The Utilization of Geographic Information Systems in Environmental Protection of Public Water Supplies

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Abstract

The Illinois Environmental Protection Agency and the United States Geological Survey are developing a factsheet for each of the community water supplies (CWS) in Illinois serving as a source of public water supply. This work was required under the 1996 amendments to the Safe Drinking Water Act (SDWA). The SDWA required that states complete source water assessments of public water supplies to determine their susceptibility to contamination. These factsheets are currently in their initial stages of development. My work during my internship was to help create a factsheet for the Decatur CWS in order to understand the watershed and its source water. I also chose to extend this analysis to focus on potential point sources of contamination and their relationship to the public water supply intakes. Potential point sources of contamination are contaminants that can be traced to specific points of discharge from wastewater treatment plants and factories or from combined sewers. The Decatur watershed has experienced problems with water quality due to a variety of reasons, including high nitrogen levels. Studies have been performed concentrating on nonpoint sources of pollution since a main cause of high nitrogen levels in the water comes from fertilizer use. Nonpoint sources are contaminants that come from many different sources, including fertilizers and pesticides from agricultural and residential lands, nutrients from livestock and pet waste, and from septic systems that drain through soil. There were no studies done on the potential point sources of contamination in the Decatur watershed. Therefore, my goals were to first evaluate this watershed as a whole through the work of the factsheet and then to concentrate on the potential point sources of contamination by analyzing components of travel time from these sources to the public water supply intakes.

Introduction

This work started in May of 1999 at the Illinois Environmental Protection Agency (IEPA) in Springfield, IL, as part of an internship experience. The Decatur watershed was chosen as the study area due to its abundance of potential point sources of contamination and the other problems it has faced in the past related to the violation of drinking water standards due to nitrate levels. It was important to make sure that the watershed was one that had problems associated with it so that there was plenty to address and analyze. Once the study area was chosen, the two parts to this project began.

The first part of this project dealt with the factsheet. This factsheet began as a two to three page document which would be distributed over the internet and eventually will become an interactive Geographic Information System (GIS). This factsheet will be accessible by the public through the IEPA's website along with online ArcView through Arc Internet Map Server. ArcView is a desktop GIS system for storing, modifying, querying, analyzing, and displaying information. In order to obtain an understanding of the Decatur watershed, five main questions were addressed in the factsheet. The questions posed by the IEPA were as follows:

"Where is the source water located?"

"What is the importance of the surface water?"

"What is the source water quality?"

"What is the susceptibility to potential contamination?"

"What are the watershed protection efforts?"

The second part of this project was an extension to the factsheet concentrating on the potential point sources of contamination and their relationship to the public water supply (PWS) intakes. The public water supplies affect the local people in the area since these are the points where the drinking water is collected. Therefore, pollutants located within the watershed that drain into these intakes could result in harm to the local population if the water is not treated prior to the consumption of the water. Depending on the pollutant potentially involved, short-term effects such as food poisoning symptoms to long-term effects such as birth defects could be involved.

After analyzing the Decatur watershed as a whole in the factsheet, a closer look was taken at these potential point sources of contamination since no other studies have been done on them. The goal was to create a product that would be useful in the future when the factsheets become interactive over the internet. Aspects contributing to travel time from a specific potential point source to the PWS intakes were also evaluated since a complex hydrologic model to calculate this was not available.

Methods

Factsheet

The Decatur watershed was chosen as the study area. The data were generated by the IEPA as an ArcView shapefile. The watershed was isolated from a shapefile that contained all of the watersheds in the State of Illinois so that the Decatur watershed itself was its own shapefile. Extensive research about the Decatur watershed along with geographic information system (GIS) analysis was necessary in order to answer the questions of the factsheet.

"Where is the source water located?" The first part of the answer to this question was where within the State of Illinois and within what counties the Decatur watershed and its source water were located. Shapefiles of the State of Illinois, the Illinois counties, the Decatur watershed, and Lake Decatur were imported into ArcView v3.1 and viewed together. The counties that were

included in the Decatur watershed were then isolated and became their own shapefile. All of these shapefiles were obtained and created from the IEPA data.

The answer to the second part of this question was found through the calculation of the watershed's total acreage. The land cover and use was added to a view and clipped to the area of the Decatur watershed. A field called acres was added to the table of these data. Area, in square feet, was already within the table. The area was divided by 43,560 to convert square feet to acres. The acres could then be added together within the table to get the total for the watershed. An Illinois EPA draft report was also researched to obtain information about Lake Decatur.

"*What is the importance of the surface water?"* This question was answered by finding the number of PWS intakes, where the water is treated, and the population in the area the water supplies. The IEPA engineering evaluation report on the public water supplies gave the answers to these aspects of the question.

"What is the source water quality?" A verbal statement by the IEPA that rated the source water quality and a brief history from an Illinois EPA technical report of the noncompliance issues were given.

"*What is the susceptibility to potential contamination?"* All water is susceptible to contamination of many kinds. Five different aspects of contamination were addressed in the factsheet. These aspects included land cover and use, potential point sources of contamination, the number of livestock farms, nitrogen use, and herbicide use. This is where the factsheet went from a three-page to a thirteen-page document.

The land cover and use data were obtained from the Illinois Department of Natural Resources and were classified by the IEPA into five groups for this part of the project. These groups were agriculture, water/wetlands, forest/grassland, urban, and transportation. The percentages of each type of land cover and use within the watershed determine which type of nonpoint pollution is the most prevalent within the watershed. For instance, if the predominant land cover was agriculture, the most likely nonpoint pollution source could be fertilizer use. Whereas if the predominant land use was transportation, the most likely nonpoint pollution source could be road salts. The percentages of each type of land cover and use was calculated by finding the individual acreage for each of the land cover and use types and dividing by the total acreage.

There were seven potential point sources of contamination addressed for this study were as follows:

1) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites,
2) cleanup sites,
3) landfills,
4) National Pollutant Discharge Elimination System Permits (NPDES) sites,
5) Resource Conservation and Recovery Act (RCRA) sites,
6) Toxic Release Inventory (TRI) sites, and
7) Leaking Underground Storage Tanks (LUST) (Sullivan, 1997).

These data came from a variety of sources. The CERCLA and RCRA sites came from the United States Environmental Protection Agency

Envirofacts Database. The cleanup sites, landfills, NPDES discharge points, LUST sites, and TRI sites came from the IEPA. The points were all clipped to the area of the Decatur watershed and were given numbers per site within their tables for identification purposes. A comprehensive table was then produced that combined the 287 potential point sources of contamination. The table included the identification number, the facility name, and the type of point source. This table was also displayed within the factsheet. This is the portion of the factsheet that will become interactive over the internet. When a specific point is clicked upon, the table will pop up and highlight the record that was specified. This will be done by the IEPA through hotlinking the points to the table.

Livestock pose a threat for *cryptosporidium* and high nutrient effects in water. *Cryptosporidium* is a parasite that lives in the intestines of animals and people that causes cryptosporidiosis. Therefore, livestock farms were counted within the zip codes that were within the watershed (Anonymous, 1999. Nitrogen Use Data). These data were obtained from the United States Department of Agriculture (USDA).

The nitrogen use and herbicide use data were downloaded from the internet from the United States Geological Survey (USGS) website and clipped to the counties within the watershed. These data were available only in the Albers projection. Since the Lambert projection was used for the other data, a conversion was necessary. Problems were encountered using the ArcView Projector! extension and also when using projection files in UNIX. Joining two tables completed the projection. One table had the correct projection and one did not, so the two tables were joined based on a common field. The wrong x,y coordinates were then deleted. The nitrogen and herbicide uses were added as event themes and converted to shapefiles. The nitrogen use data were classified from lower to higher based on the values present within the watershed.

The herbicide use data were classified into the top 10 most commonly used herbicides within the State of Illinois. The initial data were nationwide and contained 20 herbicides (Anonymous, 1999. Herbicide Use Data). After the data were clipped to the State of Illinois, the individual herbicide's values were added within the table and only the top 10 were kept. The other 10 were deleted from the dataset. The remaining values were then summed to make a new field in the table for the total herbicide use in pounds per acre. The herbicides that are included in the top 10 are atrazine, metolachlor, alachlor, eradicane, cyanazine, butalate, triflurolin, bentazone, pendatheth, and 2,4-D, respectively.

"What are the watershed protection efforts?" The watershed protection efforts were researched within the technical report about the watershed monitoring and the land use evaluation. Within this report, recommendations were made pertaining to the two-year study that was performed on the watershed in 1996.

Potential Point Sources of Contamination Related to the PWS Intakes

The second part to this project dealt with the information needed to calculate the travel time from a given potential point source of contamination to PWS intakes. Major factors that would effect travel time were analyzed. These major factors included the flow path, the path distance, the percent land cover and use that the path traveled upon, the percent slope, and the runoff. Access to this information interactively over the internet would be useful in an emergency response situation if a spill occurred or if people wanted more detailed information about their watershed. There are models that could calculate the travel time, but due to the lack of financial help, the models could not be obtained.

The path a contaminant would take if a spill occurred was determined using the ArcView Hydrology extension. This extension would only work in conjunction with the Spatial Analyst extension. The path was calculated based on the digital elevation model (DEM). The DEM was obtained from the USGS. In order to compute the flow path, the flow direction and flow accumulation had to be computed by this extension. After computing these two factors, a tool entitled "the raindrop tool" calculated the path from one user-specified point to another (from a potential point source of contamination to the PWS intakes). The path was calculated on a cell-by-cell basis within the grid of the DEM and these paths were computed from all 287 points to the PWS intakes.

These paths were created as graphics from the extension, and in order to use the paths in further analysis, they had to be converted from graphics to shapefiles. A script from the Environmental Systems Research Institute (ESRI) website entitled gra2shp was used to do the conversion. Also, when each path was created, there were two paths per potential point of contamination since there were two PWS intakes. The two paths followed the same route until a diverging point where the path either went to one intake or the other. This was at the end of the path since the PWS intakes were close together. Therefore, the second path only consisted of the length to the other PWS intake from the diverging point. The two paths were then merged using the Xtools extension to form one path that shows the route to both of the PWS intakes.

After the paths were overlaid onto the land cover and use, it was noticed that the paths were incorrect. The paths would enter water and then come back up onto the land. This is impossible especially after looking closer at the elevation surrounding the water. The land cover and use data were collected at different times and by a different agency than the DEM data, which could explain this error. Another explanation could be that the Hydrology extension was incorrect. Examination of the path created by the extension showed that the path moved uphill. Therefore, the paths had to be physically fixed so that once they entered water, they stayed in the water and did not flow up onto the land. This was accomplished by breaking down the lines into their vertices and moving them into the water when necessary. Then, the total path distance was calculated by opening the table and summing the two path distances in feet.

The percent land cover and use over which the path passed was found by using the intersect option under the Geoprocessing Wizard extension. This kept the spatial information of the path and added to it the information of the land cover and use. The totals of each land cover and use type were added, and divided by the total number of cells, in order to obtain the percentage of land cover and use that the path actually travels upon. There were 15 classification groups used for land cover and use for this second part to the project instead of the initial five. These groups were urban, transportation, agriculture (row crops), agriculture (small grains), agriculture (orchards and nurseries), urban grasslands, rural grasslands, deciduous forest, coniferous forest, open water, marsh, forested wetlands, barren and exposed land, swamp, and no data. More groups were used in order to get a more detailed description of what type of land cover and use the path would cross.

The next major component that would contribute to the travel time was the percent slope. This was also calculated from the DEM using the compute slope option within the Spatial Analyst extension. When the slope was calculated using the ArcView Hydrology extension, it was obvious that there was something wrong with the values since there was no change in the slope at all. It was common knowledge that the watershed was not located in an area of almost no slope. After computing the slope with the Hydrology extension, the Spatial Analyst extension was tried and produced values that were more realistic.

The final component that contributed to the travel time was the runoff potential. Runoff was related to soil associations. The soils data were obtained from the Illinois Natural Resources Geospatial Data Clearinghouse in the digital line graph format (Anonymous, 1997). This was converted to a shapefile for the analysis and was done using a script from ESRI entitled dlg2shp. The soils were then classified based on their soil associations to demonstrate their runoff potential (McCarthy, 1998). The National Resources Conservation Service (NRCS) and the USDA provided soil series descriptions via the internet. Each series that occurred within the Decatur watershed was researched (Anonymous 1999. Official Soils Series Descriptions). Each soil association consisted of three series that were researched individually and then averaged for runoff. For example, if the three series consisted of low, very low, and low runoff potential, the runoff was averaged to low for this association.

The final product produced from this part of the analysis was a layout that was hot linked for the interactive GIS component to each potential point source of contamination.

Results/Discussion

Factsheet

"Where is the source water located?" The Decatur watershed is located in the central eastern part of the State of Illinois. The source water of Lake Decatur is located within the Decatur watershed that covers a total of 587,949 acres in Champaign, DeWitt, Ford, Macon, McLean, Piatt, and Shelby counties (Figure 1).

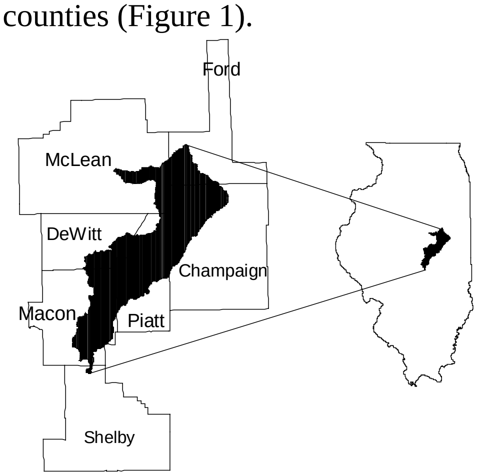


Figure 1. The Decatur watershed in the state of Illinois and the 7 counties it lies within.

The Sangamon River is the major river in the Decatur watershed, draining 925 square miles upstream of Lake Decatur. Other significant waterways within the watershed include Buckhart Creek, Camp Creek, Finley Creek, Friends Creek, and Goose Creek. Lake Decatur was created in 1922 by the construction of a dam to impound the flow of the Sangamon River. The dam created the lake with a volume of 20,000 acre-feet, but was later modified in 1956 to increase the maximum capacity of the lake to 28,000 acre-feet (Environmental Planning and Economics Inc. et al. 1997).

"*What is the importance of the surface water?"* The City of Decatur has two surface water intakes (IEPA #00122 & #45004) drawing from Lake Decatur. Water obtained from Lake Decatur supplies an estimated population of 84,000 and pumps an average of 37.6 million gallons per day. Water from Lake Decatur is treated at two separate plants referred to as the North and South plants (Illinois EPA Division of Public Water Supplies, 1997). The lake is utilized not only for drinking water, but also for fisheries, irrigation, recreation, and as a wildlife habitat.

"*What is the source water quality?"* The overall quality of this source water is considered fair by the IEPA. From 1979 to 1992 the IEPA issued eight nitrate warnings to the City of Decatur for noncompliance of drinking water standards for nitrate. These warnings are issued when nitrate concentrations exceed the ten milligrams per liter maximum concentration level. The City of Decatur signed a letter of commitment in 1992 to reduce the nitrate levels within the next nine years. A two-year monitoring study was done on Lake Decatur and recommendations were given in order to comply with the standards (Illinois State Water Survey, 1996).

"What is the susceptibility to contamination?" The contamination to Lake Decatur includes water quality problems such as nitrate concentrations, sedimentation, turbidity and others. Most of the interest is focused on the reduction of the nitrate concentrations. Figure 2 illustrates the land cover within the watershed. Potential sources of nonpoint pollution are demonstrated by this figure. This 587,949-acre watershed is composed of 80% agriculture (predominantly row crops), 14% forest/grassland, 3% water/wetlands, 2% urban, and 1% transportation. The nonpoint sources are primarily related to agriculture and fertilizer use.

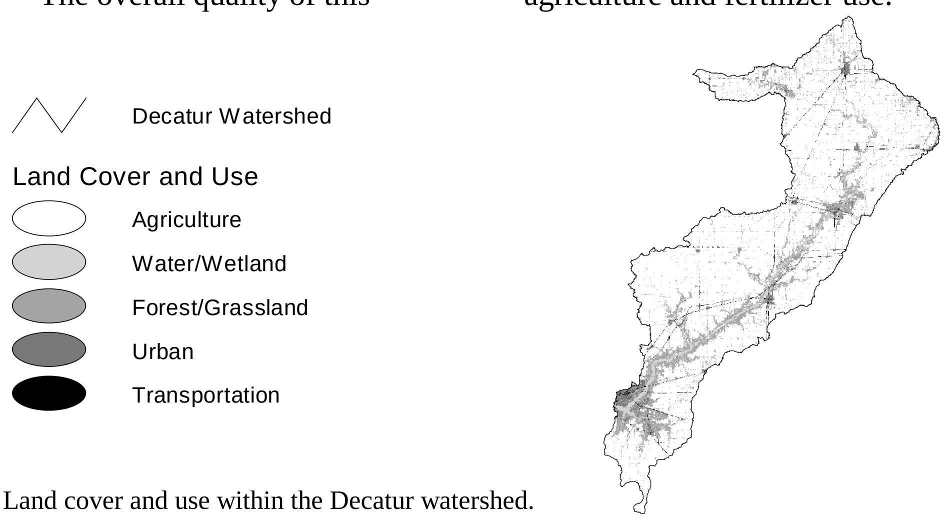


Figure 2. Land cover and use within the Decatur watershed.

Figure 3 shows the location of known potential point sources of contamination within the watershed. As stated before, there are a total of 287 potential point sources, which is a relatively large amount of points compared to other watersheds in Illinois.

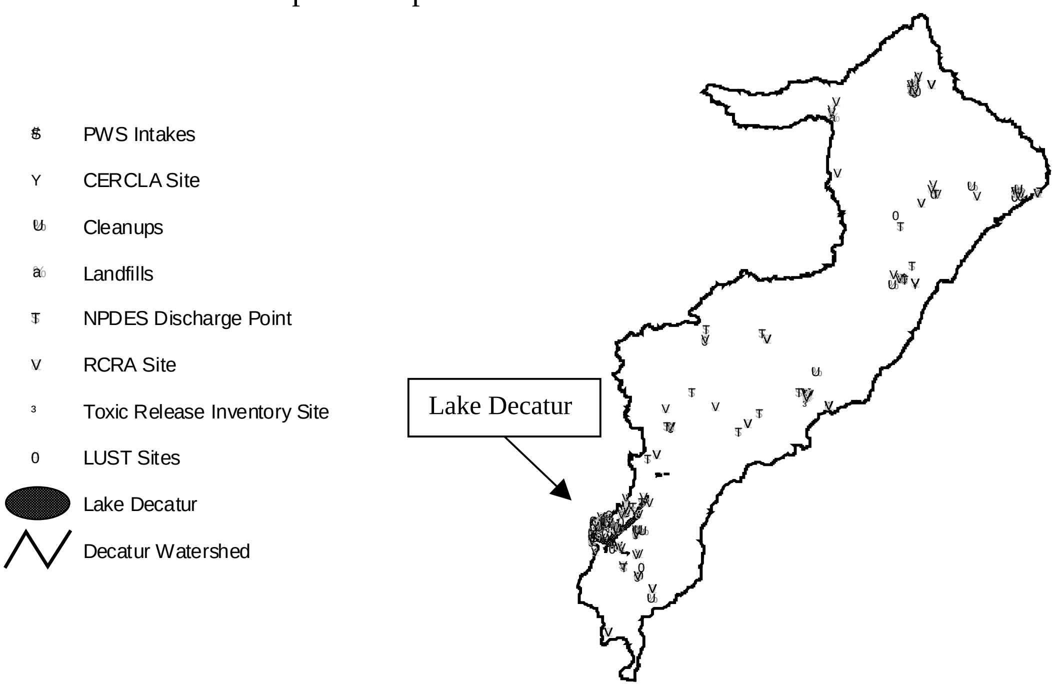


Figure 3. Potential point sources of contamination within the Decatur watershed.

Table 1 displays a portion of the table that will be hotlinked to the point sources of contamination. When a point is clicked on in Arc IMS through the IEPA'a website, this table will pop up highlighting the point in the table.

The number is the unique identification number given to each point in the watershed, the facility name is the title that the facility goes by, and the type is one of the seven potential point sources of contamination described earlier.

Table 1. Table of potential point sources of contamination that pops up when clicked on with the hotlink tool during interactive GIS.

#	**Facility Name**	**Type**
1	Prairie Paint & Adhesive	CERCL
2	ADM Corn Sweetners Division Alcohol Plant	CERCL
3	A.E. Staley Manufacturing Company	CERCL
4	Borg-Warner Corporation	CERCL

Figure 4 displays the number of livestock farms within the watershed. The farms are classified by zip code. The maximum number of farms in a zip code is fifty-nine farms and the minimum is 2 farms.

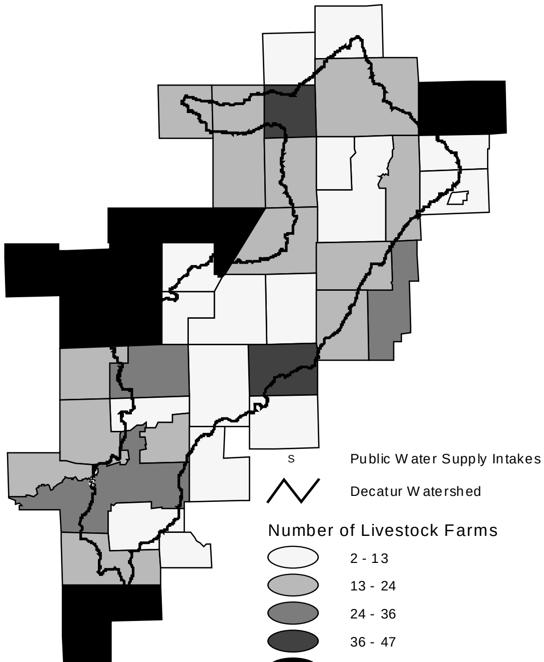


Figure 4. Number of livestock farms per zip code within the Decatur watershed.

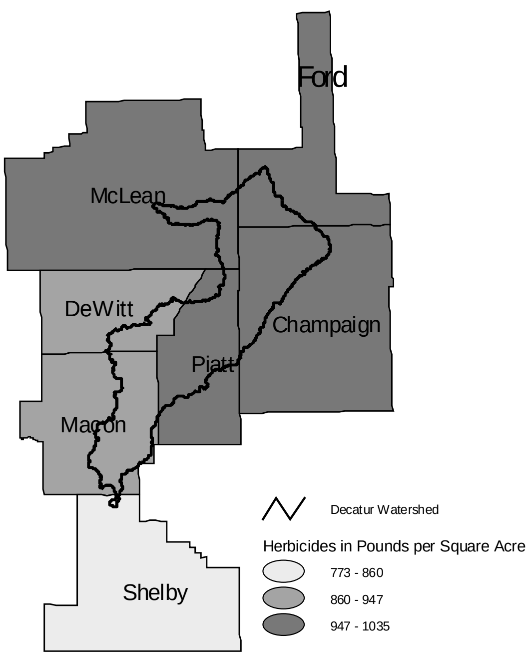


Figure 6. Herbicide Use within the Decatur watershed.

Figure 5 displays the estimated nitrogen use and Figure 6 displays the estimated herbicide use for the ten most commonly used herbicides in Illinois. The herbicide use ranges from 57 to 1107 pounds per square acre within this watershed.

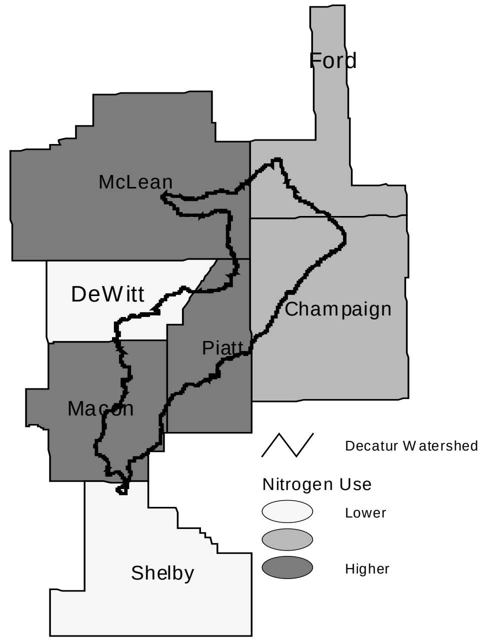


Figure 5. Nitrogen use within the Decatur watershed.

"What are the watershed protection efforts?" The watershed protection efforts pertain mainly to the two-year monitoring study done on Lake Decatur for the nitrate levels. The following recommendations were made to reduce nitrate concentrations:

1) watershed-based Best Management Practices (BMP) and mitigation projects would make significant contributions toward solving the problem, but are not a guarantee of success within a short period of time (water treatment and blending);
2) fertilizer application rate, the timing of the application, and applying at the correct rate are

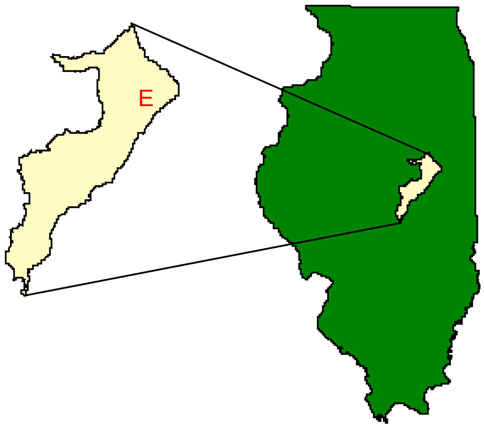
significant variables that contribute to nitrogen losses to surface waters and that *The Illinois Agronomy Handbook* should be used as guidance;
3) initiating demonstration projects by sub-watershed or county to demonstrate the effectiveness of BMPs (by showing "model-farms") using incentives along with nutrient management, conservation tillage, no-till farming, buffer strips, wetlands, and water table management;
4) educational efforts;
5) public relations;
6) continued research efforts and data collection; and
7) continuing the Nitrate Workshop held annually to present and discuss new data, latest research, and the status of the problem (Environmental Planning and Economics Inc., et al. 1997).

Sedimentation has been a problem since the Lake Decatur dam was completed in 1922. There is no deadline to take any specific action regarding erosion and sediment reduction. Erosion and sediment reduction is accomplished one field, one bank section, or one gully at a time. Successful implementation depends mainly on the decision of the City and possibly other funding sources to offer a financial subsidy or other incentive. The agreement of the landowner to bear the net cost and implement the practice is also vital. The City continues to look into this problem (Illinois EPA Division of Public Water Supplies Advisory Committee, 1998).

Potential Point Sources of Contamination Related to the PWS Intakes

Figure 7 shows an example of a layout of the final product to Cleanup Point #5. This final product was only completed for one of the 287 potential point sources of contamination due to limits on time and resources. The layout contains the aspects considered for the travel time and is presented both graphically and textually. Also presented in the layout is a locator map and the name of the potential point source of contamination. This figure is a direct example of what would appear if a point were clicked on during interactive GIS. This figure is in color in ArcView and can be zoomed in upon when accessing it interactively. This makes it easier to see and interpret the data presented. This information would be necessary for a complex hydrologic model in order to compute exact travel time. This information would also be important in the event of a spill or for general information.

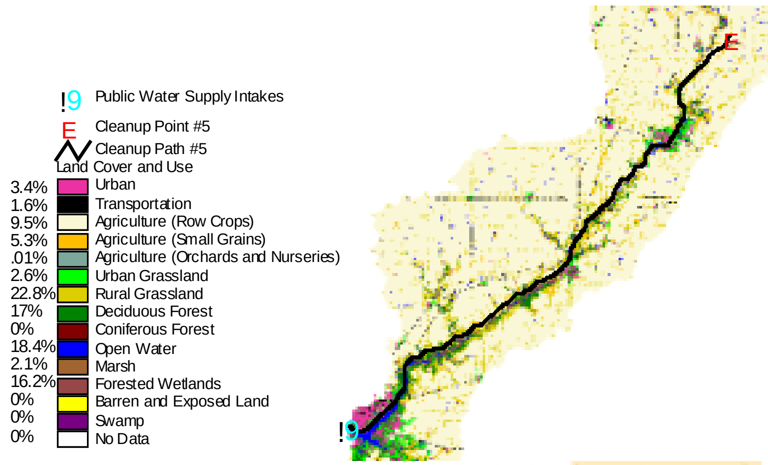
Figures 8, 9, and 10 are enlarged versions of the data present in the final product. Figure 8 displays the land cover and use for cleanup path number five, Figure 9 the percent slope for cleanup point number 5, and Figure 10 the runoff for cleanup path number five. These figures are present in this form in this paper for easier viewing since the final product graphic can only be enlarged to a certain degree in this paper format and cannot be zoomed in upon like in the online version of the project.



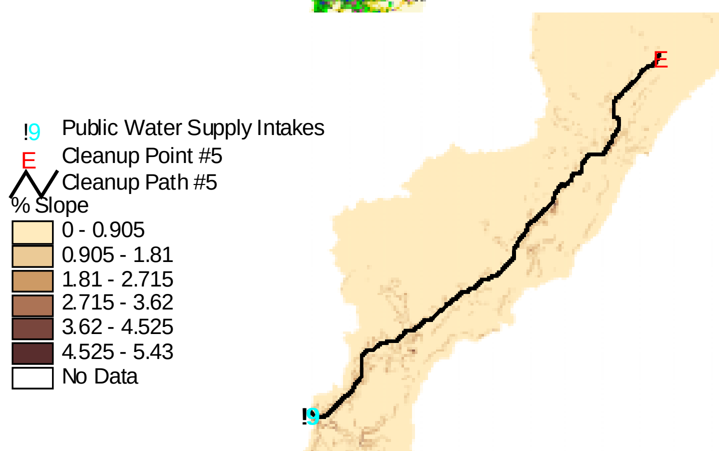
Decatur Watershed

Cleanup Point #5 -- Flo-Con North.
Total path distance to public water supply intakes = 301,843.831 feet.

Point located on agriculture (row crops) and will travel primarily on rural grasslands. It will not travel on exposed land, swamp, or coniferous forest.



Point located at a slope of 1.07. Along its path is will travel through steeper slopes up to 2.5%, but the average slope is low.



Point located on low-medium runoff and then immediately flows into an area of high runoff. The rest of the trip is primarily in the low runoff classification.

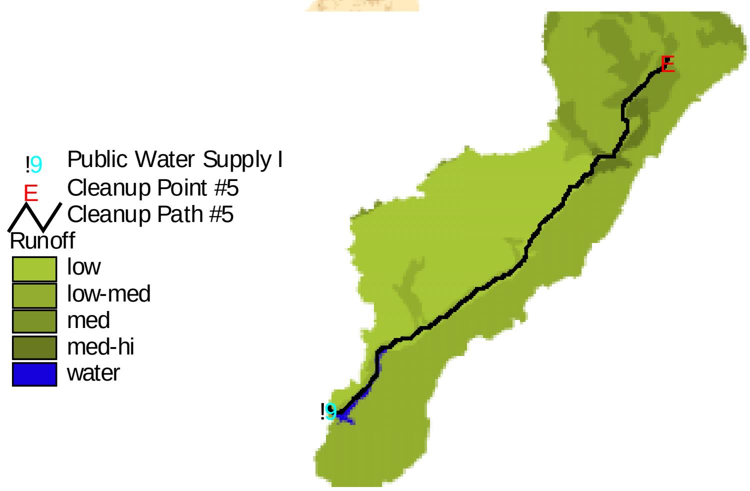


Figure 7. Final product of what is linked to potential point sources of contamination.

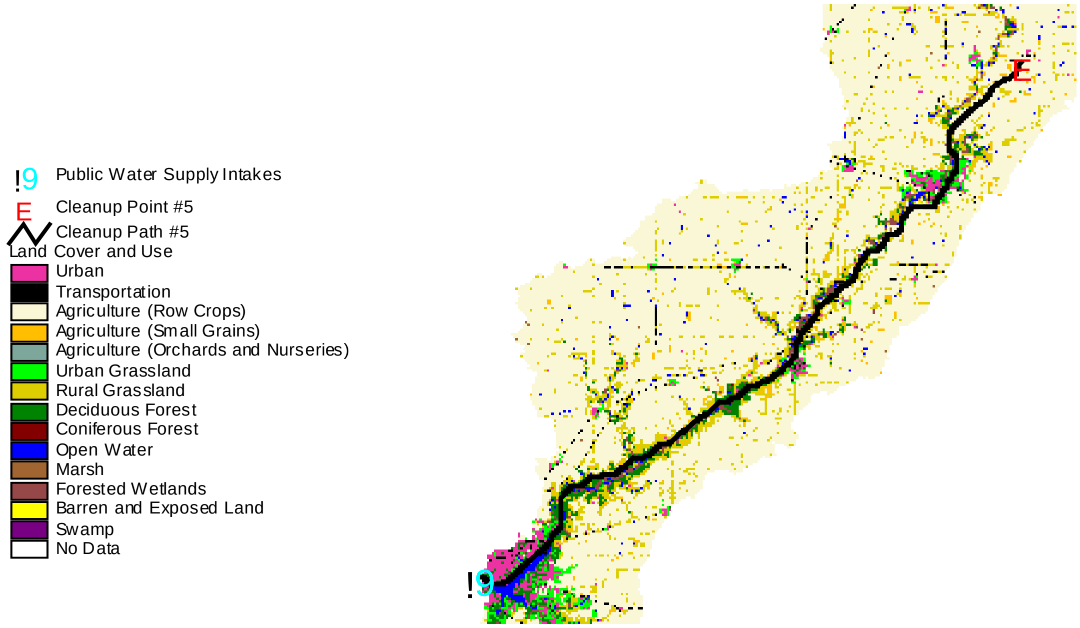


Figure 8. Land cover and use for cleanup point number 5.

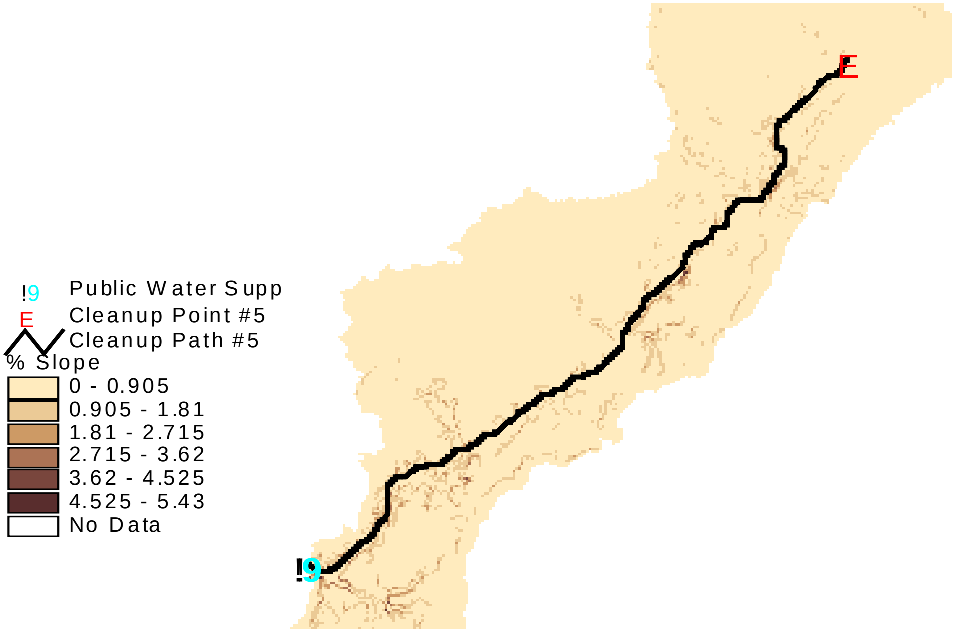


Figure 9. Percent slope of cleanup point number 5.

Figure 10. Runoff for cleanup point number 5.

Conclusion

The Decatur watershed factsheet is in the final stages of its approval process within the IEPA and USGS. There is no deadline for the factsheets to become interactive over the Internet, but it is in progress. The deadline for this project is May, 2003.

The extension to the factsheet involving the potential point sources of contamination should prove useful in the future should the IEPA ever choose to adopt it. The information and analysis presented will be useful both in emergency response and for general information pertaining to each point.

Recommendations for this project include: First, choosing a smaller watershed with which to work. Second, if the watershed is not geographically smaller, then choose one that has fewer potential point sources of contamination. Third, try to obtain a hydrologic model that could produce an exact travel time. Finally, be careful of the Hydrology extension provided by ArcView since several problems were encountered with it throughout this project.

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