Usefulness of Watershed Analysis for Predicting the Location of Groundwater Contamination from Hazardous Waste

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Table of Contents

Table of Contents 2
Abstract 3
Introduction 3
Project Description 5
Methodology 5
Results 10
Discussion 12
Conclusion 12
Sources 13

Abstract

This project looks at the usefulness of watershed analysis for predicting the locations of groundwater contamination from hazardous waste. Using two Superfund sites for the study area, the project compares site watersheds to known areas of contamination and concludes that watershed analysis is not a reliable predictor of the location of groundwater contamination.

Introduction

The U.S. Environmental Protection Agency (EPA) oversees the "Superfund," the federal government's program to clean uncontrolled hazardous waste sites. Two such sites are located very near to each other in southern Winnebago County, south of Rockford, Illinois. (See Figure 1.)

The "Pagel's Pit" site is a former landfill situated on the east bank of Killbuck Creek. The groundwater at Pagel's Pit has been found to contain volatile organic compounds (VOCs) and "elevated levels of arsenic, chloride, boron, and ammonia," and contaminants had spread to the other side of Killbuck Creek (US EPA, 2009). Remediation included cover and final leachate and gas management systems (US EPA, 2009).

The other Superfund site, Acme Solvent Reclaiming, Inc., is located just across the street to the east. Before it was closed, the Acme site was used for drum storage and disposal of waste generated by the company's solvent distillation operation. The soil was found to contain "VOCs, phthalates, polychlorinated biphenyls (PCBs) and metals, including lead and chromium" (US EPA, 2008). The EPA also found VOCs in the groundwater, not only at the site itself but also in the aquifers that provided water to area residents. As part of the remediation agreement, ACME provided an alternate water supply to affected neighbors so that they were no longer using the contaminated groundwater. Many residents have since left the area (US EPA, 2008).

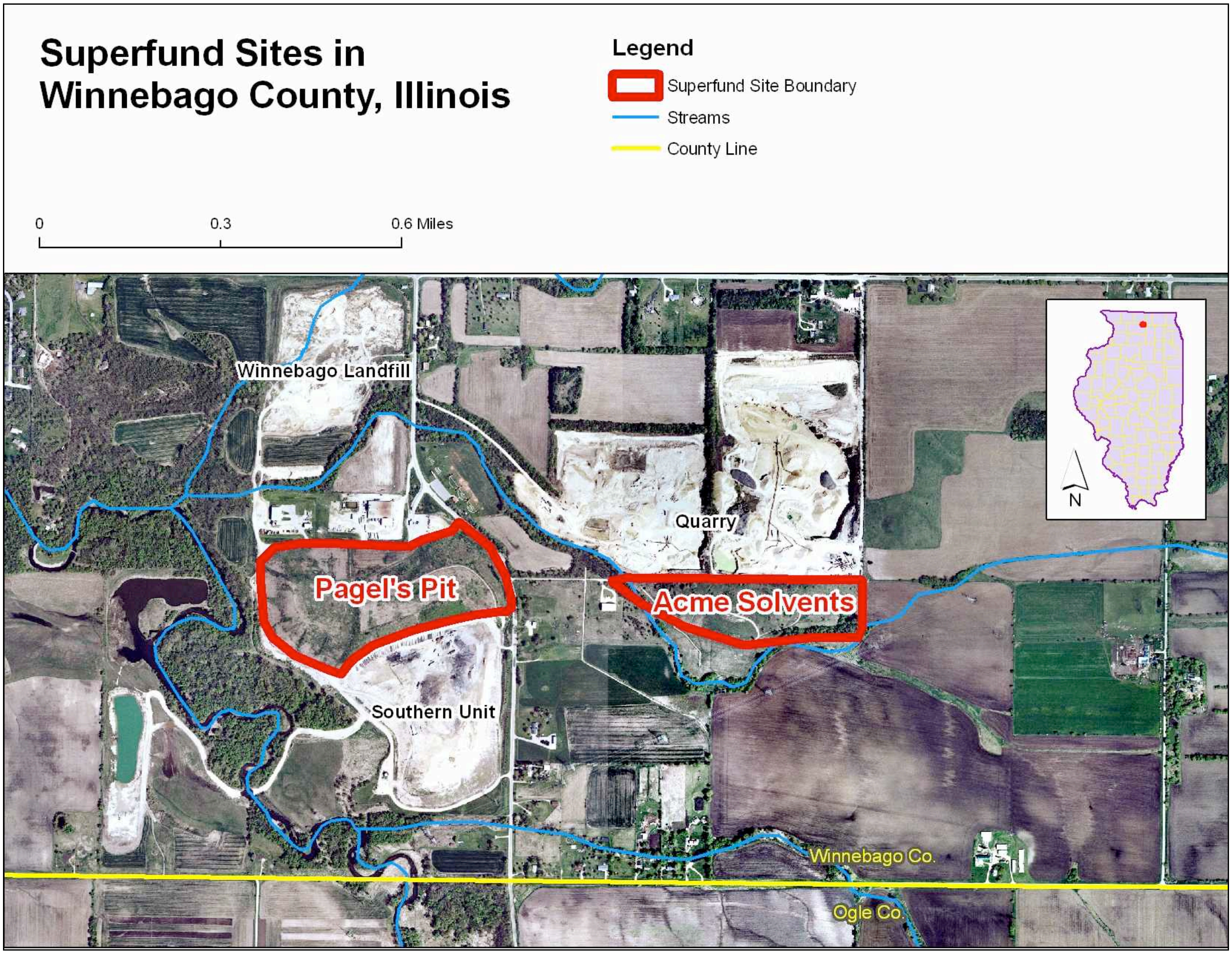

Figure 1. Map of Superfund Sites in Winnebago County, Illinois.

Project Description

Statement of the Problem

As implied in the introduction, one serious problem associated with hazardous waste is the potential for groundwater contamination by toxic chemicals. How does one detect the presence of such chemicals? Can their locations be predicted using GIS techniques?

Purpose of the Project

While ArcGIS includes several tools designed specifically for groundwater analysis, this project seeks to focus only on the watershed-related tools in the "Hydrology" section of the software program. The goal of the project is to answer the question, "Is watershed analysis helpful in predicting the locations of groundwater contamination?"

Methodology

Broadly speaking, the methodology of this project involved creating multiple watersheds for the area of interest, then analyzing the spatial relationship between "suspect" watersheds and areas of known groundwater contamination.

Specifically, the methodology involved the following steps:

1. Obtain geospatial data and images
    - Color Satellite Orthoimage RGB rasters (USGS Seamless Server)
    - Illinois shapefiles for boundaries, elevation (30 meter resolution), and water resources (Illinois Natural Resources Geospatial Data Clearinghouse)
    - National Elevation Data rasters (1/3" NED, 9.26 meter resolution) (USGS Seamless Server)
2. Use ArcGIS to derive watersheds
    a) Compare Digital Elevation Model (DEM) rasters of two different resolutions to find the most appropriate resolution
        - 30 meter cell DEM
        - 9.26 meter cell DEM (this is the raster resolution I chose)

    b) Compare different stream network thresholds to find the most appropriate threshold
        - 10
        - 25
        - 50
        - 100
        - 250
        - 500 (I used this threshold for sub-watersheds)
        - 5000 (I used this threshold for main watersheds)

3. Create several maps to convey the main steps of the process and interpret the watershed results:
    a) Map A: Location of Study Area and Superfund Sites
    b) Map B: Elevation of Superfund Sites
    c) Map C: Watersheds at Threshold of 500
    d) Map D: Main and Sub-watershed and Watershed Flow Direction
    e) Map E: Comparison of Suspect Watersheds and Areas of Groundwater Contamination

Several parts of my methodology require elaboration.

DEM raster resolution
The resolution of a DEM is an important factor in creating a watershed. I found the 30 meter cell size (from the Illinois Data Clearinghouse) to be of insufficient resolution. The raster didn't show any details of study area; one could barely discern the landfill location or smaller streams in the region. Conversely, the 9.25 meter cell raster from the USGS Seamless Server was quite adequate; it conveyed both the height of the landfill and the smaller streams in greater detail. (See Figure 2.)

Watershed network threshold choice
I experimented with watershed network threshold choice to find the most appropriate level of detail for my area of study. In the end I chose to use two different thresholds, 500 (for sub-watersheds) and 5,000 (for main watersheds). I felt that I was unable to interpret stream link direction looking only at the 500 threshold watershed layer; the relationships between the watersheds and the nearby streams were unclear (see Figure 3). By overlaying a courser (5,000) watershed on top of the 500 watershed, I could more easily see relationships between the sub-watershed and the stream network. The main watersheds also made it easier to see the overall direction of water flow into Killbuck Creek (see Figure 4).

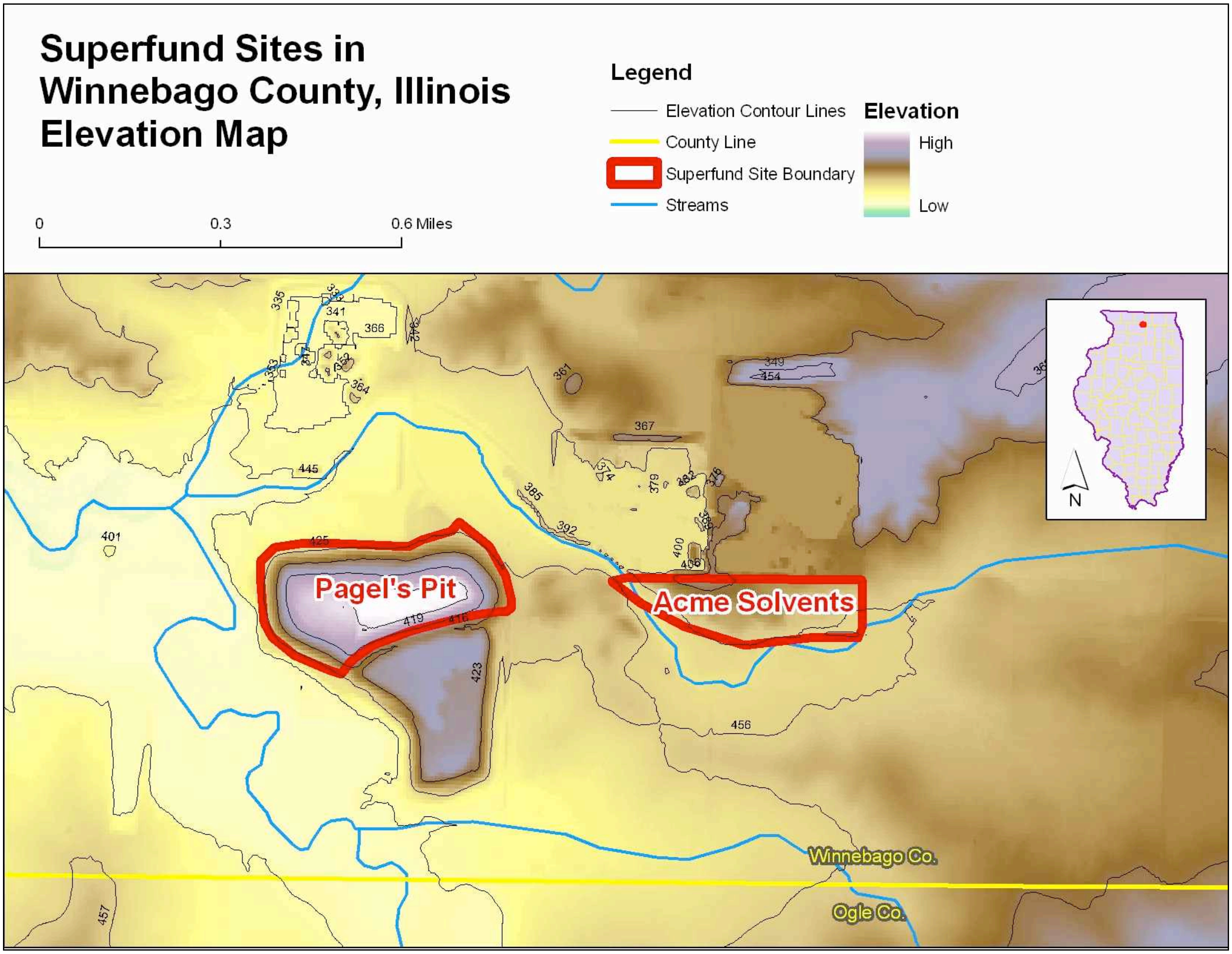

Figure 2. Elevation map of Superfund Sites in Winnebago County, Illinois. Note that Pagel's Pit, a former landfill, is actually a hill, taller than the rest of the features in the region.

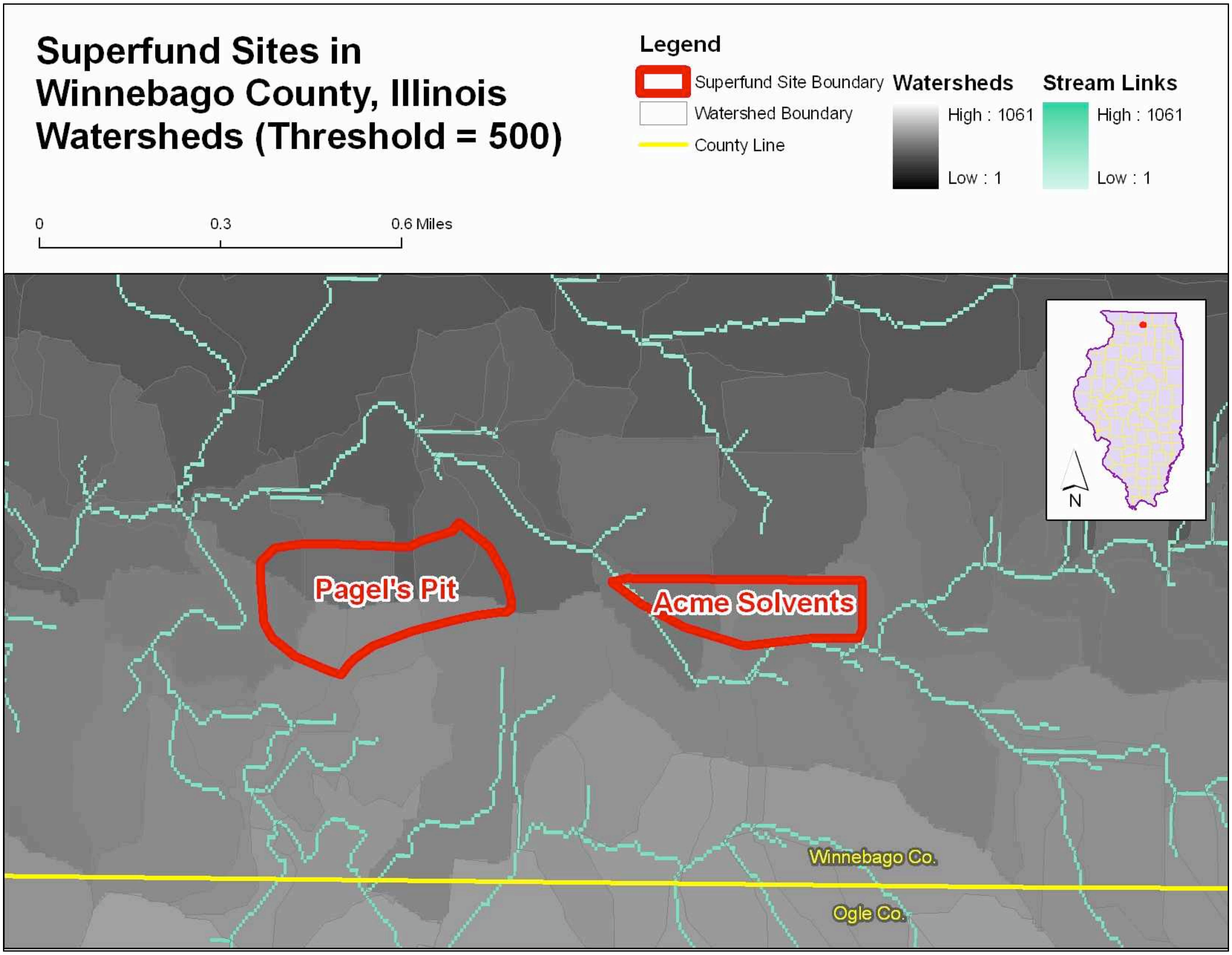

Figure 3. Map of the watersheds derived by using a stream network threshold of 500. The large number of watersheds makes it difficult to interpret the water flow direction.

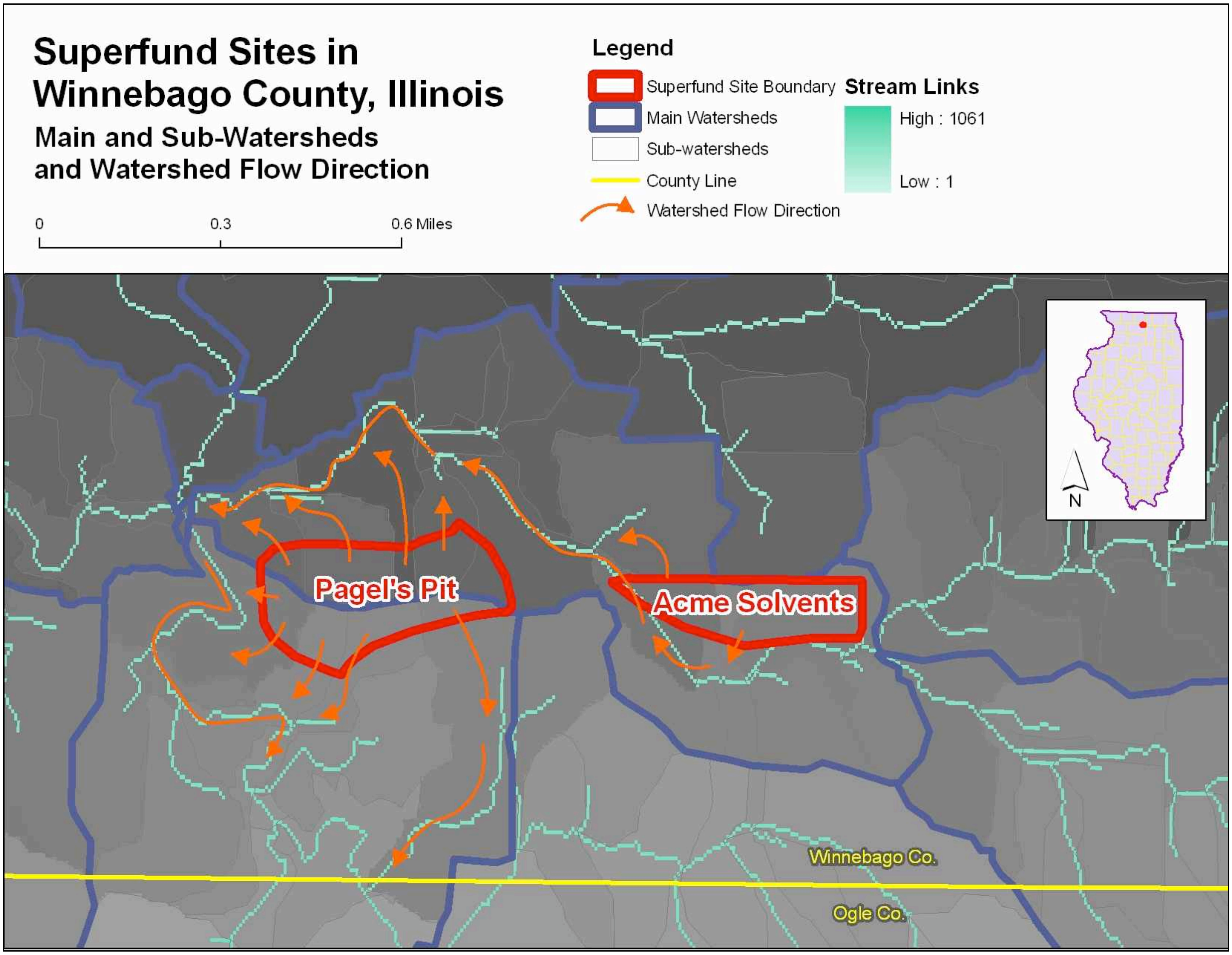

Figure 4. This map shows main watersheds and their sub-watersheds. Orange arrows indicate the direction of the water flow from the Superfund sites down the nearest watersheds and to their associated stream links.

Creating watersheds to compare with areas of contamination
For my final map I created a selection of watersheds that intersected the Superfund sites. I called these watersheds "suspect" watersheds since they are the most likely watersheds to be contaminated by runoff water (and perhaps groundwater). The purpose of the map is to compare these areas of hypothetical groundwater contamination with areas of known groundwater contamination.

Unfortunately the EPA does not provide maps or exact locations of these contaminated areas. The only such information is provided in text as part of a general description. As a result, my mapped areas of known groundwater contamination in fact are a combination of accurate and approximate areas of contamination. The accurate areas are the obvious portions within the Superfund site boundary proper; any areas that extend outside that boundary are only approximations of contaminated areas based on the EPA's inexact descriptions:

- For Pagel's Pit: "the site also includes some of the land west of the creek where contaminated groundwater has migrated" (US EPA, 2009).
- For Acme Solvents: "the groundwater flow is primarily toward the west, where residents are some distance away from Pagel's Pit. There were some nearby residents located across and along the road that touches the eastern edge of the [Pagel's Pit] site, toward the south, but most are now gone. The groundwater between the two sites was contaminated…" (US EPA, 2009).

Based on these descriptions, I drew the Pagel's Pit contamination polygon to include an arbitrarily-sized area west of Killbuck Creek. I drew the Acme Solvents contamination polygon to include the area west and south of the Superfund boundary proper, and along the road that abuts the eastern edge of Pagel's Pit. The polygon extends an arbitrary distance southward to include some of the residential areas affected by the contaminated water.

Results

The results of this project are illustrated in my final map (see Figure 5). The map compares my selection of "suspect watersheds" with areas of groundwater contamination (actual and approximate). The map shows that while the two themes overlap in obvious locations (the Superfund site proper), the areas of groundwater contamination beyond the proper border largely do not correspond with the watersheds.

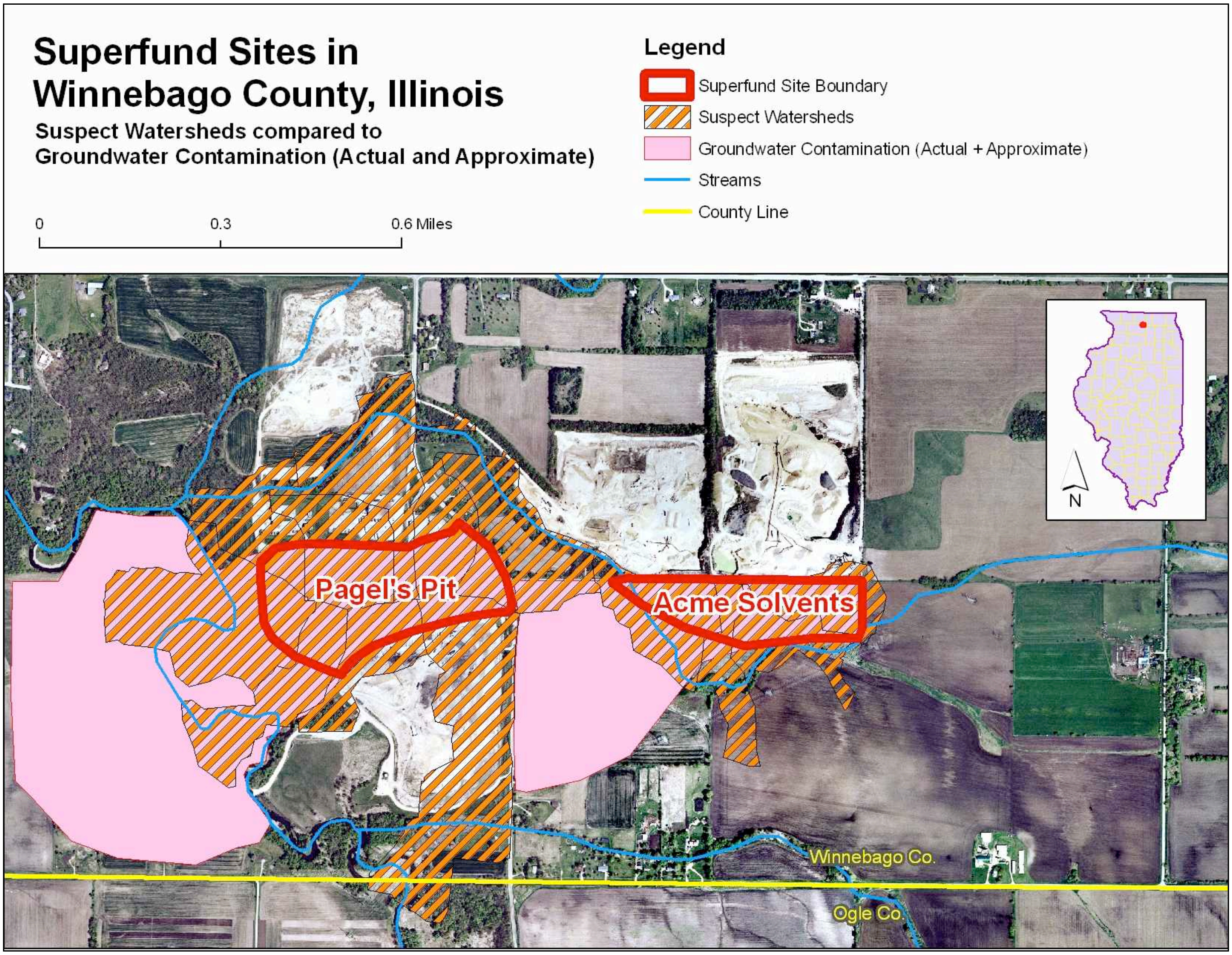

Figure 5. The final map compares "suspect" watersheds (watersheds that directly intersect a Superfund site) with areas of known groundwater contamination.

Discussion

A watershed is an area that drains water to a common outlet (Chang, 2010, p 298). The implication is that watersheds predict water flow only on the *surface* of a slope, not underground. The results of this project reveal that groundwater contamination does not necessarily correspond to the watershed areas most directly associated to a Superfund site (or other hazardous waste site). Watershed analysis could likely predict the general direction of the movement of toxic chemicals carried in water runoff, but not the accumulation of those chemicals below the surface. Presumably seepage (e.g., into underground aquifers) carries the water into areas not predicted by a watershed.

Another factor in water flow might be the composition of the study site. For example, Pagel's Pit is a former landfill (in fact, a hill), situated on a former gravel quarry and comprised of garbage and soil. Would this composition cause either surface or groundwater to behave differently than on a naturally-composed hill of similar size and slope?

No doubt the nature of groundwater flow (and contamination) is very complex and beyond the scope of this project. An exploration of the groundwater tools in ArcGIS (e.g., Darcy Flow, Darcy Velocity, etc.) would be a logical basis for further research.

Conclusion

Watershed analysis by itself is not a sufficient tool to predict groundwater contamination from hazardous waste. The flow of toxic chemicals from a hazardous waste site is a complex process that can only be fully understood by using a variety of data sources and methods. These methods might include watershed analysis, but ground testing, groundwater analysis tools and other methods would be required.

Sources

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