Watershed Planning and GIS:

The influence of geographic information systems on the watershed planning process

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Preface

This document was originally written as a research paper submitted in May of 2008 to fulfill one of the requirements for my Master's degree in Regional Planning at the Department of Geography and Planning, University at Albany – SUNY. Using the watershed as a planning unit is not a new concept, however, the way we plan for those watersheds has undergone some dramatic changes in the last few years. In 2008 GIS is still a relatively new technology. Though its roots can be traced back to the late 1960s, GIS did not become "main-stream" until the late 1990s. We continue to find new ways to apply this technology to all aspects of planning. Since this paper was written, I have made a few changes and corrections, and may continue to do so as time allows. (Last updates were made in February 2020)
If you have any suggestions or comments, please send a note to don@donmeltz.com. The latest document can be accessed at www.donmeltz.com/watershedplanning.pdf.

Acknowledgments

I would like to thank all of the professors involved with my years-long learning process at U Albany. Ray Bromley accepted my application and put up with my ignorance of all things planning during my first semester in 1998. Tom Daniels opened my eyes to the unique challenges facing our small towns and rural areas. Katherine Daniels helped me explore the many ways we can protect our vital natural resources. Cliff Ellis helped connect the dots between rural and metropolitan areas, describing how these seemingly disparate areas actually work as a system. Austin Fisher and Larry Spraker filled my head with all things GIS. Catherine Lawson was my guide, a task-master pushing me to complete my degree, helping me through the final stages, and of course our final planning studio. And even though I never had him as a professor, Gene Bunnell provided great encouragement and guidance during the writing of this final research paper. I thank him especially for the the positive comments he made when all was done.

Abstract

Watershed Planning and GIS: The influence of geographic information systems on the watershed planning process

Water resource planners have changed their focus over the years from concentrating primarily on economic development goals, to thoughts of sustainable water quality. Their understanding of the relationship between discrete water bodies and the lands surrounding them has evolved and grown.

The height of the environmental movement in the 1970's appears to be the turning point, a watershed moment of sorts, when water resource planners, government agencies, and the general public realized that water is not an inexhaustible natural resource. It became apparent that water needs to be planned for and preserved for future generations. At the same time, significant advances were being made in computer technology, specifically the ability to use computers to generate maps and analyze spatial data. This geographic information system (GIS) technology has allowed planners, and particularly water resource planners, to work much more efficiently and effectively.

The amount of literature dedicated to explaining the importance and process of planning for water resources is large. Where water resource or watershed planning is discussed, GIS is usually mentioned as a useful tool. However, the discussion about how to use GIS to its fullest potential, and how GIS technology has affected watershed planning is limited. This paper examines recent changes in water resource planning and GIS technology, and describes how they can best be used together for developing a watershed plan.

Introduction

Water is the one element necessary for every form of life on the planet Earth. Water has also historically been treated as an inexhaustible natural resource. It is constantly flowing past us in our streams and rivers, falls from the sky on a regular basis in most places, or is available from the ground simply by drilling another hole deep enough to tap into it. For these reasons, water is generally thought of as a public resource, to be used and managed for the good of the people. Also for these reasons, the federal and state governments see water as a natural resource important enough for them to plan for and regulate (Tarlock & Lucero, 2002, p. 972). On the other hand, the land uses that surround and overlay these water resources are mostly privately owned and regulated by local governments. As our population continues to grow and to place increasing pressure on our water resources, the various levels of government must find ways to work together to protect this vital natural resource.

In their article “Connecting Land, Water and Growth” (2002), Dan Tarlock and Lora Lucero describe the disconnected state of water resource planning, outline the reasons for these disconnects, and provide some solutions for overcoming them. The primary reason they give for the disconnect is the division of responsibilities for controlling water supplies, and controlling growth. Other reasons given are a separation between the planning process and those responsible for implementing the plan, a separation between those making development decisions and budgeting decisions, and the general separation of powers between the various levels of government (federal, state, county, and local). They recommend a four-pronged approach to filling the gaps between these disconnects.

- Using an inclusive, participatory process to restore the public's confidence
- Using an integrated planning system, pulling together all levels of government, and addressing all substantive planning areas (land use, transportation, economic development, etc.)
- Making informed decisions that are consistent with a well thought-out plan
- Monitoring and measuring the effectiveness of the decisions made

The authors go on to explain the need for more direction from federal and state level governments, going so far as calling for a constitutional amendment that establishes the right of future generations to a sustainable environment. Given the history of the federal government's disdain for interfering with local control over land use issues, this seems unlikely. In fact, at the height of the environmental movement in the 1970's, when the National Environmental Policy Act (NEPA) was passed, its sister act, the National Land Use Policy Act failed to pass.

Some questions not answered by the Tarlock & Lucero article are:

- How are these solutions any different from the recommended planning process outlined in most modern planning textbooks?
- Is there a process, program, or initiative available to planners today that can help us overcome these disconnects?
- What are the tools currently available to planners that can specifically help them with this process?

Planners charged with managing water resources have altered their approach in recent years. The federal government has become more involved in planning for water resources in a sustainable manner, and advances in technology have made it much easier to analyze, plan for, and manage those resources. The purpose of this paper is to examine recent changes in water resource planning and technology, and how they can work together for the improvement of both.

River Basins to Watersheds

Planning by watershed is not a new idea. Water resource planners have long been aware that the watershed provides the best planning-unit when developing water resource plans (Loucks, 1998, p. 38). As the timeline in Appendix 1 shows, early water resource planning efforts used the river basin as a common planning unit. These river basin plans were usually geared toward controlling water as a source of economic development. Rivers and streams were wild things that needed taming. If they were not tamed, they could not be used effectively as a source of power, navigation, irrigation, or recreation. They also often overflowed their banks, affecting nearby development. From the early 1800's through the 1960's, this economic development focus continued. Watershed planning was synonymous with river basin planning.

Probably the most notable project during this time was the creation of the Tennessee Valley Authority (TVA) in 1933. Formed as a response to the Great Depression, and part of FDR's New Deal, the TVA is the largest regional planning agency ever created by the federal government (Tennessee Valley Authority, 2008). The TVA used the Tennessee River Basin as a unit for planning for power, navigation, flood control, and general economic development of the region. While the TVA came to be known as a great success, not all river basin planning projects were. In 1944 the Army Corps of Engineers and the Bureau of Reclamation were admonished for their "Pick-Sloan" plan for the Missouri River Basin. The plan limited its focus to flood control, navigation, and hydro electric power, neglecting to address the nearby land uses affected by the plan. By flooding 900,000 acres of prime farmland, the loss of farm production outweighed the gain from controlling annual flood loss by three to one (Buie,1979 , p.14).

In the 1940's and through the 1950's, increasing emphasis was placed on making sure the costs of these large projects did not outweigh the benefits they provided. River basin planners began placing more emphasis on upstream and upland resources, and how activities there affected things downstream. A much more comprehensive approach to watershed planning began to evolve. Soil erosion and land uses figured more prominently in the decisions made, and the federal government began relying more on state and local governments and organizations to develop water resource plans. However, the focus was still on taming the wildness of the rivers for economic gain.

Things changed more dramatically in the late 1960's and 70's. People became aware that water, while considered a renewable resource, is not an inexhaustible resource if not properly planned for. With the passage of NEPA, governments were required to evaluate more rigorously, the impacts of their actions on the environment, and to include an element of public participation in the decision making process. The National Water Commission in 1973 called for the end of large federally funded river basin engineering projects, and moving toward a planning/licensing/regulating role for the federal government (Loucks, 1998, p. 39).

Modern thought has evolved into ideas about sustainability of water resources, and how we can address watersheds in not just a comprehensive way, but holistically. Addressing things comprehensively ensures everything is covered, and all of the issues are addressed. This is a fine approach to take, but it can sometimes devolve into a checklist type system of analyzing the elements and addressing the issues. Taking a holistic view emphasizes the interdependent relationships between the watershed and all of its parts. It looks at how the elements work together, and how altering one element might have an impact on the functioning of all the others. Increasingly, water resources are viewed not as things to be conquered, but valuable possessions to be preserved for future generations. There is more concern now about the quality of the water flowing through the watershed and the impacts of water pollution on our water resources.

The Watershed Protection Approach

In 1972, the Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), required states to establish water quality standards, and determine pollutant loads that would ensure those standards would be met. This was the beginning of the EPA's Total Maximum Daily Load program (TMDL) (Environmental Law Institute, 2007, p. 7).

> A TMDL is the sum of allocated loads of pollutants set at a level necessary to implement the applicable water quality standards (U. S. Environmental Protection Agency, 2008, April 23)

Through the 1970's and 80's, state and federal programs dedicated to improving water quality focused on correcting point source discharges by large industrial and municipal facilities. Point sources are stationary locations from which pollutants are discharged, such as a pipe, ditch, ship, ore pit, or smokestack (U. S. Environmental Protection Agency, 2005, p. Glossary-4). These end-of-pipe, point-sources were easily identified, and easy to regulate. While this was a very successful approach at the time, it became clear that more was needed. It was not only individual point-sources that were degrading the water quality of surface and ground water resources, but also polluted runoff from larger areas. These non-point sources do not have a single point of origin or specific identifiable outlet. The pollutants are generally carried into streams and lakes by stormwater. Some examples of non-point sources are agriculture, forestry, urbanized areas, and construction sites. Regulating non-point sources however, can be problematic. This is because the federal government, and in some cases, state governments, do not have the legal authority to control the land uses that cause the pollution. This is one of the disconnects identified in the Tarlock & Lucero article (2002). The EPA's answer was the watershed protection approach, a framework that local agencies could use to coordinate their efforts to improve and preserve water quality. Begun in 1991, and refined over the years, the EPA describes the watershed approach on its website (2007, May 8) as follows:

> "The watershed approach is a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, taking into consideration both ground and surface water flow."

The Watershed Protection Approach encompasses three core principals represented graphically in figure 1, and described in more detail in the following paragraphs.

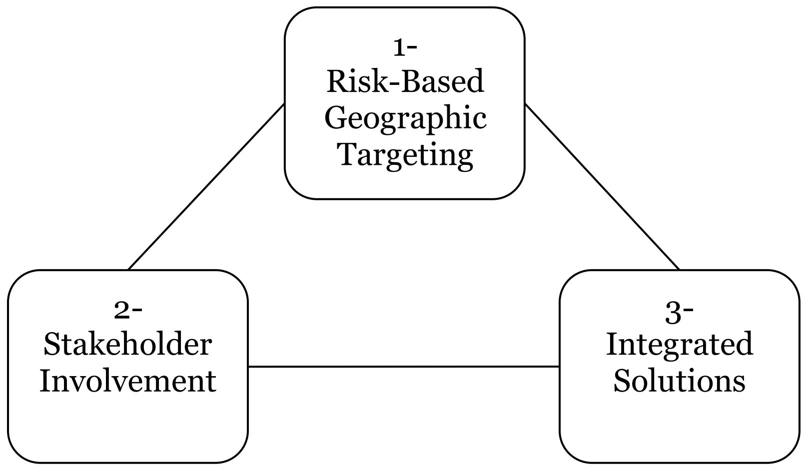


Figure 1 Elements of the Watershed Protection Approach (U. S. Environmental Protection Agency, 1991, p. 2)

1. **Target the watersheds where pollution poses the greatest threats.**

   In the watershed protection approach, emphasis is placed on identifying water systems that pose the greatest risk to the environment and the health of the people. Areas with high concentrations of industrial and wastewater discharges, combined sewer overflows, hazardous waste spills, unnatural runoff, wetland loss, and stream bank erosion are given a higher priority.

2. **Participation by all of the stakeholders within the problem areas.**

   Consensus is reached by all those involved in the activities and regulations within the target area. The EPA and other federal government agencies coordinate efforts with state public health, agricultural, and environmental agencies. Local government boards work cooperatively with private conservation organizations and industries. The academic community is relied upon to help with educational and research aspects. All of these public entities work together in an effort to improve the health and general welfare of the community.

3. **Use the full range of tools available in an integrated fashion**

Permits and enforcement programs are applied uniformly and consistently within and among the various political jurisdictions. Economic incentives, financing, and technical assistance are given where needed. Educational programs are used to encourage voluntary pollution reduction, and emergency response and remediation efforts are coordinated.

The goal of the EPA in promoting the watershed approach is to encourage all levels of government, from federal to state and local, to collaborate and coordinate their efforts to protect and improve their water resources. The EPA's role is to help in this coordination, and to provide technical support to those other government agencies. Within the EPA, the Office of Wetlands, Oceans, and Watersheds (OWOW) is responsible for promoting the Watershed Approach and facilitating the exchange of data, ideas, and other information between participants.

The Watershed Protection Program

When the watershed protection approach was first developed, the goal was to come up with a flexible framework to integrate existing planning efforts, and to explore innovative ways for locally tailored techniques to evolve into a routine process for enhancing water quality (U. S. Environmental Protection Agency, 1991, p. 1). Many projects implementing the watershed protection approach have been initiated. The federal government, however, does not have the authority to require implementation of these projects. The projects are often begun by local governments, organizations, or state agencies, as a reaction to an identified problem within a water system. The initiators of such projects realize that they need the cooperation of the stakeholders within the project boundaries, but also need assistance from higher levels of government, more familiar with the technical aspects of watershed planning, and in a better position to fund those projects.

The EPA realized that different regions of the country should be treated differently based on their unique qualities and characteristics. Climates vary widely throughout the country, and no two watersheds share identical physical characteristics. In an effort to institutionalize the Watershed Protection Approach, a basic framework was set up that allowed a great deal of flexibility as to how it was to be applied to various watersheds across the country. By giving the authority to develop regionally based watershed planning programs to EPA Regional Offices, and by encouraging individual states to develop watershed planning programs on their own, the plans produced through those programs are better able to concentrate on the unique aspects of the watersheds being evaluated.

The EPA has identified three critical components they feel are necessary for any regional or state watershed planning program to work. These components are (U. S. Environmental Protection Agency, 1991, p. 5):

- A set of well defined goals and objectives
- Specific criteria for selecting high-priority watersheds
- Flexibility built into the process for planning and implementing any watershed protection measures

One of the first steps in setting up a watershed protection program is to inventory the water resources within the region. This means not only mapping and describing the water bodies within all of the watersheds, but also deciding what the best use of the water bodies should be. Water bodies are used to evaluate the watershed, because they are the ultimate receivers of whatever processes go on within the watershed. If there is a problem found in a particular pond, lake, or point along a stream, it can usually be traced back "up-watershed" to whatever element is producing the identified impact. It should be kept in mind that we are still discussing the watershed program here, not the actual watershed planning process. These inventories cover vast areas, and are done in order to identify those water resources that should be targeted for more detailed watershed planning efforts. By doing this, time and money is not wasted planning for areas that are not in immediate need of remediation.

Scientifically valid indicators are developed to help identify the potential best use of a water body, or water system. These same indicators are then used to help identify water bodies that do not live up to the expected use. By using local knowledge of pollution problems, along with these scientific indicators, impaired water bodies are given a higher priority. As a part of the process, possible causes of the identified impairments are also documented. Once planning for the specific watersheds has begun, and the necessary controls are applied to the source of the impairment, the effectiveness of the control measures can then be measured by continued monitoring of the water bodies. Scientific indicators similar to those used to identify the impairments in the first place are used again for this monitoring. By doing this, control methods used to mitigate impacts can be evaluated for their effectiveness, and modified as needed. In this way, standards can be developed for use in future projects that are specific to the region.

Federal Agency Cooperation

There are many federal agencies other than the EPA that are responsible for protecting and/or managing water and public land resources. In October, 2000, eight of these agencies adopted a unified federal policy on watershed management.

The goal of this policy is to apply the watershed approach to federally owned and managed lands and water resources in order to protect water quality and aquatic ecosystems within those resources (U. S. Environmental Protection Agency, 2008, January 2). The eight signing agencies are: the Environmental Protection Agency (EPA), the Army Corps of Engineers (ACOE), the Department of Agriculture (USDA), the Tennessee Valley Authority (TVA), the Department of Commerce, the Department of Defense, the Department of Energy, and the Department of the Interior. An example of how this policy is being implemented by the ACOE is their requirement that any mitigation measures required to offset impacts to wetlands occur within the same watershed as the wetland being disturbed.

Applying GIS to the Watershed Protection Approach

Targeting high-priority Watersheds

In order to identify high-priority water bodies, a system of inventorying and analyzing the water bodies has to first be developed. Taking a complete inventory of the entire country's water resources would be an impossible task, if it were not for the concurrent advances in computer mapping technology. As the EPA and other agencies were promoting the watershed protection approach, advances in geographic information systems (GIS) were keeping pace with their needs. Improvements in satellite and aerial photography, and digital terrain mapping have made it much easier to delineate smaller watersheds over larger areas of the country. The ability to integrate the attributes of a watershed with its boundary on a map help to track and prioritize these watersheds.

Involving Stakeholders

Watershed boundaries almost never follow political boundaries. Agencies given authority to control land uses within a given watershed do not have complete control over the entire watershed. Modern planning methods require seeking out the involvement of all of the stakeholders in a given planning unit. This is especially important when planning at the watershed scale. It is also much more difficult to accomplish. Again, advancements in technology can and have helped.

Being able to accurately delineate a watershed's boundaries, and overlaying this with municipal and tax parcel boundaries makes it easy to identify specific stakeholders. GIS can also be used to show these stakeholders their place within the watershed; what the land uses are upstream and downstream from them, where their water supply comes from, and where their wastewater flows to. There is no better way to get a landowner's attention than to show their water source on a map in relation to the neighboring village or city's sewage treatment plant, and then follow the water flow or topography upstream to make a connection between the two.

Integrated Implementation Toolbox

Given the overlaps between the various stakeholder jurisdictions and their differing levels of control and influence, it is imperative that a full range of planning tools be used in implementing the watershed plan. Equally important is evaluating the effectiveness of the tools used during the plan's lifetime. By viewing the watershed as a system with measurable inputs and outputs, GIS technology can be very useful in making this evaluation.

Individual federal level agencies are making their data more GIS friendly. The

GIS savvy watershed planner can acquire weather related information (rainfall), and show specific storm events with their rainfall measurements. That rainfall can be plugged into a model that measures runoff over different soil types, and calculates the impact on stream flows. Stream flow gauge data can also be accessed online, and plugged into the model. As data is gathered over time, the stream's health can be measured and compared with an original baseline. The various strategies used to protect or improve the watersheds health can also be measured and evaluated for effectiveness.

Figure 2 A weather station in the Taskinas Creek watershed near Williamsburg Virginia. This station measures wind direction and speed, temperature, humidity, atmospheric pressure, solar radiation, and precipitation.

Figure 3 A stream gauge on the Kinderhook Creek, in Stockport, NY. A typical stream gauge records the water flow in cubic feet per second at 15 to 60 minute intervals. The data is electronically transmitted to USGS offices every 1 to 4 hours.

Defining and Identifying Watersheds

> A watershed is the area of land that drains water to a common point along a river, stream, pond, lake, estuary, ocean, or other water body (U. S. Environmental Protection Agency, 2008, April 23).

The first step in any planning exercise is to identify the area the plan is to address. This is a fairly straight forward decision when planning for a town, village, or city where the political boundaries of the municipality define the planning area. When planning for a watershed, the boundary is not as self evident. In an effort to standardize how watersheds are identified, cataloged, and named, the USGS, EPA, and other government agencies have developed a variety of similar standards.

The boundaries of a watershed follow the highest ridgeline surrounding the water feature that serves as its drainage point. The boundary between two watersheds is the dividing line where water flows in two different directions. Watersheds are not always easy to distinguish and define. While the watershed of a small stream or pond is more discrete and quite easy to identify, watersheds of tidal estuaries and coastal areas can be more difficult to identify. There is also the matter of scale to consider. Large watersheds include a number of smaller watersheds. Conversely, small watersheds nest inside of larger watersheds. In order to standardize and catalogue watersheds in the US, the USGS, in 1974 developed a hierarchy of what they called Hydrologic Units. Each was assigned a code number based on where in the hierarchy the watershed belonged. The largest of these watersheds were called Regions, and given a 2-digit hydrologic unit code, or HUC. There are 21 Regions in the United States. These 21 Regions were divided into 222 Subregions, and given a 4-digit HUC. These Subregions were in turn divided into 352 Accounting Units with a 6-digit HUC, and then into 2,149 Cataloging Units with an 8-digit HUC. The first pair of numbers in a cataloguing unit's HUC identifies the Region it belongs to. The second pair of numbers identifies the Subregion. The third pair of numbers identifies the Accounting Unit it belongs to, and the fourth pair, its cataloging unit. While this mapping exercise was helpful for very broad planning efforts, its usefulness was limited because state water agencies, conservation districts, and drinking water suppliers needed more detailed information. The delineation process was also labor-intensive, requiring looking at hardcopy topographic maps, and manually drawing watershed boundaries by deciphering contour lines. The NRCS, USFWS, and other federal agencies were at the same time, delineating smaller watersheds using a similar, but not identical system.

In the early 1990's, GIS technology started making it much easier to delineate watersheds at a small scale for large areas. The Federal Geographic Data Committee (FGCD) sponsored a group of nine federal agencies to develop an Interagency Standard for Delineation of Hydrologic Unit Boundaries. A draft standard was completed in 2000 that closely follows the previous USGS system, but uses the terms Basin and Sub Basin to replace Accounting Unit and Cataloging unit, respectively. The new standard also calls for more detailed delineations into Watershed and Subwatersheds. The standard led to the creation of the Watershed Boundary Dataset (WBD) in 2003 (see figures 4 and 5). Currently, 28 states have complete WBD available. However, GIS technology and available data has advanced to the point where agencies, organizations, or individuals can delineate watersheds for any area they desire, at a very high level of precision. This ability does not replace the need for a standardized system of watershed cataloging, but augments it; supplying data where gaps exist, and providing more detailed boundaries where required. Large scale watershed boundary data is very useful in evaluating potential land use impacts when writing comprehensive plans at the town and village level. It can also be used for flood hazard mapping, stormwater management projects, and aquatic and riparian monitoring programs.

A watershed cannot be delineated without knowing the water body it is based on. As a part of the WBD project, the USGS developed the National Hydrography Dataset (NHD). This data set maps and contains information about all of the surface water features in the United States, such as lakes, ponds, streams, and rivers. The NHD combines these surface water features into reaches, which provide a framework for linking water-related data into a surface water drainage network. These linkages enable the analysis and display of water-related data in upstream and downstream order (U. S. Geological Survey, 2007,).

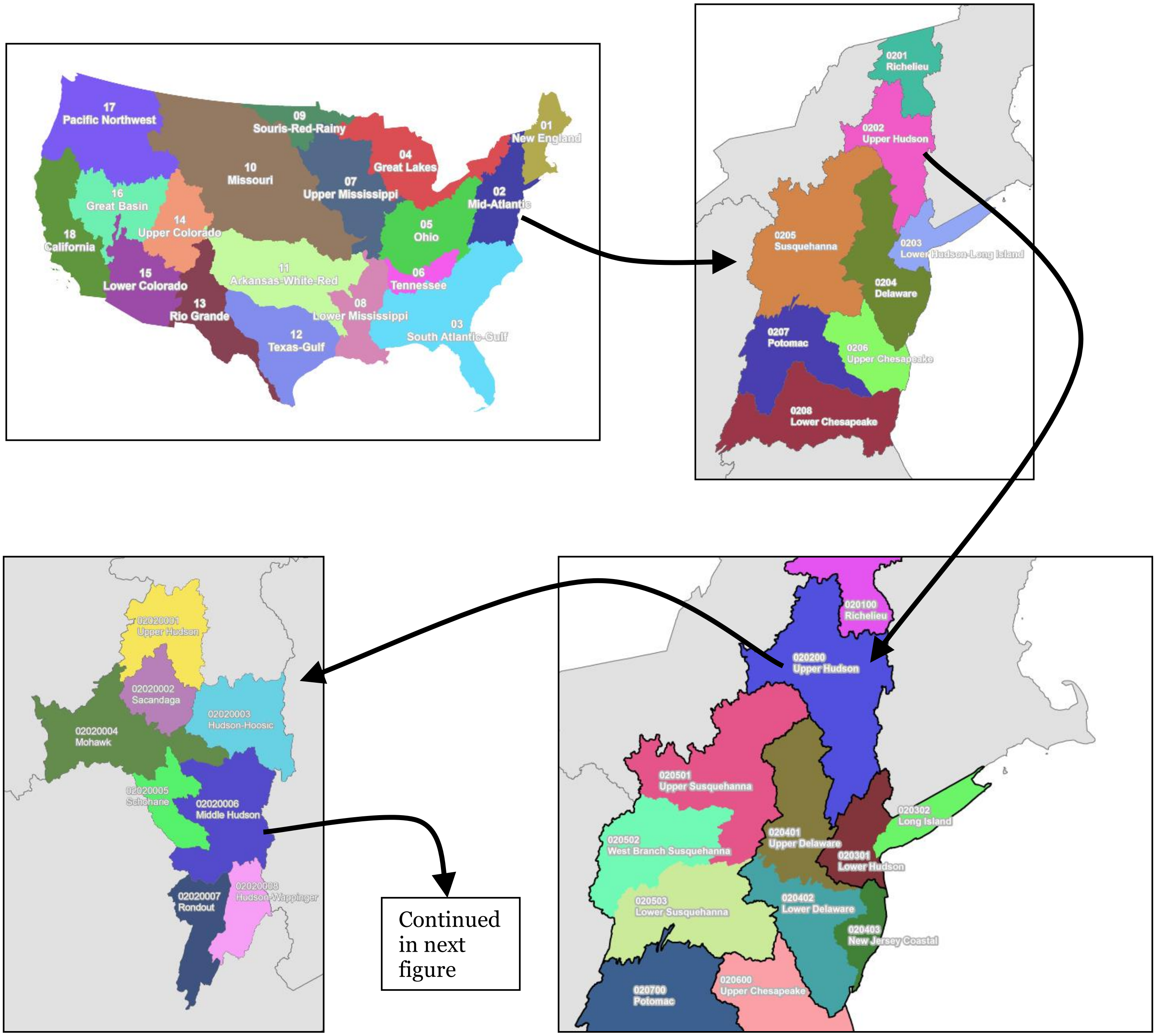


Figure 4 The Conterminous United States is divided into 18 Regions. Alaska, Hawaii, the Caribbean Islands, and the Pacific Territories compose Regions 19-22 respectively. The Mid Atlantic Region is divided into 8 Subregions, which is in turn, divided into 14 Basins. Four of the Basins boundaries are identical to the Subbregions they are a part of. The Upper Hudson Basin is then divided into 8 Subbasins.

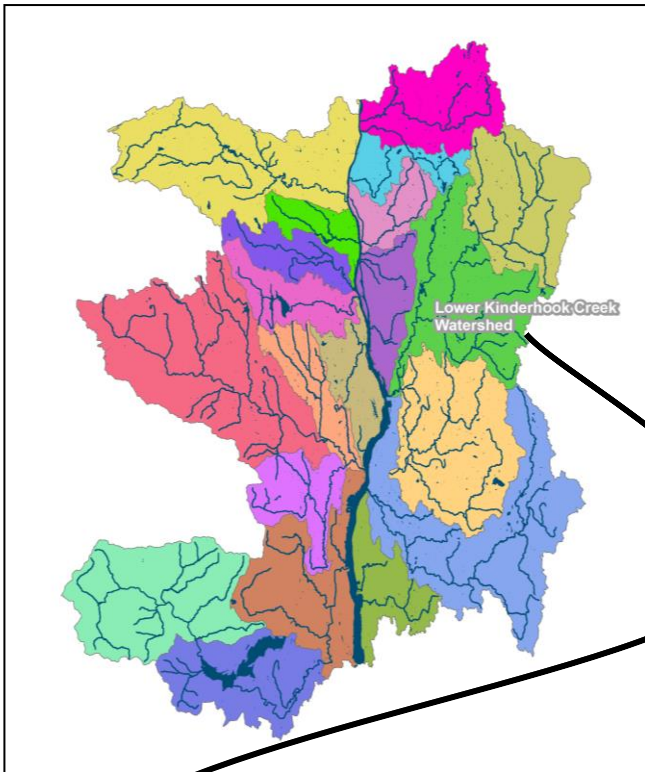
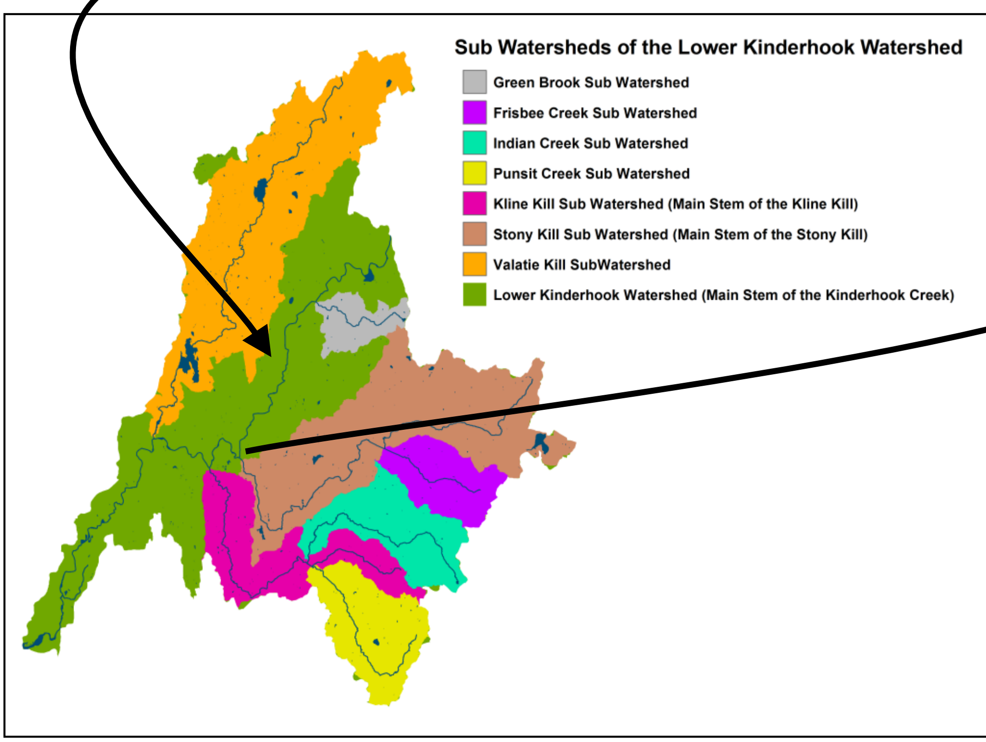


Figure 5 The Middle Hudson Sub basin is divided into 20 Watersheds, which can then be subdivided into a number of sub watersheds, or catchments, depending on the needs of the user.

Catchment area of a small water body within the Lower Kinderhook watershed



Watershed as a System

Watersheds are usually defined in terms describing it as a single, inert physical entity. Watersheds can also be viewed as an active system based on its natural attributes, sometimes referred to as an ecosystem (Lotspeich, 1980). While a watershed and an ecosystem can be equivalent in area, they are not always identical. A single watershed may include multiple ecosystems, and a single, large ecosystem can encompass a number of smaller watersheds. While a watershed can be defined based on topography and water flow, an ecosystem is usually more difficult to define, because it does not necessarily have fixed physical boundaries. A watershed is an unusual type of ecosystem, because it does have well defined boundaries.

The two controlling elements of a watershed system are its climate and geology (topography). Climate supplies the energy and water into the system. Once the energy and water enter the system, the geology of the watershed controls how they proceed through the system. Within the watershed, other elements, such as soil, vegetation, animals, and human activity react to the water and energy. These elements then store that water and energy, and can pass them back and forth among other reacting elements in the system. These elements also influence how the water and energy flow through the system, and in turn, can also influence to some extent the climate within the watershed. Ultimately these elements transport their byproducts to the water body at the bottom of the watershed. The water body that defines the watershed actually plays a very passive role in the entire system. It is at the mercy of all of the other elements in the system, and can only react to all of the other actions occurring within the larger system (Lotspeich, 1980).

Viewing the watershed as an integrated system leads to some interesting observations. Systems can be modeled, and GIS provides an ideal technology to assist in that modeling. A watershed, much like most other systems, has measurable inputs and outputs. While the water entering the watershed cannot be precisely measured, it can be accurately estimated. The water flowing past the point that defines the watershed can also be measured rather easily. By comparing the quantity and quality of the water entering the system, to the quantity and quality exiting the system, one can see the results of any actions that might be occurring within the system. This is one of the fundamental differences between watershed planning and most other planning processes. As long as the plan starts with high quality base data, the influences of the planning strategies used within the watershed can be measured as the plan is implemented.

GIS is more than just a software program running on a computer. A GIS is nothing if it does not have data to feed into it for processing. In addition to the advances on the software side of GIS, there have also been significant advances in the quantity and quality of data available. In addition to the previously mentioned WBD and NHD data sets, high resolution digital elevation models (DEMs) are readily available, as well as soil surveys, land cover, stream gauging station, and Nexrad radar rainfall system data. These last two data sets are unique, in that they can be incorporated into a watershed model as time-series data, producing a four dimensional (time-series) GIS model of an ecosystem. By integrating all of this data into a single database, the geographic information system can be transformed into a hydrologic information system (Maidment, 2002, p. 8).

Geographic data models can be approached in two ways; as an inventory model, or as a behavioral model (Maidment, Morehouse, & Grise, 2002, p. 18). The inventory approach results in a classic GIS database, where elements in the landscape are categorized and combined into discrete layers. Water features such as streams and lakes are combined into one layer. Topography is represented by another. Soils, land cover, and dams are stored in their separate layers. These layers can then be stacked, one upon another to visually analyze their interaction.

In the behavioral approach, there is less emphasis placed on where things are located, and more on how the various elements interact. Streams are shown connected to the lakes and ponds they enter and drain. Soils are given a runoff coefficient so they can be connected to their effect on stream flow or erosion potential. Dams are attributed with their water storage capacity. At first glance, the behavioral approach might appear to be the more sophisticated, and modern way to model the landscape. However, water resource managers have been using this approach for decades. It is a fairly straight forward process to plug these interactions into a spreadsheet, or mathematical equation, and represent the interactions in a schematic form without relying on a GIS.

User friendly GIS software programs have been widely available since the early 1980's, making the inventory approach to geographic modeling much easier to use. Only recently has the technology progressed to the point where GIS can integrate both of these database models. In 2000, ESRI totally reengineered its entire line of GIS software products. Between 2000 and 2002, ESRI and the Center for Research in Water Resources (CRWR) of the University of Texas at Austin, led by David R. Maidment, developed a new geospatial/temporal water resource data model called Arc Hydro. Arc Hydro has become the industry standard for water resource modeling.

Watershed Planning Tools

In 1995, in order to promote the watershed approach and watershed level planning, the EPA produced a pair of documents outlining how individual states can implement the watershed approach, and what elements are required for successful watershed planning projects. One of these documents, *Watershed Protection: a Statewide Approach*, added an additional element to the watershed protection approach; measuring success. Measuring success involves agreement by the stakeholders on what indicators they will use in order to set a baseline for existing conditions, and how to measure the progress and effectiveness of the plan as it is implemented. The other document, *Watershed Protection: a Project Focus*, describes the broad issues that affect watershed projects, and outlines the specific elements found in successful watershed plans. Together, these documents set the stage for a number of watershed planning workbooks describing how various government agencies and private organizations should proceed through a watershed planning process.

In 1998, the Center for Watershed Protection (CWP) collaborated with the EPA to produce the seminal work *Rapid Watershed Planning Handbook: a Comprehensive Guide for Managing Urbanizing Watersheds*. This 336-page book is now out of print, but is still used as a major reference in many watershed plans. The CWP has replaced this book with a new series of planning guides that focus more specifically on urban watersheds (those that contain more than 10% impervious surface). As a result, the EPA has developed its own planning guide, the *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (2008). One of the dilemmas in developing a single authoritative watershed planning guide, is that every watershed is unique. The people, topography, climate, level of development, and political jurisdictions all vary from one region and watershed to the next. The EPA recommends their Handbook be used to supplement other local and state guides that exist for particular areas.

The EPA Handbook mentions some common features of all successful watershed planning processes. Watershed plans are geographically defined, collaborative, integrated, holistic, and iterative (U. S. Environmental Protection Agency, 2005, pp. 2-3). By definition, watershed plans encompass a geographic area defined by the watershed being addressed. Since the watershed boundaries nearly always cross political boundaries, collaboration between the various political entities has to be a priority. The various political entities will probably already have plans drawn up for their specific jurisdictions, which must be integrated into the watershed plan. There is usually not a single "silver bullet" that will fix the problems identified in a watershed. Using a holistic approach will best ensure that all of the measures that need to be taken, are taken, and that all of the impacts of the implementation measures suggested are evaluated. Because watershed plans are very complex, evaluating a watershed plans effectiveness is essential to its success. Even more so than other types of plans, the watershed plan depends on ongoing review and revision to make sure the goals of the plan are being met. Adjustments to the strategies must also be made as necessary.

In order to embrace all of these features, the EPA Handbook describes a six step process for developing and implementing a watershed plan. This six step process is the amalgamation of the three elements of the Watershed Protection Approach, and the three critical components of the Watershed Protection Program.

The CWP's *Rapid Watershed Planning Handbook* (1998) describes an eight step process similar to the EPA document. An outline of the common elements of a watershed planning process culled from the CWP handbook can be found in appendix 2 of this paper.

Figure 6 This table lists the steps for producing a watershed plan recommended in both the EPA and CWP handbooks. The arrows identify the common elements.

EPA *Handbook for Developing Watershed Plans*	**Relationship**	**CWP *Rapid Watershed Planning Handbook***
1-Build Partnerships		1-Establish a watershed baseline
2-Characterize the watershed		2-Set up a watershed management structure
		3-Determine budgetary resources
		4-Project future land use change
3-Set Goals and identify solutions		5-Determine goals for the watershed and subwatersheds
		6-Develop subwatershed plans
4-Design an implementation program		
5-Implement the watershed plan		7-Adopt and implement the watershed plan
6-Measure progress and make adjustments		8-Revisit and update the watershed and subwatershed plans

Overall, most of the guidelines published in print, or online are very similar, differing only in the order things are done, or emphasizing one element over another. One item that the CWP Handbook notably emphasizes more than the EPA Handbook is focusing on the sub-watershed as the primary planning unit. Because the watershed being planned for will usually cover a very large area, CWP suggests it be broken up into more manageable subwatersheds that cover between 1 and 10 square miles each. According to CWP, doing this makes it easier to identify sources of pollution, measure influences of impervious cover, and monitor the effects of the strategies used. The strategies can also be customized and limited to those political agencies that have jurisdiction within the subwatershed. Essentially, a mini-plan is developed for each subwatershed. The following sections describe in more detail the reasons for each step in the process, and how GIS can be used in that step.

Building Partnerships

Building partnerships involves identifying the boundaries of the watershed, the stakeholders involved in the watershed, the issues facing the watershed, and conducting public outreach regarding the watershed. Some issue usually drives the watershed planning process. This issue may be a highly visible environmental problem that needs fixing, a sensitive natural feature that needs protecting, or simply a group of residents that want to evaluate and protect their watershed. Regardless of the driving force, the relevant stakeholders must be identified and asked to commit themselves to the watershed planning process. In order to build the interest and commitment of the stakeholders, an information and education program is often used. The most successful plans often have an outreach sub-committee dedicated to ongoing public and stakeholder education throughout the planning process.

GIS can be a very useful tool for an information and education program. Assembling the various data in layers can reveal the many overlaps in jurisdictions and resources within the watershed. Particular land uses that affect, or are affected by water resources can be identified. Maps are very powerful tools and people love to pour over them and look to identify where their home or business fits into the watershed picture. When people can visualize where they live, what natural features surround them, how the watershed system works, and how their home or business affects that watershed system, they are much more likely to buy into the watershed planning process, and become an involved stakeholder.

In addition to the watershed boundaries, hydrography, and elevation data previously mentioned, some additional useful GIS layers are municipal boundaries, property boundaries, roads, wetlands, bedrock and surficial geology, soils, flood hazards, agricultural districts, and zoning. Depending on the location, parks and historic sites might be inventoried, as well as other types of preserved lands, recreational areas, sensitive plant and animal habitats, and critical environmental areas. This list would not be complete, however, without mentioning two of the more useful and difficult layers to obtain: land cover and aquifer recharge area. These two layers are usually not readily available at a scale useful for a watershed plan. Land cover can be identified using aerial photos, or by using more sophisticated methods as in biodiversity mapping. Groundwater resources need to be ascertained by a hydrogeologist, but is becoming less expensive and more common as the data needed for such studies becomes more readily available. For a comprehensive list of GIS layers available to NYS watershed planners, see appendix 3 of this document.

Putting together a complete GIS database should not be viewed as just a way to assemble a set of maps. It can and should be used as a partnership-building opportunity. While assembling the data, potential stakeholders should be identified, either from within the data itself, or from the providers of the data. As gaps in the data are identified, stakeholders can become involved in the process of filling those gaps. For example, a farmland inventory can be verified or completed by driving around the watershed, and ground-truthing a printed map. New data can be developed by using the local knowledge of streams by sportsmen. Detailed information about municipal water sources, and wastewater treatment plants can help local officials become more interested in the watershed project.

Characterize the watershed

This is the point in the watershed planning process where GIS really shines. Characterizing the watershed involves creating a complete inventory of the watershed, analyzing the data gathered, determining the causes of water quality degradation, and estimating pollutant loads. All of the data available is assembled, and any gaps in the data must be filled, where possible. This is also referred to as assembling a watershed baseline. Future conditions should also be considered. A buildout analysis of the watershed using the existing zoning regulations can give an indication of where future problems might lie. Vacant lands that are zoned for potentially impacting uses won't show up in the existing datasets, but will if a buildout analysis is done.

The first step in characterizing the watershed is to define the scope of the plan. This obviously includes defining the watershed boundaries, but also involves limiting the plan to address a set of specific issues and goals. Watershed systems are very complex, and can include so many elements and variables that if a scope is not determined early in the process, the plan can easily get out of hand, become unmanageable, and in the end, not adequately address the priority issues facing the watershed. The scope must be manageable by the stakeholders involved in the process and the data available. Stakeholders are those people who are intimately involved in the workings of the watershed, or some element within it. Many of the issues to be addressed in the plan will be identified directly from the stakeholders. In addition to stakeholder knowledge, the GIS data assembled at the start of the process will also reveal potential issues. Land uses that are incompatible with adjacent natural features become more apparent when viewed on the same map. Aerial photographs are very useful, especially if historic photos are available for comparison. Stream channels and changes in land use patterns that may influence the watershed can then be evaluated over time. The relationship between drinking water sources and wastewater discharge points can be identified.

Sometimes the GIS layer is produced specifically to identify potential problems. Under the 1972 Clean Water Act, states are required to inventory all of their water resources, identify the best use of that resource (e. g. drinking water, swimming, fishing), and then produce a list of all of the water resources that do not meet their specified best use. These are called 303(d) listed waters, named after the section of the Clean Water Act that outlines these requirements. Watershed plans that specifically address 303(d) listed waters can qualify for additional funding for remediation from the federal government (U. S. Environmental Protection Agency, 2005, pp. 2-16). NYS DEC also maintains a layer that shows land uses requiring a permit from that agency, and another layer that shows hazardous waste sites in need of remediation.

One characteristic of the watershed that should be documented is the level of land use planning being done by the municipalities within the watershed. If the towns and villages all have up to date comprehensive plans, and recently adopted zoning ordinances, they can also be valuable sources of information. They will also serve as the foundation for the buildout analysis mentioned earlier.

Other pieces of information that should be considered, if available, are fish advisory warnings, beach closures, volunteer monitoring data, and biodiversity mapping projects. Local sportsman associations may have information about fish habitat or land areas that support unique or changing wildlife populations. Some of these data sources might not be readily available, or not be available for the entire watershed, but they can be very valuable in identifying issues that need to be addressed.

Ultimately, the goal of all of this data collection is to produce a complete picture of the watershed that reveals the most pressing problems that need attention. The watershed planner should remember that data gathering is not the goal of the plan. The data does not have to be "perfect", only complete and accurate enough to identify the problems, and the sources of those problems.

Two of the most useful characteristics of the watershed to identify and evaluate are impervious surface and pollutant loads. Impervious surfaces are surfaces that can not infiltrate rainfall. These are usually man-made surfaces, such as rooftops, pavement, sidewalks, driveways and compacted earth. Pollutant loads are simply the amount of a particular pollutant that is found in a water body. Pollutants can be pathogens, metals, nutrients, sediments or temperature.

As farms, forests and wetlands are converted to buildings roads, and lawns, impervious surfaces are created. The amount of impervious surface found within a watershed has a profound effect on the hydrology of the watershed (Center for Watershed Protection, 1998, p. 1.8). Water runs off these impervious surfaces at a far faster rate than from forest or grasslands. Any pollutants found on these surfaces are also carried directly into the water. There is increasing evidence that watersheds containing greater than 10% impervious surface have a greater chance of containing degraded steams. The larger the percentage of impervious surface, the greater the impacts are on the receiving water body.

In order for a water body to support its intended use, be that swimming, fishing, or water supply, the amount of pollution in that water body has to be limited. The Clean Water Act requires that total maximum daily loads (TMDLs) be set for all of the waters in the United States that do not meet their intended best use. This rule, however, has been slow to be implemented, so not all impaired waters have TMDLs set. Where TMDLs have not been set, or for water bodies that are not impaired to the point of requiring a TMDL, pollutant loads can be estimated by the watershed planning group. Pollutants can be measured directly through a monitoring program, or estimated by evaluating the land uses surrounding the water body. Mathematical models can also be used to estimate pollutant loads, and to predict changes in those loads once the strategies are identified.

Set Goals and identify solutions

The goal setting process can start during the scoping phase of watershed plan development, but must be refined after the watershed has been fully characterized. Combining all of the information gathered from the stakeholders and the data acquired, the watershed planner should have a detailed picture of what the specific problems in the watershed are. The goals and objectives of the plan are simply to correct the identified problems. The strategies are the specific actions taken to reverse these problems. Remembering that watershed plans should rely on sound science to justify the decisions made, the goals and strategies should be linked to specific measurable indicators that will help identify progress toward those goals. The EPA Handbook emphasizes the reduction of pollutant loads because of the EPA's focus on TMDL. The CWP Handbook includes reduction of pollutant loads as a likely goal, but also includes examples such as reducing wetland loss, limiting flood-plain development, and accommodating economic development as possible goals (Center for Watershed Protection, 1998, p. 3.24).

The GIS database assembled in the initial stages of the watershed plan development usually plays a small role during goal setting and strategy development, but can be very useful. By keeping the maps and data handy for frequent review, the relationship between the strategies decided upon can be assessed. By comparing the zoning district map with the goals of a particular area, the planners can determine if a change in the zoning is needed, or if the current zoning is adequate. If improved stream buffers are called for, it's easy to see where they are needed, or where they exist and need to be preserved. Farms that do not have erosion control plans in place can be identified and specifically targeted in the strategies. Open land can be mapped and prioritized for purchase or preservation purposes.

Design an implementation program

A plan is not complete until it is implemented. No matter what the watershed plan calls for, or how well it is written, if the strategies are not applied the goals will not be achieved. The watershed plan's implementation program should have both a schedule and a budget. The implementation program should outline how technical and financial assistance is to be secured, and assign responsibility to the stakeholders for continued reviewing and revising of the plan. Milestones should be set to measure progress along the way. The implementation plan should also include the specific criteria to be measured, in order to show progress towards the plan's goals. An educational component is also useful for gaining public support for, and participation in the plan.

At this point, the GIS becomes more of a mapping and tracking exercise, rather than an analysis tool. During the baseline development phase, the goal was to assemble an all-encompassing, comprehensive database. Now, the GIS database can be whittled down to represent just those items that are targeted by the strategies. The strategies can focus on specific parcels, stream reaches, or subwatersheds, and discrete locations can be identified where impacts can be easily assessed. As these strategic locations are added to the watershed map, they then become the starting point for measuring the progress towards implementation of the plan, providing a bridge between strategies and implementation. A plan for updating the GIS data on a regular basis will also help track changes within the watershed that are not a result of the plan, such as land use changes.

Implement the watershed plan

When implementation of the plan begins, the dynamics of the planning group will change (Environmental Protection Agency, 2005, p.13-2). The stakeholders assembled for the plan are no longer thinking about what should be done, but being asked to follow through with the strategies outlined in the plan. Sometimes, this means a significant change in the planning group's participants. It is critical that any new group members brought onboard are committed to the goals of the plan, and invest themselves in implementing the plan. In order to ensure the strategies in the plan are properly applied, a work plan can be used, which describes the implementation measures that are to take place within certain time-frames.

The GIS becomes more static at this point. The data might not change, but it can still be used during implementation. As public outreach and education continues through all phases of the watershed plans life, the GIS can be used to produce posters, pamphlets, websites, and other graphic materials that show how the plan is being implemented.

Measure progress and make adjustments

As the plan is implemented, progress is continuously tracked, measured, and reviewed. The watershed group receives feedback from stakeholders and makes adjustments as necessary. The effectiveness of the strategies is measured, and consequences are evaluated. This is where watershed monitoring comes into play. The GIS database is updated as the strategies are applied. Any noticeable changes in water quality are documented. The data should be archived on a regular basis to provide a history of the changes resulting from the strategies.

If any models were used to predict the effects of the strategies, they can be re-run using actual monitoring data. Models are also useful for extrapolating data. Monitoring in just a few strategic locations is much more cost and labor effective than trying to cover the entire watershed with monitoring equipment.

The Wallkill River Watershed Conservation and Management Plan

The Wallkill River watershed conservation and management plan (Wallkill River watershed plan) is a useful example of a watershed planning project. The watershed crosses a number of town, county, and even state boundaries. It contains a variety of land uses and associated real and potential impairments. The variety of impairments requires the use of many different strategies. The planning group also made extensive use of GIS throughout the planning process. The following paragraphs describe the process the planning group followed, and shows a number of ways they incorporated GIS into their decision making. All of the information in the following sections is taken from the plan document, which is available on the Ulster County Soil and Water Conservation District website at: www.ucswcd.org

Background

The Wallkill River begins flowing from Lake Mohawk in New Jersey, and then travels 93 miles on its way to the Hudson River in New York State. It drains 806 square miles in 47 different municipalities, located in four different counties. Land uses within the watershed range widely, from forestland and agriculture, to high density residential and intensive commercial. Land use trends in the watershed are towards less agricultural and forest lands and more urban and suburban uses, similar to most other watersheds in the region. This growth has led to increasing concerns about water quantity and quality, and loss of wildlife habitat.

Plan Development/Approach

The Wallkill River watershed plan follows closely the procedure outlined in the CWP's *Rapid Watershed Planning Handbook*. In fact, several of the project's stakeholders attended a two-day workshop facilitated by CWP staff in July of 2005. Funding was supplied by a $40,000 grant from the NYS DEC Hudson River Estuary Program. The formal planning process began in September, 2004, when 40 stakeholders met to identify the major issues facing the watershed. The top issues identified, were:

1. Buffers, as a way to protect water quality
2. Biodiversity and habitat loss, both terrestrial and aquatic
3. Regulations, both their enforcement and funding of implementation measures
4. Recreation, increasing access to the Wallkill River
5. Wastewater, failing septic systems and the capacity of existing treatment facilities
6. Pesticides and other pollutants, particularly those associated with agriculture, and urbanization
7. Agriculture, its positive impacts on the economy, and its negative impacts on water quality
8. Development, causing loss of habitat and increasing stormwater runoff
9. Wetlands, loss and degradation
10. Groundwater, both quantity and quality
11. Local planning, and public awareness
12. Non-point source issues, which includes many of the other issues, but particularly stormwater runoff

A committee structure was set up, made up of 26 individuals from 23 different state, county, and local government agencies, and private organizations. Most of these plan partners were from the Ulster and Orange County Soil and Water Conservation Districts and Planning Departments. Some were from the various town and village governments, State agencies, and not-for-profit organizations. There were also representatives from the farming community, and from private consulting firms.

As recommended by the CWP, the watershed was broken up into smaller subwatersheds for individual analysis. This resulted in 14 separate study areas within the larger watershed. These subwatersheds were then categorized and grouped according to the percentage of impervious surface found in each. As the CWP Handbook explains, there is strong evidence that suggests impervious cover is linked to the quality of other subwatershed water resources (Center for Watershed Protection, 1998, p.1.8). If two or more subwatersheds share similar levels of impervious cover, they may also suffer from similar types of impacts, and therefore respond well to similar sets of strategies.

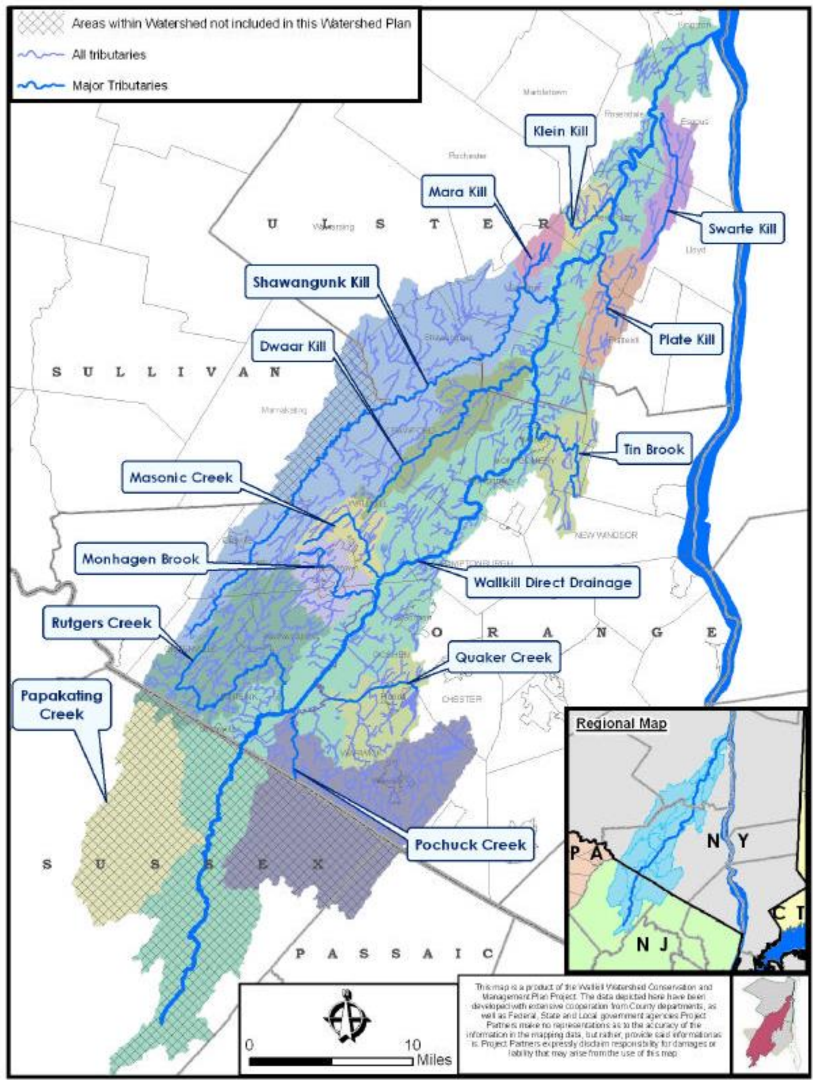


Figure 7 Wallkill River subwatersheds (Ulster County Soil and Water Conservation District, 2007, p. 10)

Goals and strategies were applied to the subwatersheds depending on their unique problems. These strategies range widely, due to the extreme diversity of the land uses found throughout the watershed. Strategies for subwatersheds containing a high number of agricultural operations, for example include coordinating a regional manure composting system for horse farms, and establishing riparian buffers where cropland is currently tilled up to the stream banks. Subwatersheds containing more suburban development will need to focus on stormwater treatment. The recommendations here include both stronger enforcement of the existing rules, and retrofitting older subdivisions that were built before those rules were adopted.

Use of GIS

It is obvious by looking through the Wallkill River watershed plan that GIS was used extensively during the planning process. The document contains 19 maps, graphics, charts, or tables that rely directly on GIS data for their production. In the introduction, it is recognized by the editors that planning efforts as recent as the late 1980's were "...not as sophisticated as current-day watershed management plans supported by computer generated maps and other new technologies." (p. 6).

Beyond the usual assembling of data layers to produce maps of the various features in the watershed, the planning group used GIS in a number of innovative ways. They made determining the amount of impervious surface in each subwatershed a priority. After evaluating a number of options, the planning group decided on a methodology using linear feet of road per a given area to calculate impervious surface for each subwatershed. They also used historic aerial photos to identify stream channel changes. Land use change was evaluated by comparing past assessment role data to present data. 2004 aerial photos were used to inventory land cover within 534 feet of all 14 of the major tributaries within the watershed.

Observations

Despite the large size of the Wallkill River watershed, and the diversity of the land uses found within it, the Wallkill River watershed planning group was able to put together a complete and workable plan with a total budget of $40,000. As stated in the plan (p. 8), the CWP recommends a budget of $150,000 to $200,000 for a watershed plan covering less than 50 square miles. The planners recognize in their conclusion (p. 64) that only a very dedicated group of volunteers, in addition to the extensive use of GIS, made it possible to put together a plan that fully addresses the many unique issues facing the communities in the watershed.

Conclusion

Watershed planning and GIS have not only grown together, they have benefitted from each other along the way. GIS technology has benefitted from the movement towards planning at the watershed scale. Tools are not usually developed unless there is a need for them. While GIS was not developed specifically for watershed planning, elements of it have been. Watershed planners have used mathematical and schematic models in their work for many years. The Arc Hydro data model represents the leading edge of this evolutionary/revolutionary process. As Merwade and Maidment explain it,

> What is emerging is a new kind of technology that might be called a “hydrologic information system”, defined as a structured database of geospatial and temporal water resources data, combined with tools for information processing, which supports hydrologic analysis, modeling, and decision making (2000, p. 170).

The technology and lessons learned from the Arc Hydro data model have been applied to a number of other data models developed for Arc GIS, for other planning areas.

Watershed planning has benefited greatly from advances in GIS technology. GIS allows planners to work much more efficiently and effectively. As the Wallkill River watershed plan points out, their planning group saved tens of thousands of dollars by using GIS to characterize and analyze their watershed. The growth of the EPA's watershed protection program would not have been possible without the ability to assemble, develop, and distribute vast amounts of watershed related data using GIS technology.

There are some pitfalls that must be avoided when using GIS for watershed planning. The technology is very complex. While the Arc Hydro data model represents the ultimate tool in watershed planning, the effort, knowledge, and data needed to use it effectively precludes it from being used for most small watershed plans. The GIS operators need to be intimately familiar with the watershed planning process. Too often, the GIS work is done by a separate department within a planning firm, or is subcontracted to a GIS consultant that knows the technology very well, but doesn't know how it fits into the watershed planning process. Conversely, the watershed planner must be educated in GIS. Inexperienced users can draw some inappropriate conclusions if the technology is not used correctly.

GIS helps planners to understand relationships of the elements within the watershed and how they work together. In my experience however, planners don't fully realize the impact GIS has on the way they work, or the benefits it provides. For example, the seemingly simple act of assembling the various data layers needed for the watershed plan puts the planner in close contact with immense amounts of information about the watershed and the people who live there.

Watershed planning projects using GIS can help overcome many of the disconnects described at the beginning of this paper. I view the watershed protection approach being promoted by the EPA as a movement toward the increased direction from the federal government called for by Tarlock and Luciero (2002). Watershed planning requires bringing together the various parties responsible for making water supply, planning, growth, and budgeting decisions. It brings together decision makers from all levels of government. It uses an inclusive, participatory process. It uses sound science to support the decisions made, and it includes continuous monitoring to measure the effectiveness of the decisions made. It moves us in the direction of a more sustainable environment available to future generations, without requiring a constitutional amendment to do so.

Appendices

Appendix 1- Water Resource Planning Time Line

This timeline was assembled using information from Buie (1979) and the National Research Council (1999)

- 1850 The US Army Corps of Engineers (ACOE) authorized to develop a plan to control flooding along the Mississippi River
    - After evaluating two different approaches, ACOE decided on a "lower-river levees only" approach to flood control, which neglected the influences of up-stream tributaries and land uses
- 1899 River and Harbors Act
    - Authorized the ACOE to regulate dumping into navigable waters
- 1902 Reclamation Act
    - Created the Reclamation Service (Bureau of Reclamation)
    - Federal agency responsible for irrigation and hydropower development
- 1906 Inland Waterways Commission
    - Appointed by President Theodore Roosevelt, and charged with preparing a comprehensive plan for the improvement and control of U.S. river systems
- 1911 Weeks Act
    - Authorized the Secretary of Agriculture to plan for, and purchase land necessary for regulating the flow of navigable streams and rivers
- 1917 USDA research station in Tennessee
    - Conducted experiments measuring rainfall and runoff within six small watersheds
        - These tests formed the basis of the "rational method" of computing the maximum rate of runoff during a given rainfall event

- 1920 Federal Water Power Act
    - Authorized the licensing of non-federal development of water power on public waterways and land.
- 1927 Rivers and Harbors Act
    - Authorized the ACOE to inventory and assess all navigable streams for their ability to support navigation, flood control, irrigation, and power. These surveys were known as 308 reports; the first comprehensive national river basin development plans.
- 1928 McSweeny-McNary Forest Research Act
    - Authorized the Secretary of Agriculture to investigate ways to maintain water flow and the prevention of erosion
- 1933 Tennessee Valley Authority
    - Based on the 308 plan for the Tennessee River Basin
- 1933 – 1943 series of National Resource Planning Organizations
    - 1933 National Planning Board
        - Developed multi-purpose plans for 10 river basins
    - 1934 National Resources Board
        - Recommended planning water projects by considering entire drainage basins, including all of the water resources and land uses within them
    - 1935 National Resources Committee
        - A nationwide study of drainage basin problems and programs
    - 1939 National Resources Planning Board
        - Authorized to analyze water problems, and to report to the President and Congress
        - Their reports recognized the need for a comprehensive approach to drainage basin management.
- 1935 Soils Conservation Act
    - Formation of the Soils Conservation Service (now the Natural Resources Conservation Service, NRCS)
    - Congressional policy to provide for the control of soil erosion, control

of floods, and to maintain reservoirs and navigable rivers

- 1936 Flood Control Act
    - Recognized the need to incorporate tributaries and upland areas in controlling downstream flood problems
    - Required the ACOE to subject all projects to a benefit-cost analysis
        - The costs of water projects should not outweigh the value of the benefits provided by that project
- 1937 Water Facilities Act
    - Provided for water storage projects in arid areas of 17 western states
    - Included conservation management plans for farms
- 1943 Federal Interagency River Basin Committee (FIARBC)
    - Formed to resolve competition between ACOE and the Bureau of Reclamation
- 1944 Missouri River Basin Plan
    - Pick-Sloan Plan, part of the Flood Control Act amendment
        - 5 dams on the Missouri River
        - 103 dams on upstream tributaries
        - 36 major reservoirs proposed
        - Flooding of 900,000 acres of farmland and 20,000 citizens
        - 18 million dollar loss in annual agriculture production, which was 3-4 times the amount to be saved in flood loss
        - Realization that a program was needed that controlled the water from the time it hit the ground, all the way to the time it entered the major waterways
            - In other words, taking a comprehensive approach to river basin management
- 1944 Flood Control Act
    - Implemented 11 watershed reports
    - Initially consisted of improved land use measures, and did not include any structural improvements
- 1948 The Federal Water Pollution Control Act

- the first major U.S. law to address water pollution

- 1949 Young Plan
    - Reworking of the Pick-Sloan Plan
    - More coordination between various federal agencies
    - Relied on over 14,000 upstream structures to control flooding over an area covering $^{1}/_{6}{}^{th}$ the area of the United States
- 1950 Presidents Water Resources Policy Commission
    - Made recommendations for interagency cooperation
    - Identified standards to be used for evaluating water projects
- 1954 Watershed Protection and Flood Prevention Act
    - Authorized the USDA and SCS to provide technical and financial assistance to local watershed groups
    - Emphasis placed on smaller watersheds, initiated by local people, using local matching funds.
    - Limited the size of structures used to store water
- 1965 Water Resources Planning Act
    - Formation of the executive level Water Resources Council
    - Framework for establishing interagency commissions
    - Required establishing standards and procedures for preparing and evaluating comprehensive regional river basin plans
- 1969 National Environmental Policy Act
    - Required public participation in the planning process
- 1970 Environmental Protection Agency formed by executive order
- 1972 Federal Water Pollution Control Act (Clean Water Act)
- 1986 Water Resources Development Act (amendments to the 1974 Act)
    - Required cost-sharing of the construction costs of projects
- 1990 The EPA begins promoting the Watershed Protection Approach to water resource management

Appendix 2 - Typical Watershed Management Plan Process

(Assembled from the Center for Watershed Protection's *Rapid Watershed Planning Handbook*, 1998)

- Map the geographic extent of the Watershed Plan
- Identify sub-watersheds
- Identify stakeholders
    - Federal Agencies
    - Sate and local agencies
    - Non-Profit Organizations
    - Private sector
    - Other citizens
- Establish a watershed baseline
    - Identify technical, human, economic resources
    - Identify land uses and impervious cover
    - Assemble historical monitoring data
    - Assess existing mapping resources
    - Conduct an audit of local watershed protection capability
        - Number of stormwater management waivers granted per year
        - BMPs inspected per year (percentage of total)
        - Maintenance operations per those required
        - Plan review backlog
        - Staff per construction site
        - Number of construction sites, and total disturbed area
        - Grading and building permits issued
- Bundle sub-watersheds with similar sets of problems/conditions
    - Identify impaired waters
        - Biomonitoring - fish
        - Citizen/volunteer monitoring – macro-invertebrates
        - Channel assessment
- Project future land use change

- Develop goals for the watershed, and sub-watersheds
    - Pollutant load reduction
    - Wildlife migration
    - Greenways
    - Flood control
    - Include water quality standards in setting goals
- Prioritized implementation strategies
    - The eight tools of Watershed Protection
        - Land Use Planning
        - Land Conservation
        - Aquatic Buffers
        - Better Site Design
        - Erosion and sediment control
        - Stormwater BMPs
        - Non-stormwater discharges
        - Watershed stewardship programs
- Include cost estimates for implementation
- Identify funding sources
- Integrate with other planning efforts within the watershed
- Identify opportunities for collaboration and participation of stakeholders
- Set up a watershed management structure
    - Government directed
    - Citizen directed
    - Hybrid Model

Appendix 3 - A list of GIS layers readily available to watershed planners in NYS, through the NYS GIS Data Sharing Cooperative website

(This list was assembled by the author over many years working as a GIS consultant, with the primary source of information being the New York State Office of Cyber Security and Critical Infrastructure Coordination's GIS Clearinghouse website.)

Layer	Source	Description
Municipal Boundaries	NYS OCSCIC	State, County, Town, City and Village Boundaries
Tax Parcel Boundaries, and attributes	County-Office of Real Property	Property boundaries, owner information, property class, assessed value, etc.
Roads	NYS OCSCIC and some County Govs.	Public Roads
Railroad Lines	OCSCIC	Railroads and Stations
1:24,000 scale Hydrography	NYS DEC	Water, Streams, Stream Classification, HUC, Smaller Wetlands
Freshwater Wetlands	NYS DEC	NYS Designated Wetlands
National Wetlands Inventory	USFWS	Very detailed inventory and classification of Open Water, Rivers, Estuaries, Streams, and Wetlands
Flood hazards	Federal Emergency Management Agency	100 and 500 year flood hazard zones
Soils	US Natural Resources Conservation Service (NRCS)	Digitized version of County Soil Survey. Identifies primefarmland, hydric soils, on-site septic system suitability, depth to bedrock and water table, erosion potential, etc.
Digital Elevation Model	US Geological Survey and NYS DEC	Elevation, Hillshade, Slope, Aspect, Contours, Viewshed, Watershed delineation, Stream network generation
Digital Orthophotos	NYS Dept. of State	Orthorectified aerial photos for the entire State
Agricultural Districts	CUGIR and Individual Counties	Agricultural Districts
NYS Parks, and Historic Sites	NYS OPRHP (Office of Parks Recreation and Historic Preservation)	State Parks, Historic Sites, and some other State owned properties
National Register Sites	National Park Service	Sites on the National Register of Historic Places
Sensitive Plant and Animal Habitats	NYS Natural Heritage Program	
Public Land Boundaries	OCSCIC	Adirondack and Catskill Park Boundaries; Federal, NYS, County, and Municipal Recreational Properties; Federal and NYS Non-Recreational Properties; Airports; NYC Water Supply Reservoirs; Indian Reservations
State and Federal Trails, local trails	NYS DOT, and local sources	Hiking and Biking Trails, incomplete, no ADK or Catskill Park Trails
Public Boat Launch Sites	NYS DOT	Public Boat Launch Sites
USGS Quadrangles	ESRI	24K, 100K, and 250K Quad Reference Layers

School District Boundaries	NYS Office of Real Property Services	School Districts
Hydrologic Unit Code Maps	USGS	Drainage Basins and Watersheds
Empire Zones	Empire State Redevelopment	NYS Empire Zones
Bedrock Geology	NYS Department of Education	Bedrock Geology
Surficial Geology	NYS Department of Education	Surficial Geology
Preserved Properties, Conservation Easements, Public Preserves, Public Access Holdings	CLC, Scenic Hudson, TNC, DLC, CCCD, BNRC, Mohonk Preserve	Property holdings
Open Space and Recreational Properties	NYS DEC, and local sources	State Forests, Forest Preserves, Wildlife Management Areas, Unique Areas, Campgrounds, etc.
State Coastal Area Boundary	NYS Dept. of State	Designated Coastal Area Boundary
Scenic Areas of Statewide Significance	NYS Dept. of State	Areas within the Coastal Area identified as significantly scenic
State Significant Coastal Fish and Wildlife Boundaries	NYS Dept. of State	Areas within the Coastal Area with containing important habitats
Canal System	NYS Canal Corporation	Canal System, Locks
Catskill Park Boundary	NYS DEC	
ADK Blue Line	Adirondack Park Agency	
APA Land Classification	Adirondack Park Agency	APA Land Use regulations
APA Rivers, Wetlands, and Other APA specific layers	Adirondack Park Agency	
Digital Raster Graphics (DRG)	USGS	Digitized topographic maps
Real Property Data (Centroids)	NYS Office of Real Property Services	Property ownership information
National Hydrography Dataset (NHD)	USGS	Water Features and Stream Networks
Small Public Land Sites	NYS DOT, and local sources	Historic Sites, and other government properties, very limited coverage
Remedial Sites (formerly Inactive Hazardous Waste Sites)	NYS DEC	DEC classified Hazardous Waste Remediation Sites
Water and Wastewater Facilities	NYS Dept. of Health, Local sources	Dept of Health Regulated Water Supply Systems, List - not geocoded
DEC Permitted Facilities	NYS DEC	Projects or Operations needing permits from NYS DEC, not up to date
Census Demographics	US Census Bureau	

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