Tools For the Source Water Assessment Program Trade

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Abstract

Implementing a source water assessment program (SWAP) for large complex systems is an extremely cumbersome and expensive task. This paper describes how the combination of Microsoft Access®, ArcView® and ArcInfo® was creatively used to streamline and reduce the level of effort on two such projects. The first project is at the Philadelphia Water Department for several surface water intakes and the second project is at Nassau and Suffolk counties in Long Island, New York for a complex groundwater system. The efficiencies realized by using these tools and pitfalls to avoid will be presented.

Background

Surface Water SWAP

Protecting, maintaining, and improving the quality of a community's water supply is vital for its sustenance and development. Local, state and federal agencies have all been promoting various approaches and concepts to protect valuable water supply resources. The Safe Drinking Water Act Reauthorization in 1996 included a specific component for source water protection called the Source Water Assessments (SWAs). The SWAs process involved water suppliers, watershed organizations and other stakeholders, and identified the protection priorities of the water supply. As part of its federal requirement to conduct the SWAs, the Pennsylvania Department of Environmental Protection (PADEP) sought to involve water suppliers and the community in the SWA process. It is believed that the partnership approach will increase the potential for public, community, and water supplier involvement to address source water issues after the assessments have been completed.

Using this partnership approach, the SWA Partnerships were formed for the Schuylkill River and the Delaware River Watersheds. The partnership includes water suppliers working with the state to conduct the assessments. The PWD has partnered with other water suppliers to lead the SWA Partnerships and conducted source water assessments for 42 surface water supplies within the Schuylkill River Watershed and 8 within the Delaware River Watershed. The Schuylkill River watershed included over 3,000 contaminant sources while the Delaware River watershed included over 5,000 sources.

To efficiently and cost-effectively develop such a large-scale SWAP, a uniform and comprehensive prioritization process was established. Without extensive use of GIS and database management tools, this process could not be completed in a timely and cost-effective manner.

Schuylkill River Watershed. The Schuylkill River Watershed is over 130 miles long, includes over 180 tributaries, and drains an area of 2,000 square miles. The watershed is located in southeastern Pennsylvania and is comprised of 11 counties and over 3 million residents. The headwaters of the Schuylkill River drain approximately 270 square miles of Schuylkill County and flow in a southeasterly direction into the tidal waters at the river's confluence with the Delaware Estuary at Philadelphia. Figure 1 displays the entire Schuylkill River Watershed, its subwatersheds and tributaries.

Delaware River Watershed. Originating in the Catskills (Schoharie County), New York to the mouth of the Delaware Bay in Philadelphia, Pennsylvania, the 330 mile-long Delaware River winds its way through four states on the eastern coast of the United States, encompassing 42 counties and 838 municipalities in the Mid-Atlantic Region of the country. The Delaware River flows southeast for 78 miles through rural regions along the New York-Pennsylvania border, heads southwest, along the border between Pennsylvania and New Jersey. It turns southeast again at Easton, PA, where the Delaware River is met by the Lehigh River (its second largest tributary). The Delaware then flows approximately 80 miles to the tidal waters of Trenton, New Jersey, thus completing about 200 miles of its 330-mile journey. About 30 miles downstream of Trenton, the river passes through the fifth largest metropolitan region in the nation—the heavily industrialized Philadelphia (PA)/Camden (NJ) area—and the mouth of the Schuylkill River, its largest tributary, which flows into the Delaware. From there, the river flows on past Wilmington, Delaware and through the more rural regions of Cape May, New Jersey on its eastern shore and Cape Henlopen, Delaware on the west, completing its course as it meets the Delaware Bay. Along its route from the headwaters to the mouth of the bay, the Delaware River drains a total of 13,539 square miles (0.4% of the land mass in the U.S.) in New York, Pennsylvania, New Jersey, and Delaware.

The Delaware River, its bay, and 216 tributary streams play a significant role in sustaining life and the economy in these areas. Among other things, these bodies of water are used for fishing, transportation, power, cooling, recreation, and other industrial and residential purposes. Most importantly, though, they provide drinking water for about 17 million people. Figure 2 presents a map of the entire Delaware River Drainage Basin, its major subwatersheds, and its tributaries.

Figure 1 - Schuylkill River Watershed

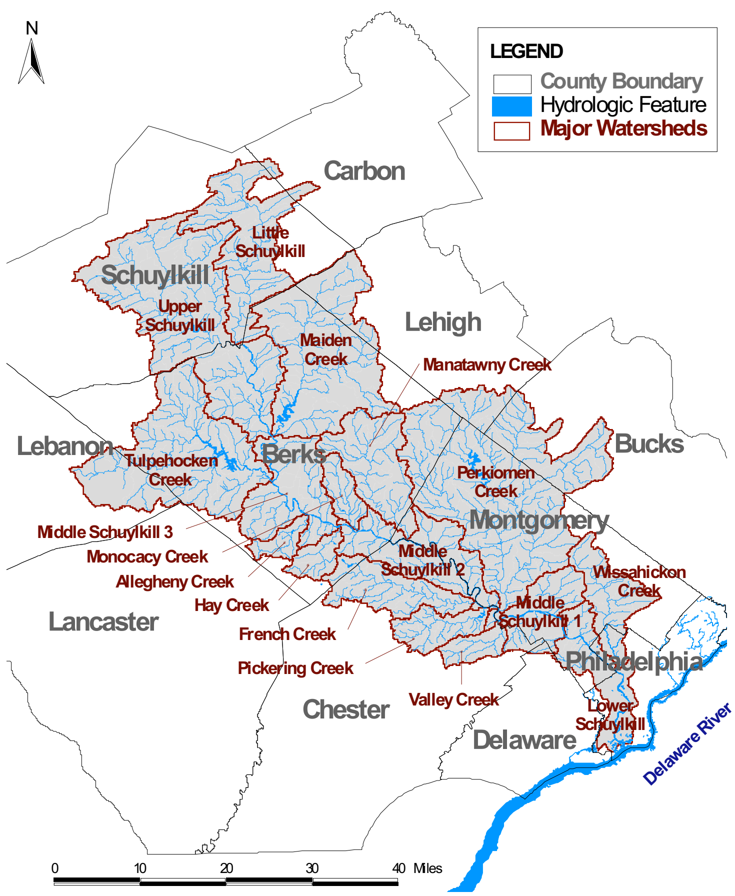
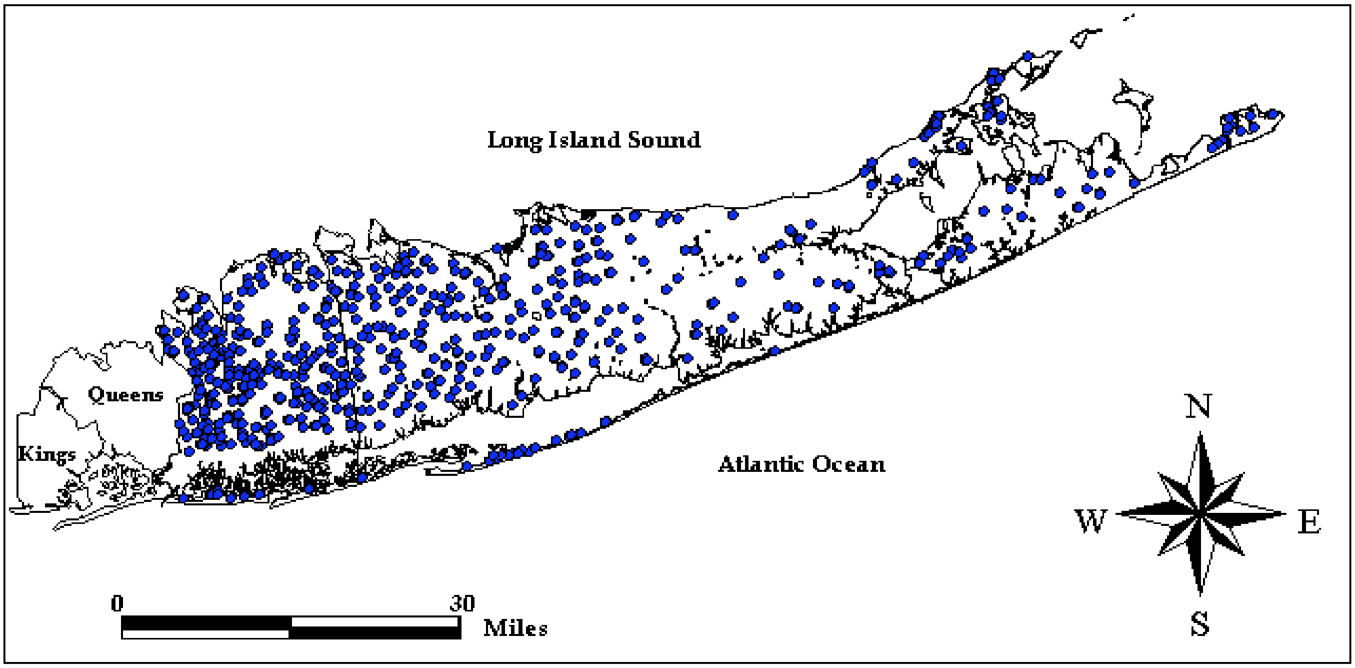


Figure 2 - Map of Delaware River Drainage Basin

Groundwater SWAP

Nassau and Suffolk counties, located in the eastern portion of Long Island, New York, depend entirely on groundwater sources for their drinking water supply. Over 1400 public supply wells provide potable water to the residents of Nassau and Suffolk Counties. To comply with federal and state requirements for assessing the susceptibility of the drinking water systems to various contaminants, a comprehensive source water assessment program was undertaken by the New York State Department of Health (NYSDOH), Nassau and Suffolk Counties and Camp Dresser & McKee (CDM). Each active community and non-community supply well was identified, using databases provided by Nassau County Department of Public Works (NCDPW), Nassau County Department of Health (NCHD), and Suffolk County Department of Health Services (SCDHS). A source water assessment was completed for each well, and the results were summarized in individual well reports, each of which is comprised of a set of tables, accompanied by two figures. Figure 3 shows a map of the community wells that were assessed using the innovative approach described in this paper.

Figure 3 – Community Wells in Study Area



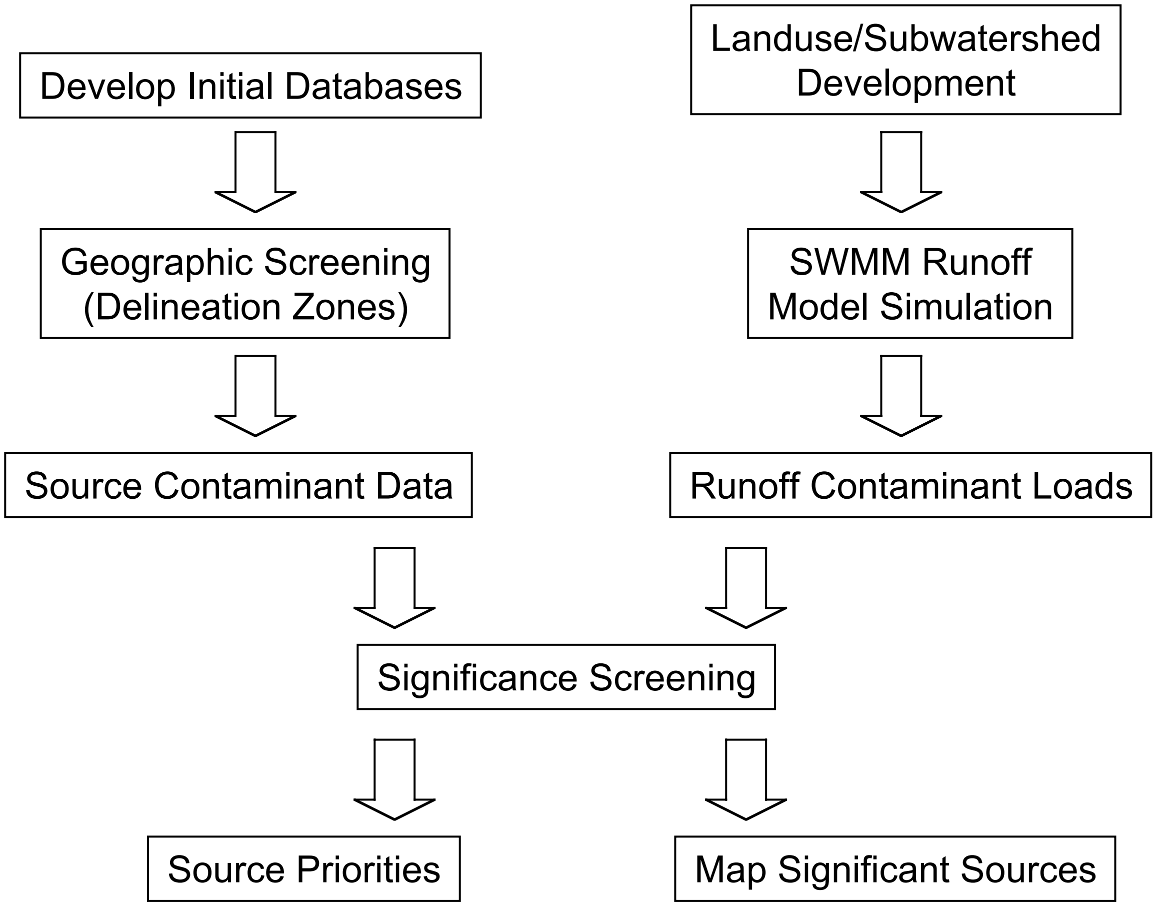
The Overall Process

Surface Water SWAP

In general, the surface water SWAP process consists of identifying potential sources of contamination to water supply intakes, evaluating the impacts and assessing and prioritizing risks to the water supply. Each of these elements is data intensive and requires processing of significant amounts of spatial and other data. Without GIS and database tools, it is almost impossible to successfully complete these projects. The following provides some general descriptions for the overall process in the surface water and the groundwater SWAPs.

As a result of the large number of potential sources of contamination that have been identified, the method behind the susceptibility analysis relies on a process of successive screenings. These screenings help focus the efforts of source water protection on those sources that have the greatest potential to affect the water quality of the source water at an intake. The source prioritization process is shown in Figure 4.

Figure 4 - Source Prioritization Flow Diagram



Contaminant Categories. There are two difficulties in trying to prioritize potential sources of contamination of the drinking water. First, due to the size of the watersheds, there are thousands of potential sources to be assessed. In addition, the assessments must also cover a full range of contaminant types. The SWA approach groups all potential contaminants into a limited number of contaminant categories, and then assesses all sources for each of the contaminant categories. For this study, ten contaminant categories have been developed. For each category, a planning level threshold concentration based either on ambient water quality in the river, or on regulatory standards such as the drinking water standard has been developed. This threshold value is used as a relative measure of the significance of contaminant concentrations that could potentially occur due to a spill or discharge from each of the sources. The major contaminant categories include:

- *Non-Conservative Contaminants:* Total/Fecal Coliform, Turbidity, volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and metals
- *Conservative Contaminants. Cryptosporidium/Giardi,* Nitrate, disinfection by-products (DBPs), petroleum hydrocarbons, and salts

Screening Processes. Potential source data comes from a number of data sources, and each database can contain hundreds of potential sources. Less significant point sources needed to be screened out, leaving only the most important sources for final rankings. Potential non-point sources were identified using the SWMM model and event mean concentrations (EMCs) to calculate total annual pollutant loading for each subwatershed. A slightly different screening approach was needed for each type of source because of the data available and the structure of the databases.

Geographic Screening. The PADEP zone concept is used to narrow the list of sources down to include only those with higher priority. Potential sources within Zone C are dropped from further analysis within this preliminary assessment, leaving those sources within Zone A or B for the intake. The first screen applied to eliminate less important potential sources makes use of the zone concept recommended by PADEP for use in the SWAP:

- Zone A: the critical segment covering _ mile on either side of the stream upstream of the intake within a 5-hour travel time to the intake. All potential sources within this zone are included in the subsequent steps.
- Zone B: a second segment located within 2 miles of either side of the stream upstream of the intake, within a 25-hour travel time to the intake. All potential sources within this zone are also included in the subsequent steps.
- Zone C: the rest of the upstream watershed. These sources remain listed in the database, but are eliminated from further analysis because they are deemed less significant than sources in Zones A and B.

Threshold Based Screening. The percent change in the concentration of a chemical at the intake due to releases from each site was roughly estimated and was used to screen permit compliance system PCS (NPDES) sites. This threshold screening was performed to select the largest dischargers. A cutoff of a 1 percent change in concentration at the intake was initially established, based on the percent increase by the discharged mass loading. In most cases, the median flow at each intake was significantly higher than the discharge flow from a PCS source. As a result, none of the PCS sources met the threshold criteria. In such cases, all the major dischargers (flows greater than 1 MGD) and discharges with reported violations were included in the prioritization matrix.

Multi-Criteria Evaluation (EVAMIX). Following the zone-based screening, the most important screening and evaluation method used for most of the analysis relied on a multi-criteria evaluation software package called EVAMIX. EVAMIX is a matrix-based, multi-criteria evaluation program that makes use of both quantitative and qualitative criteria within the same evaluation, regardless of the units of measure. The algorithm behind EVAMIX is unique in that it maintains the essential characteristics of quantitative and qualitative criteria, yet is designed to eventually combine the results into a single appraisal score. This critical feature gives the program much greater flexibility than most other matrix-based evaluation programs, and allows the evaluation team to make use of all data available to them in its original form. The overall appraisal score is used to determine the final ranking of alternatives from best to worst, or most important to least important.

The use of EVAMIX requires the development of a two dimensional matrix consisting of the options to be evaluated and a set of evaluation criteria. For every combination of options and criteria, a score is assigned. The other input variable required for the evaluation procedure is the selection of weighting factors for each of the criteria. Examples of criteria used include:

- *Total Tank Volume*
- *Volume Weighted Chemical Ranking*
- *Number of Leaks Reported*
- *Storage Tank Age*
- *Location (Zone A or B or Floodplain)*

- *Travel Time from Source to Intake*
- *Relative Concentration Impact at Intake*
- *Potential for Release*
- *Potential Releases*
- *Impact on Treatment Operation*
- *Potential Health Impacts*

Finally, all the significant (those that passed the screening) point sources and runoff loads (entered as pseudo point sources) were prioritized, accomplishing the main goal of the assessment. There were two types of final rankings. The first ranking was a combined ranking of sites from all categories, compared against each other. The second ranking was by contaminant type, with all significant sources contributing to a particular contaminant category included.

Groundwater SWAP

The overall groundwater SWAP process consisted of groundwater modeling, compilation of land use and contaminant sources and estimation of well contaminant prevalence, sensitivity and susceptibility. Existing three-dimensional computer models of the Long Island aquifer system were updated and expanded to predict ground water flow within the entire aquifer system and to each community water supply well. The computer model delineates the area that contributes recharge for each well and approximates the time it takes water to travel from the water table through the aquifer to the well. For purposes of these assessments, travel time intervals of 2, 5, 25, 50, 75 and 100 years were assigned. Information specific to each well (screen interval depth, pumping rate, etc.) was incorporated into the model. Water supply pumping rates for each well were assigned based upon documented patterns of pumping and upon the ready availability of pumping data. For most wells, water supply pumpage during 1993-1994 was selected as "representative" for the source water assessments.

Contaminant prevalence within a supply well's contributing or source water area is one significant factor in determining whether the well is susceptible to contamination. New York State's SWAP plan provides a framework for identifying the possibility that different types of contaminants may be associated with a variety of land covers and potential point sources that could be found within a well's contributing area. This framework was modified and refined to better utilize the data available to characterize Nassau and Suffolk Counties, and to be more applicable to Long Island conditions. The land uses and specific facilities (point sources) within the well's contributory area are inventoried and their potential to contaminate ground water (contaminant prevalence) are assessed for each of four contaminant categories (microbials, nitrates, volatile organic chemicals (VOCS) and pesticides). The overall plausible impact from these potential contamination sources is aggregated for the source water area to develop what is termed a contaminant prevalence rating for each contaminant category.

The assessments also consider the likelihood that ground water contamination will reach the well, which is called the well's sensitivity to contamination. The sensitivity rating for each of the four contaminant categories takes into account the fate and transport of those contaminants within the aquifer. For example, microbial contaminants, such as viruses are inactivated and lose their ability to cause disease over time. The sensitivity ratings for pesticides reflect the use of more soluble pesticides in recent years. Assignment of the well sensitivity is based upon time of travel to the well

Well susceptibility is the assessed potential for each contaminant category to deteriorate water quality. Well susceptibility ratings are assigned based upon the well ratings for sensitivity and contaminant prevalence, using the matrix in Table 1. For many of the deeper wells, the time of travel from the water table to the well exceeds 100 years. For 91 wells, the 100-year simulations could identify no source water areas. These wells have therefore been identified as low susceptibility for each of the four contaminant categories (microbials, inorganics, VOCs and pesticides).

Table 1-Well Susceptibility Matrix

	Negligible Contaminant Prevalence	Low Contaminant Prevalence	Medium Contaminant Prevalence	High Contaminant Prevalence
High Sensitivity	Low	Medium	High	Very High
Medium Sensitivity	Low	Low	Medium	Medium-High
Low Sensitivity	Low	Low	Low	Medium

To complete the SWAP in a timely and cost-effective manner, an innovative, database-driven approach was used. Due to the complexity of the analysis and the large amount of data that had to be managed, the database approach proved to be a logical and appropriate choice. Figure 5 summarizes the groundwater SWAP database approach.

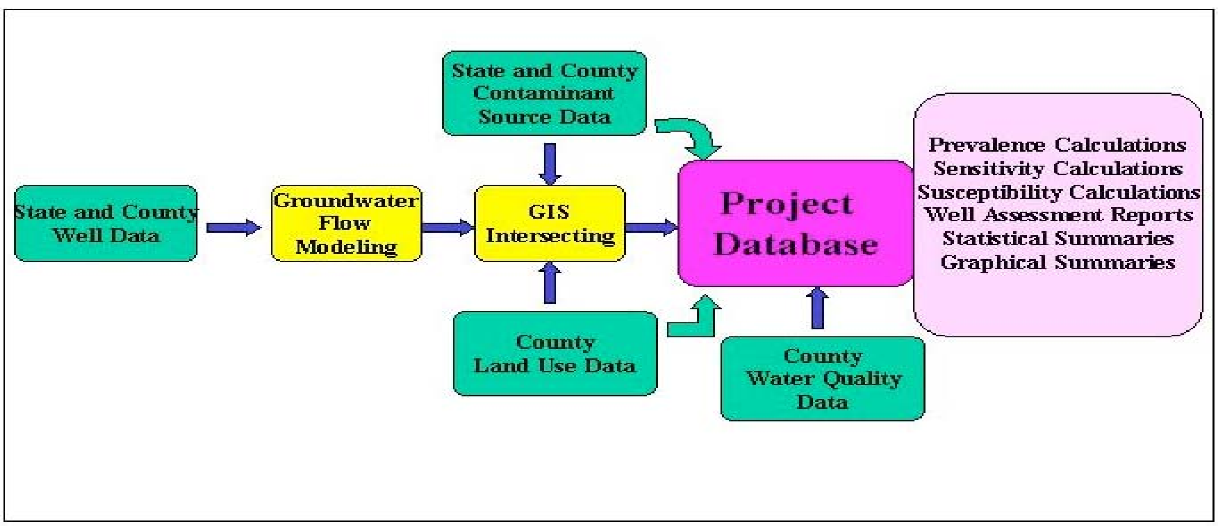


Figure 5 - Database Approach Summary

GIS and Database Tools

The most critical aspect of this plan was the careful up front planning. The project team anticipated that an enormous amount of data was available and that they needed a system in which the data efficiently could be compiled and summarized. The project team created a Microsoft Access® database in which all the tabular data was housed. This enabled the team to use the database tools to bring the data into uniform formats and find and delete duplicate or erroneous data. The team also used ESRI's ArcInfo® as the primary GIS tool. Data was obtained from various federal, state and local agencies, health departments, and other water supplier inputs. The data was organized and summarized such that multiple evaluation objectives could be met with a single database.

The following is a snapshot of some of the tasks completed using the GIS and database tools.

Surface Water SWAP

GIS Tools

- Geocode and locate contaminant sources with missing coordinate information
- Summarize the various landuses within time of travel zones for each intake
- Associate the sources to the time of travel zones for each intake
- Build the stream segment network, to associate USGS gages, intakes and sources to the nearest downstream mile segment
- Compile the base data needed for the SWMM modeling
- Display the sources prioritized for each intake

Database Tools

- Summarize the source inventory for each intake, subwatershed or watershed
- Calculate all the prioritization criteria values to feed into the EVAMIX models
- Provide the data summarizes required to characterize the SWAP for each intake
- Calculate time of travel to intake based on hydrologic modeling data
- Summarize the water quality data used for intake characterization and model result comparison
- Streamline the SWAP report process for each intake

Groundwater SWAP

GIS Tools

- Geocode and locate contaminant sources with missing coordinate information
- Develop the polygons for time of travel zones based on groundwater modeling outputs and intersect the various landuses within time of travel zones for each well
- Associate the sources to the time of travel zones for each well
- Graphically display the source, landuse, sensitivity and susceptibility for summaries for each well

Database Tools

- Process the groundwater modeling output files for use by the buffer and intersect automation done in ArcInfo®
- Load and process hundreds of files generated by ArcInfo® which listed source and landuse data within travel time zone for each well
- Calculate the contaminant prevalence, sensitivity and susceptibility for each well using established evaluation matrices
- Summarize the water quality data from each well and provide comparisons with SWAP results
- Provide the data summarizes required to characterize the contaminant prevalence, sensitivity and susceptibility for each well
- Streamline the SWAP reports for each well

Positives, Pitfalls and Points to Remember

With all our careful up-front planning and powerful programs we still learned some lessons, encountered some problems, and learned some tricks for even smoother run projects in the future. Without ArcView®, Access® and ArcInfo® we could not have completed a project of this scope as easily or as quickly, if at all.

One problem we encountered was the variability in the reliability and accuracy of standard downloads from federal and state databases. The formats and content could change over time and could be challenging during the implementation of projects which span several months. A backup strategy to validate, simplify and verify the downloaded data is highly recommended.

It is important to avoid changes to a primary set of spatial data late in the process if at all possible. For example if the subwatershed delineations are changed midway through the project, this will create significant extra work since all the related model and intersect data need to be recreated and processed in the database.

During the project execution, it is extremely helpful to carefully document where the data came from, from whom it came, how the data was processed, what was done with each piece of data, and what data was used for each calculation. This will avoid redundant work as the project progresses and will help in final project data documenting. It is easy to forget data management tasks several months later and unnecessarily repeat tasks.

When working on such large regional plans, one of the limitations is that detailed plans at a water supplier and or individual well level cannot be developed. Additional data refinement and collection/compilation will be needed to develop such details. In spite of the enormous benefits the well summaries provided in this project, there were some limitations to this approach in that the data became generalized across a huge area. As with any such large-scale data collection process, the varied quality of data and inherent inaccuracies need to be accounted for when evaluating the results. The assessment summaries, however, provide a general snap shot of expected conditions and enable the water suppliers to focus their energies on the higher priorities.

We also found it useful to periodically make copies of the databases and keep older versions at different points in time. Several times we went back to get old data we either deleted or changed so much we needed the old version of the table or map again.

Finally, automating the data management tasks where possible saves months of work and provides consistency to the project approach.

Conclusions

Identification and prioritization of significant sources of pollutants is valuable, not only to the SWA process and the water suppliers in the basins, but also for use in the wide-scale, generalized watershed management planning efforts of the PWD's Office of Watersheds. Experience to-date reinforces that the use of a comprehensive, complex watershed modeling system lends credibility to the robustness of the runoff pollutant estimates and is considered a key success factor for the SWA program. GIS and database tools can streamline the SWA process for large watersheds and intakes with hundreds of contributing sources.

The prioritization process for intakes in the Schuylkill and Delaware River watersheds has a multitude of tasks, each with demanding and comprehensive data management needs. Using an integrated data management technique and combining all the data management activities into a unified approach has proved to be crucial and vital to the success of such large-scale efforts. Careful up-front planning and the building of a well-thought out, relational data management system can prove to be not only an enormous benefit but a necessity. Not only will such an approach reduce the time and effort required to execute the planning tasks, but also enhances the accuracy, reliability and quality of the data evaluation process. The combination of ArcView®, ArcInfo®, and Access® provides an excellent, high-speed tool for the prioritization process.

Using a unified GIS and database approach to develop source water assessment summaries for hundreds of wells in a complex groundwater system proved to be crucial for the execution of the SWAP for Nassau and Suffolk counties in Long Island, New York. Data compilation and reporting was achieved in a very cost-effective and efficient manner. The best outcome from the database approach was the ease with which the summaries could be repeatedly generated to incorporate continually changing criteria during the course of the project.

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