives insight into possible trends. In an area with predominantly agricultural land use combined with extremely low biotic integrity, even a loose correlation gives cause for examination of the practices that have likely contributed to declining fish communities.

Overall, habitat scores relative to the other streams in the Maumee AOC were even worse than IBI scores. The Tribs' low QHEI scores can be attributable to extensive channelization, complete removal of riparian vegetation, tile drainage and excessive sedimentation, all of which can be traced back to extensive agricultural practices within the watersheds. Agricultural fields, at various locations throughout the Tribs watersheds, are cultivated to within less than a meter of streams and drainage ditches. The lack of vegetation in these areas means lost habitat for macroinvertebrates and fish. Furthermore, these practices input large amounts of sediments to streams. The Ohio EPA assessments determined that siltation is heavy to moderate and silt is the dominant substrate type for all sites in the study area. Most sites also exhibit recent or sustained channelization with a few sites in stages of recovery from channelization. In contrast, many of the urban and residential sites in the Maumee AOC have no channelization (for example lower reaches of Tenmile Creek/ Ottawa River and Grassy Creek).

Comparison of IBI summary statistics between the study area and the entire Maumee AOC indicate that nearly homogeneous agricultural land cover may be just as detrimental as or worse for stream biotic integrity than urban land uses. In addition to the habitat impacts mentioned above, agricultural pollutants such as nutrients, pesticides and dissolved organic matter are also a likely cause of degradation to the Tribs' fish communities. IBI scores below 20 are not usually seen in areas where degraded habitat is the sole problem. Scores will generally descend below 20 only when a watershed has been impacted by toxic effects of land use or point sources of pollution, resulting in the loss of large portions of fish communities and reduced biomass (OEPA 1998). Assuming that the threshold of 20 can be applied to the study area, 14 sites in the study area have IBI scores below the threshold for toxic impacts, with a few sites showing scores as low as 12 and 6. Without a history of industrial point source pollution in the Tribs the question arises: what may be contributing to the apparent toxic effects in the Tribs? If low IBI scores are due primarily to the input of toxins via non-point source pollution from agriculture, then the abundance of habitat is not likely to improve IBI scores. Rather, altering farming practices to include significant reductions in chemical fertilizers and pesticides may help improve biotic integrity.

Aside from agriculture, other land cover types likely have varying effects on biotic integrity. Although impervious surfaces were not a significant predictor of IBI or QHEI, effects may be missed due to the fact that the majority of impervious surfaces within the study area fall outside of the 500 m buffers that were used for analysis. Forest and wetland land cover types have been shown to have mitigating effects on water quality (Wang et al. 1997) in the form of sediment retention, providing habitat, thermal control. Forested areas represent roughly 8% of total land cover and water/wet vegetation about 4%. However, in the Tribs watersheds, the distributions of these land cover types are so fragmented they may be providing only minimal habitat functions. Although grassy areas were predicted to have a weak negative correlation with IBI and QHEI, no relationship was found after excluding water/wet vegetation from the analysis. This is despite the fact that grass is the second most dominant land cover in the study area. The negative associations of grass with modified landscapes may be negated by its function in erosion control. Bare soil, also an indicator of residential development and only a minimal proportion (2%) of total land cover, was not a predictor of biotic integrity or habitat.

In addition to land use, many other conditions within the Tribs watersheds have made contributions to the current conditions. Channel slope, total drainage area, flow velocity and spatial scale are all important considerations when attempting to quantify land/water interactions. It has also been suggested that in addition to land cover analyses, landscape patterns such as patchiness, average patch size, connectivity, etc. are important in understanding the processes that influence water quality and biotic integrity (Gergel et al. 2002; Wiens 2002). Another important factor is the influence of seasonality, specifically the seasonal fluctuations in avian predation. The Ohio EPA fish surveys were conducted in late summer when evaporation is high in NW Ohio. During this time, small sections of streams may begin to run dry, providing an easily accessible fish community for birds, resulting in few available samples for calculating IBI scores. Seasonal predation may have a larger influence in the Tribs than in the other streams in the Maumee AOC due to their relatively small size and lack of riparian canopy in many areas.

Overall, the datasets used for this study were extremely informative. The use of secondary data provided a cost effective means for examining land cover/biotic integrity relationships in the Tribs. Examination of the secondary data also revealed the insufficiencies of the dataset. The dataset used for these analyses are 10–12 years old and may be of questionable relevance today as land use and stream conditions have certainly changed over 15 years. Collection of more current habitat, biotic and water quality data is necessary for current and future water resources research and monitoring (recently Ohio EPA has completed additional data collection of water quality and aquatic habitat conditions in the Lake Erie Tributaries for the preparation of a TMDL study). Unfortunately, resources and time are often a limiting factor for individual studies, universities and state agencies. When data are collected, it is usually in the context of a specific localized study making the data inapplicable for other larger scale studies. Data collected at a broader spatial scale, as with the statewide Ohio EPA biotic and habitat data, cannot conceivably be maintained on a continual basis nor do they provide a good representation of the variation within a smaller watershed. As this study shows, the use of secondary data can result in small sample sizes and unclear significance of results.

10.6 Conclusions

This study has provided insights into possible relationships between land cover and biological/habitat conditions in the Lake Erie Tributaries in the Maumee AOC within northwest Ohio. While agriculture appears to be the main culprit in stream health degradation, numerous other interrelated factors have created the conditions seen in these rural streams. Examination of the datasets for the entire Maumee AOC indicates that habitat and fish communities in the Tribs are in most cases worse than their urbanized counterparts.

This study would not have been possible without the 1993–1996 data provided by the Ohio EPA. However, continued and regular collection of biological and habitat data in Wolf, Cedar, Crane and Turtle Creeks is clearly needed for analysis of current land cover/biotic integrity relationships. In conjunction with the expansion of water quality and biological data collection, there is a need for semi-regular analysis of publicly available satellite data to determine current land cover and to monitor land use changes in the Lake Erie Tribs and across the Maumee AOC. This is especially important as these watersheds experience rapid residential development.

With their low biotic integrity and habitat scores, the Lake Erie Tribs present many opportunities for future research utilizing the spatial analysis functionality offered by GIS. Possible future work includes examining the influence of site specific factors (e.g. rail yards, package plants, faulty septic systems) as well as watershed-scale analyses. Additionally, this analysis did not take into consideration geographic and geologic factors that form the hydrology of the watersheds and thus influence the taxonomic and functional characteristics of these systems. In-depth modeling of stream gradient as it relates to the biotic communities of the Tribs could provide great insight into ecological responses that may contribute to the low IBI scores in the Tribs.

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Chapter 11
Use of Geospatial Technology for Oil Spill Response Planning in the Western Basin of Lake Erie

David B. Dean and Patrick L. Lawrence

Abstract This study reviews existing plans and proposes a development process for geospatially enabled oil spill protection strategies in the Western Lake Erie basin. Geospatially enabled protection strategies take advantage of existing data and the capabilities of a GIS to develop variations of protection strategies to allow for strategic changes to plans as a result of seasonal or meteorological conditions. It also allows the analysis, display and distribution of geospatial data in a manner that meet the different needs of planners, responders and incident managers. Data distribution options are discussed, including multiple paper and electronic publication options including, but not limited to Adobe Acrobat, GEOPDF, ArcReader, Google Earth and ArcIMS to make data available in the appropriate format to all personnel who require it.

Keywords Oil spilling planning • GIS • Emergency response

11.1 Introduction

Area Contingency Plans (ACPs) and their associated Geographic Response Plans are site-specific documents designed to outline steps to be taken in response to an oil or chemical spill. They are designed to improve the speed and efficiency of a response during the critical 6–48 h after an incident, whether an oil or chemical spill in water, an accidental release of hazardous chemicals from a manufacturing or storage facility or an accident involving hazardous substances transported via road or rail networks, when quick action on the part of responders can keep a small incident from becoming much larger or limit the damage caused by the incident while a broader response is initiated. ACPs are prepared by Area Committees,

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which consist of representatives of federal, state and local agencies such as the United States Coast Guard (USCG), United States Environmental Protection Agency (USEPA), state Environmental Protection Agencies, state Departments of Natural Resources and other stakeholders who may be affected in the event of an oil spill.

Local stakeholders may include representatives of Oil Spill Response Organizations (OSROS), refineries or other organizations that store significant amounts of hazardous materials, local fire departments and first responders. Representatives from federal, state and local wildlife reserves that may be affected by an incident are also included on the committee. The contingency plans are created in consultation with Regional Contingency Plans (RCP) and National Contingency Plans (NCP). The associated Geographic Response Plans (GRPs), also known as protection strategies, are site-specific documents that outline the steps to be taken to protect ecologically, culturally and economically sensitive areas in the event of an oil or hazardous chemical spill at or near that location.

The aim of this study was to develop and propose a methodology to systematically develop and update geospatially enabled geographic response plans, also known as protection strategies, to support the mission of the Western Lake Erie Area Committee. The flexibility of geographic information systems makes it practical for the Area Committee planners and interested agencies to develop multiple versions of a protection strategy and associated maps for sensitive areas along the Lake Erie shoreline based on, for instance, seasonal conditions or prevailing wind direction and strength. Geospatial technologies can simplify the task of maintaining and updating the protection strategy data and documents as well as making them easily available to responders and planners via digital or paper publishing and distribution methods (Alfultis and Miller 2007; Burns et al. 2002). Response plans must be flexible, as no two incidents occur under the same conditions. Flexibility – the ability of a system to adapt input and output to changing conditions – is strength of geospatial technology (Jensen et al. 1998; NRC 2007). A goal of this project is to produce a template for the use of the technology for response planning that can be applied to data collection and analysis projects across Great Lakes Basin and beyond (Dean 2009).

11.2 Study Area

The navigable streams and US waters of the Western Lake Erie basin from the Detroit River lighthouse located at approximately 42°00′ N, 83°08′ West to the mouth of the Vermilion River in Erie County, Ohio including the Lake Erie islands are the responsibility of the Western Lake Erie Area Committee (Fig. 11.1). Counties represented include Monroe County Michigan, Lucas, Wood, Ottawa, Sandusky and Erie Counties in Ohio. A study area the size of the entire western basin of Lake Erie is too large for this project. To keep this project manageable, shorelines representative of the variety of conditions found in the basin – hard, manmade shorelines in the lower reaches of the Maumee River, sensitive wetlands north of Toledo, Ohio along the Michigan shore of the lake, and areas of heavy

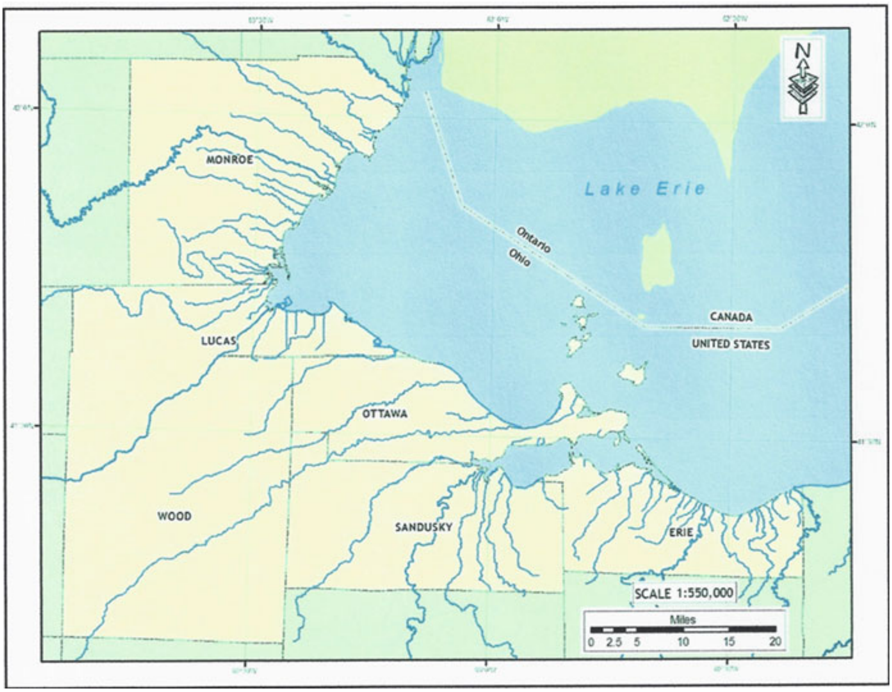


Fig. 11.1 Western Lake Erie basin study area

recreational and tourism use around Sandusky and Catawba Island have been selected for use to develop map layouts and a systematic approach to protection strategy planning as examples for the production of associated maps covering the western basin and possibly elsewhere in the Great Lakes.

11.3 Methods

All disasters or emergencies are local by nature and occur in a geographic context of space and place (Brooks 2008). The relationship between the event and its surroundings is important to the conduct of response activities. The primary goal of any emergency response is to minimize property damage and loss of life as a result of a natural or manmade disaster. Any kind of event requiring the attention of public safety officials is by its nature spatial. For example, in the context of this study, an accident involving a collision between two ships in the open lake has a spatial location, any response to the accident must take into account the location of the accident, amount and type of product spilled, weather conditions and the location of potentially affected resources among other considerations. The emergency management process is generally organized into four phases: mitigation, preparedness, response and recovery (Cova 1999).

Mitigation activities are designed to reduce the probability of an event and/or the risk posed by a hazard, in this case, an oil spill. Preparedness is defined as actions taken in advance of an event that improve the effectiveness of the response in the event of an emergency. A response to an emergency involves actions taken immediately before, during and/or directly after an event occurs to minimize the impact of the event. Actions taken in the recovery phase are designed to return conditions to 'normal' as quickly as possible. Each emergency management phase does not exist independently of the others as they often overlap. Cova (1999) notes that in the context of a GIS, it may be appropriate to consider preparedness and recovery as its own combined phase since geospatial tools developed in the preparedness phase are frequently used in the response to an emergency.

Contingency planning for oil spills follows the same four phases and in fact, done well, integrates into emergency response planning for other hazards, both natural and man-made. Depending on the location of the spill, local fire, police and EMS response personnel are normally the first on scene. Oil Spill Response Organizations, (aka OSROs), utility personnel, NGOs such as the Red Cross and other organizations involved in emergency response support are contacted as deemed necessary. In the event an incident is beyond the capacity of local response organizations, additional response resources from state and federal sources can be called in. This process is documented in the area plan.

Conversations with persons responsible for emergency management or preparedness activities at the county and regional level indicated that speaking generally, emergency managers and emergency management agency staff are aware of the benefits that come from using geospatial technologies for incident planning and response. However, whether from institutional inertia, a lack of understanding of the potential benefits of using geospatial technology, or a "that's not the way we do it around here" attitude, geospatial technologies are often relegated to the task of producing paper maps for reference rather than being used as a tool that can assist an emergency manager in the effective management and analysis of a dynamic situation. Gunes and Ertug (2000), p. 137) notes that "GIS technology brings to the user the ability to integrate, store, process and output geographic information." Martin et al. (2004, p. 239) observed that "certain relationships and operational trends are more easily conveyed in a geographic context than in a traditional tabular format." Both make convincing cases for using geospatial technology as an effective tool in all phases of the emergency management process.

At present there is standard but limited data and few graphic representations of booming strategies for protection strategies in the western Lake Erie plan. Ultimately, an important goal of this project is to improve the clarity and usability of the containment/protection strategy maps detailed in the Western Lake Erie Area Plan (Dean 2009). Following a presentation of the protection strategy mapping approach from various locations to the Western Lake Erie Area Committee, input was solicited from responders and managers regarding what data they felt are required in response map layouts and which of the protection strategy maps reviewed best met the needs and goals of the committee. The consensus was that a combination of elements from maps produced by the Northwest Area Committee for Central Puget Sound and the Snohomish River would be a reasonable starting point for developing response plans appropriate for conditions found in the western basin of Lake Erie (Dean 2009).

11.3.1 Base Map Data Layers

Protection strategies are grouped geographically from the northern part of the western Lake Erie Area of Responsibility (AOR) in Monroe County MI to the eastern edge of the AOR at the mouth of the Vermilion River in eastern Erie County, OH. The Lake Erie Islands, part of Ottawa and Erie counties are also included in the AOR. Protection strategies may not exist for the entire shoreline, but are developed for sites that have been determined to be environmentally or economically sensitive. These locations will be noted with a callout on the index map which is linked to a .pdf of the strategy. Other significant points outside a protection strategy such as oil collection points, and shoreline access can be noted on the map as well. The protection strategy maps include multiple data sets grouped by general functionality.

Base maps provide a spatial reference for the response data. Base maps may be raster imagery from various sources and of varying resolutions and may include, but are not limited to:

- Transportation networks – local roads, state, federal and interstate highways and railroads.
- Physical geography layers include the Lake Erie shoreline, major streams and a high resolution streams layer from the National Hydrographic Dataset (NHD) to provide higher spatial resolution for use when the map is zoomed in to larger scales.
- Political boundaries – township, village, city, county, state and international, in the case of the Great Lakes. It may be beneficial to create both filled and open polygons of these layers.
- NOAA navigation charts, both DRGs (scans of existing charts) and vector data containing similar data. These layers should be considered for reference only and should not be used for navigation.
- Aerial and satellite imagery at appropriate resolutions along with USGS or US Forest Service 7.5 min quads (DRGs) can be used under the vector data layers.

These and other pertinent base map data layers are available from various federal, state and local government agencies (e.g., street networks from US Census or county auditors, hydrographic data from the US Geological Survey) usually by data download. Geocoding or address matching the location of hospitals, fire stations, police stations and other public service agencies may be necessary where such data are not already available. When a significant incident takes place, it may be possible to acquire current or very recent satellite or aerial imagery, such as that flown by NOAA after Hurricane Ike in September, 2008 (http://ngs.woc.noaa.gov/ike/IKE0000.HTM). The data/imagery is then available for analyses of affected resources. It may be possible to leverage work done by other county or state emergency management agencies to reduce the effort necessary to compile base maps.

An additional benefit of using existing base data is multiple agencies will be working from the same base map and will all reference the same data.

11.3.2 Response Specific Data Layers

Data layers that are specific to an Area Committee's Area of Responsibility and are of importance to responders and planners are stacked on the base map layers. In this case, the response data layers have been sourced from the 1998 edition of the Western Lake Erie Area Contingency Plan and were prepared by the Great Lakes Commission at a reference scale of 1:24000 as indicated in the metadata. These layers include, but again, are not limited to

- Sensitive species polygons that describe that approximate location and type of environmental sensitivity of organisms that may be threatened by contact with oil or other hazardous chemicals.
- The shoreline Environmental Sensitivity Index (ESI) provides planners with important information about the relative sensitivity of a shoreline to contact with oil. The sensitivity is related to the difficulty removing stranded oil from the shoreline and the sensitivity of plants and animals potentially affected by oil.
- The location, extent and type of public and private land managed for wildlife or conservation purposes are contained in the managed areas layer; the information is important for planning and notification in the event of an incident.
- Marinas and boat ramps are separate but similar layers that provide vital data on the location, capabilities and contact information for marinas and boat ramps. The most significant difference between the two is boat ramps when listed separately, provide access to the water and are typically not associated with a marina and may have limited dockage and services, if any are available at all.
- The petroleum pipelines layer provides the location, diameter and number of pipes in a route. Information on ownership and emergency contact are also included. This layer may be password protected for security reasons.
- Petroleum storage locations / potential spill sources provides information on the amount and kind of petroleum product stored at a particular site. This data enables planners to devise a response plan for the worst-case scenario – a release of the entire contents of a storage tank. This data too may be password protected.
- The water intakes layer provides the location and emergency contact data for water intakes both in the lake and along inland streams. Access to this layer may be password protected for security reasons.

These data layers are contained in the various Area Contingency Plans. The data may be already available as shapefiles, however some processing may be necessary to create files useful for analysis in a GIS.

11.4 Western Lake Erie Protection Strategy

The proposed page layout for the Western Lake Erie protection strategy maps uses elements from the Central Puget Sound protection strategy maps (Northwest Area Committee 2007) and the Snohomish River GRP. The index map provides a small scale (large area) overview of the area of responsibility of the area committee with links or references to pages containing response strategies. The western basin of Lake Erie covers a fairly large area. An index map is necessary to give responders an overview of the area and the relative location of each protection strategy. The map contains standard base map layers appropriate to the scale with callouts for each protection strategy within the Western Lake Erie Area Committee's AOR. Each of the callouts on the Western Lake Erie Protection Strategy Index Map is an existing protection strategy found in the Western Lake Erie Plan. Where there is no data in the existing strategy, the new data fields are left blank. The missing data will be filled in as protection strategy updates are completed. The final map when published as a .pdf will have links from the index map to each protection strategy. Where there are multiple strategies within a small area, such as the Maumee River in the Port of Toledo or the River Raisin in Monroe, MI, the link will be to a sub-index map. Like the larger index map, the sub-index map contains links to protection strategy pages.

Figures 11.2 and 11.3 reflect the proposed protection strategy map design for the Sun Oil docks on the Maumee River. Existing data from the 1998 edition of the Western Lake Erie Area Plan are the basis for the proposed protection strategy maps. There has been no data added to the strategies. Where there are numerous strategies within a limited area, a local index map may be necessary. In the western Lake Erie basin, rivers, commercial waterways and harbors may require a local index map. Each protection strategy noted on the local index map then has its own two page strategy, documenting steps to be taken and resources required by responders to execute the pre-planned strategy at that location. The protection strategy pages are designed to allow adaptations to local conditions. For instance, collection points that are capable of accommodating collection and removal of spilled product whether the flow direction is up river (toward the head of the river) or down river (toward Lake Erie). Protection strategies that can accommodate bi-directional flow have notations made to that effect.

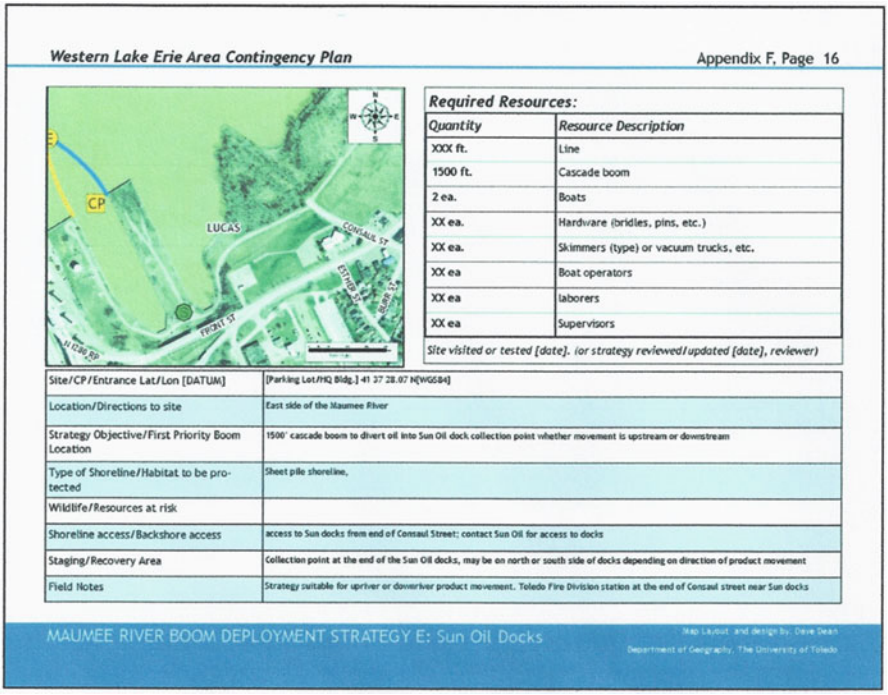
There are standard data fields found in the same location on the front/back page set. The front page (or page 1 if not printed front/back) of the strategy contains a map that consists of base map layers and an orthophotograph of sufficient spatial resolution as to be able to discern details on the ground, typically one foot to one meter per pixel spatial resolution. This map should be large enough (small scale) to provide responders with an idea what surrounds the area to be protected and an idea of how to get there. It also provides visual information about the general configuration of the boom used in the protection strategy and where the collection point may be.

The reverse side of the map (or page 2 if not front/back) contains a larger scale map of the collection point, pertinent boom anchor points and if appropriate a detail

Fig. 11.2 Proposed Maumee River protection strategy for Sun Oil Docks site (page 1)

map of complex boom deployment configurations. Other detail maps can be included as deemed necessary by planners and incident managers or conditions. The bulk of the second page is devoted to tabular data important to the crews tasked to execute the protection strategy. During the planning stage, planners and/or responders should have visited each location and compiled an inventory of equipment required to execute the strategy. A table containing an inventory of resources required to execute the strategy is found at the top of the page, to the right of the small-scale map of the collection point. This data eliminates guesswork by response crews who, in the event of a major incident, may not be familiar with local response strategies and location or sources of response assets. Some strategies may require more resources than are available locally. Under these circumstances, a notation is made further down the page to that effect (in the “field notes” data field) and should have information about how and where the necessary resources can be obtained.

A larger table below the small-scale map and response resources table contains additional data required for a crew to effectively execute the strategy. The site entrance/headquarters/staging area/command post (as appropriate and determined by planners) latitude / longitude expressed as degrees, minutes, seconds which is a Coast Guard navigation standard, and digital degrees is displayed in the first field. Either the WGS 84 or NAD 83 datum can be used along with the Universal Transverse



Western Lake Erie Area Contingency Plan Appendix F, Page 16

Required Resources:

Quantity	*Resource Description*
XXX ft.	Line
1500 ft.	Cascade boom
2 ea.	Boats
XX ea.	Hardware (bridles, pins, etc.)
XX ea.	Skimmers (type) or vacuum trucks, etc.
XX ea	Boat operators
XX ea	laborers
XX ea	Supervisors

Site visited or tested [date]. (or strategy reviewed/updated [date], reviewer)

Site/CP/Entrance Lat/Lon [DATUM]	[Parking Lot/HQ Bldg.] 41 37 28.07 N[WGS84]
Location/Directions to site	East side of the Maumee River
Strategy Objective/First Priority Boom Location	1500' cascade boom to divert oil into Sun Oil dock collection point whether movement is upstream or downstream
Type of Shoreline/Habitat to be protected	Sheet pile shoreline,
Wildlife/Resources at risk	
Shoreline access/Backshore access	access to Sun docks from end of Consaul Street; contact Sun Oil for access to docks
Staging/Recovery Area	Collection point at the end of the Sun Oil docks, may be on north or south side of docks depending on direction of product movement
Field Notes	Strategy suitable for upriver or downriver product movement. Toledo Fire Division station at the end of Consaul street near Sun docks

MAUMEE RIVER BOOM DEPLOYMENT STRATEGY E: Sun Oil Docks

Map Layout and design by: Dave Dean
Department of Geography, The University of Toledo

Fig. 11.3 Proposed Maumee River protection strategy for Sun Oil Docks site (page 2)

Mercator (UTM) projection. Final determination regarding the appropriate datum and projection will be made in consultation with the Coast Guard as the project progresses. Written directions to the site from major easily recognizable intersections are contained in the second field.

A description of the booming strategy objective and the first priority boom location if appropriate are described, the type of shoreline to be protected, if applicable, is next (Fig. 11.4). This may include a description of the shoreline as well as the ESI values for vulnerable shorelines within the boundaries of the strategy. An outline of wildlife at risk is contained in the next field. This may not be significant in an area of heavy industry characterized by hard shorelines; however it becomes important elsewhere along the lakeshore where more sensitive shorelines exist. A description of the location of the staging /recovery area follows. The staging and recovery areas may not necessarily be co-located so directions to each should be part of the data contained in this field. Field notes is a catch-all data field intended for any important information not found elsewhere in the strategy. The location of additional resources, other water access points, contact information in the event access to private property or a restricted area is necessary, etc. can be found here.

An essential element not yet present on the layouts which will require development and input from higher levels of response management is the development of a naming convention for each strategy that includes the lake, strategy number, strategy name

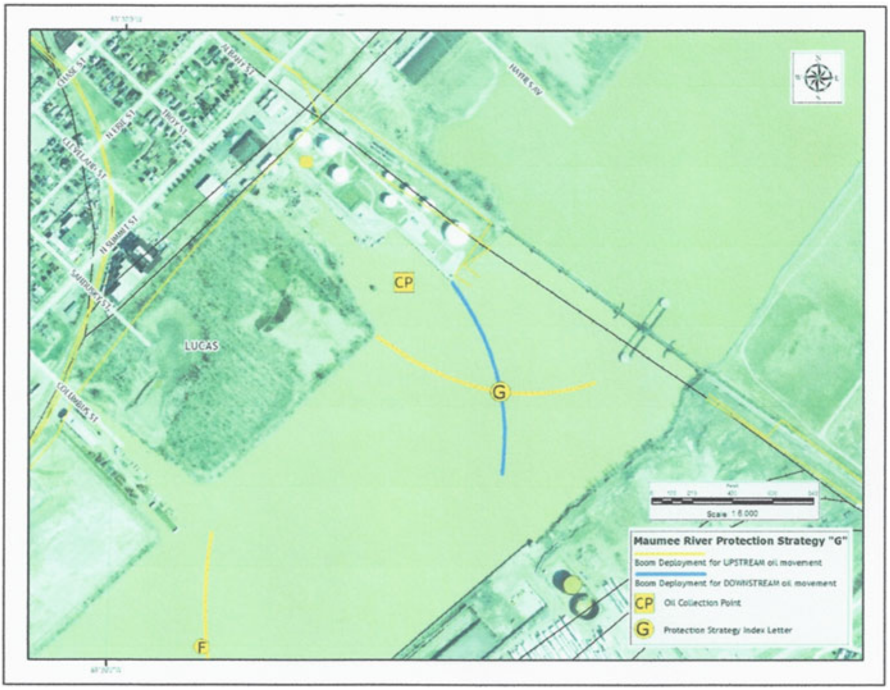


Fig. 11.4 Example of a river boom protection strategy

and Coast Guard District or US EPA Region number if appropriate. This information will be on the sheet with the strategy name; it will also be on the right edge of the previous strategy (assuming a left to right numbering sequence) and the left edge of the next strategy. This convention allows easy reference and access to adjacent strategies should it be necessary. Another element that must still be added to the maps subject to guidance from the Coast Guard is the application of a reference grid to the maps. The US National Grid (USNG) is based directly on the Universal Transverse Mercator (UTM) and the Military Grid Reference System (MGRS). The Federal Geospatial Data Committee has defined the USNG as a standard reference system for emergency response for federal agencies involved in emergency response (Brooks 2008).

11.5 SCAT/Shoreline Assessment Data Collection

Rapid, accurate, and consistent data collection during an incident is important to planners and responders for a number of reasons, not the least of which is good data makes good decisions. The established SCAT – Shoreline Cleanup Assessment Teams (term used by NOAA) or Techniques (term used by Environment Canada) – data collection methodology provides a systematic framework for collecting data describing the presence or absence and amounts of oil on the water or stranded on a shoreline.

As part of the protection strategy development process, crews who may be responsible for performing SCAT surveys in the event of a spill should collect data on shorelines as they exist before an incident occurs. Pre-incident data collection not only documents the condition of the shorelines before a spill event, it serves to supplement existing protection strategy data and can alert planners and responders to potential hazards to cleanup crews, both in the foreshore and backshore. For example, low cliffs are common along the shores of the Lake Erie Islands and Catawba Island, limiting backshore access and restricting cleanup activity to boats along the shoreline. The presence of cliffs and backshore access restrictions presented by them should be noted in the appropriate protection strategy and consideration given as response strategies for shorelines in the area are developed. The pre-incident shoreline assessment process also helps managers determine where and when to deploy crews to execute protection strategies, recover oil from the water, remove oil from shorelines and determine when a shoreline is considered clean. It has the added benefit of familiarizing SCAT crews with the shorelines that may be affected in the event of a spill. NOAA has several shoreline assessment forms available for assessment teams to standardize data collection activities.

Data collected during pre-spill shoreline assessments should be included in layers provided in the protection strategies. This not only provides data for before – after spill comparison, but the data collection activity using the shoreline assessment forms provides practice for personnel who will eventually be responsible for shoreline assessment in the event of a spill. Data collected and incorporated into layers using the shoreline and wetland assessment forms from NOAA (or other appropriate source) can be important for processing and making a comparison of before and after conditions easier and quicker. NOAA and Environment Canada have developed protocols for completion of SCAT forms. The forms contents and protocols for data collection are outlined in the NOAA Shoreline Assessment Manual (NOAA 2000) and Environment Canada's The SCAT Manual (Owens and Sergy 2000).

A geospatially enabled version of the SCAT forms are being developed by NOAA's Office of Response and Restoration in Seattle and the University of New Hampshire's Coastal Research Response Center (Zelo 2007). Properly designed data entry forms will allow the use of either data collection methodology, depending on the availability of the handheld GPS computers. SCAT crews equipped with GPS enabled PDAs or ruggedized handheld GPS receiver/computers allow for faster, more accurate data collection, better consistency between crews collecting data and easier, quicker integration of the data into the planning and response database (Zelo 2007). An important element in developing a set of geospatially enabled protection strategies is relating tables to each other using key fields found in separate tables. The shoreline is broken into segments based on natural breaks in shoreline type, access, proximity to staging or response assets or other criteria as determined by planning personnel. Each segment is assigned a name or number.

This name or number becomes a key field for linking related tables in the geodatabase. Segmentation and survey of the shoreline by trained personnel before an incident allows SCAT data collected during an incident to be quickly and accurately integrated into a response database whether the data is collected on paper forms or using a GPS enabled handheld computer. That data can then be displayed on maps available to response managers or used for further analysis of threats to resources, for example.

11.6 Discussion

Geospatial technology is commonly used to create printed maps for various purposes. Producing printed maps is certainly an appropriate use of geospatial technology, but misses the real potential for analysis of data when used in emergency management applications. The map layouts produced for this paper are useful output from an ArcMap, however the analytical capability of geospatial technology is where it can provide significantly improved situational awareness when compared to printed maps. When an incident is of sufficient size to warrant the presence of a GIS specialist as part of the response effort, the possibilities for output include both pre-planned products such as display of results from model runs predicting the trajectory of a spill or chemical plume or print out pre-planned response documents to ad-hoc responses to requests for information from emergency planners and managers.

Up to this point, the uses of geospatial technology in this project have been for planning rather than as a decision support tool. The use of GIS for planning is certainly an appropriate use of the tool but it does not take advantage of the analysis capabilities of the technology. The US Coast Guard Marine Safety Unit (MSU) Toledo and US Environmental Protection Agency in collaboration with the Ottawa County (Ohio) Emergency Management Agency held a joint oil spill response exercise at the Ottawa County Emergency Operations Center (EOC) in Port Clinton, OH June 10, 2009. The exercise scenario had two ships (one a steamship) colliding in US waters at 41°40′ N 83°00′ W. The collision resulted in the release of approximately 15,000 gal of Bunker C fuel oil into the lake. Winds were assumed to be from the northwest, which would move the oil toward the Lake Erie Islands. An ArcReader project was created and bookmarks for printed maps at scales of approximately 1:150,000 for reference maps and 1:24,000 for each of the Lake Erie islands in US waters (South Bass, Middle Bass and North Bass) were created. These maps contain data of potential interest to managers on a spill but are generally less useful for responders as there are no response strategies illustrated on them.

To illustrate the potentially useful data that can be quickly extracted from an Arc Map project and used for decision-making, the area around the Lake Erie islands projected to be affected by the spill in the Mistake on the Lake scenario was selected and attribute data from the selected layers was displayed in tables. The area affected was determined by output from the oil spill model run by NOAA at the

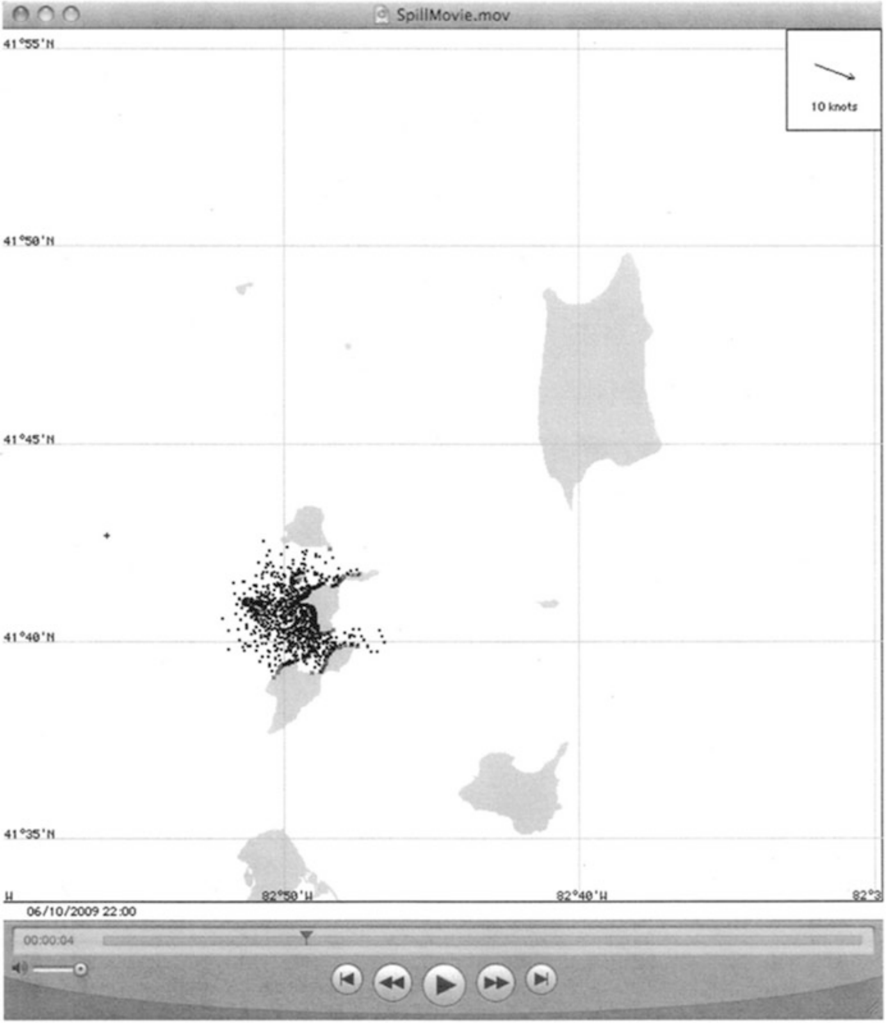


Fig. 11.5 A screen capture from a Quicktime Animation of an oil spill event, South Bass Island, Lake Erie

request of the Western Lake Erie Committee planners. A frame capture from 2200 h on June 10, 2009 shows the projected distribution of oil some 19 h after the simulated collision (Fig. 11.5). Economic and ecologic resources in the potentially affected area were selected in ArcMap and the attribute tables containing contact information and resources at risk displayed. In this exercise, no polygons describing projected oil movement were provided by the oil trajectory models making the selection of resources a best guess based on information from the animation provided by NOAA.

In this case a quick query was created simply by selecting the assets that were in the projected path of the oil. The result was a set of tables containing the information necessary to contact those responsible for economic or ecologic resources that may be at risk from the spill so that appropriate responses can be taken. This is by no means an exhaustive examination of the data that can be extracted from Arc Map. Queries can be developed that can display whatever data planners or responders feel is important. For instance, near real time meteorological data is available online from data buoys in the lake as well as stations along the shore. Personnel with a copy of the Arc Reader project and an internet connection can use hotlinks built into the Arc Reader project created for the Mistake on the Lake exercise to access weather data as reported at Coast Guard stations, airports, NOAA data buoys moored in the open lake. Live or recent data from other sources, for instance USGS/NOAA river current gauges, can be made available through the ArcReader project, again as deemed appropriate or useful by planners and response management personnel. Additional data tables can be added at the discretion of the Area Committee.

11.7 Conclusions

Geospatial technologies have matured in recent years to become a useful tool to develop, update, display and publish protection strategy data and maps. Geospatially enabled response plans can be developed, response options analyzed pre- and post-incident or post-exercise and changes made to the strategies relatively easily. The flexibility of geospatial technologies provides planners with a way to develop protection strategies for different conditions at a particular location. This study selected a limited set of protection strategies already established in the Western Lake Erie Contingency plan for display using a geographic information system; print page layouts for the data and maps were also developed.

Existing protection strategy maps in the western Lake Erie plan were evaluated for readability clarity and usefulness for responders. The quality of the maps varied widely, from high quality, legible maps of some areas to low line resolution, pixelated maps of others that are of little use. Page design and data fields to be included in the geospatially enabled protection strategies for the Western Lake Erie were found in a number of locations. The primary source of inspiration was the work done by the Northwest Area Committee in the Puget Sound GRPs (marine environment) and the Snohomish River protection strategies (riverine environment). Design elements of each were included in the draft page design, potentially useful data fields that were not included in the western Lake Erie plan were included for review by planners and responders. An important facet of the data layout is the ability to link to dynamic data, such as SCAT data, that will allow the import of data from existing external sources during an incident.

Most of the elements necessary to accomplish this task are in place. Once a page layout is approved and the appropriate data fields updated, the data fields must be populated, the maps published and included as part of the Western Lake Erie Plan. It should be noted all work done on the western Lake Erie protection strategies to this point should be considered draft, subject to revision and approval by the area committee. The development of well-designed geospatially enabled response plans which conform to established emergency management protocols and standards will provide consistent, clearly presented data to response personnel. The updated data and maps will help improve contingency planning, data analysis and response activity in the event of an oil spill within the Western Lake Erie area of responsibility.

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