Parcel Based Stormwater Runoff Calculator for Hamilton County Ohio

Andrew Swift

Abstract

Complaints about stream and sewer flooding have been increasing. Many departments need to do accurate stormwater calculations but have lacked affordable and useful software tools. Hydrologists and engineers usually calculate stormwater data for watersheds (i.e., drainage areas); the majority of a local government's work is based on individual parcels and addresses. Quantifying stormwater in a fair, accurate and economical way was so difficult that these calculations were seldom included in the review of subdivisions or building permits. When such calculations were made, sharing them throughout the enterprise was difficult. CAGIS has developed a runoff calculator that makes the model output useful and accessible for local government.

Introduction

Local governments need software that works at the parcel level. Federal-level data and software are too general (one pixel might be bigger than a house). And, while engineering data and tools are good for specific projects, they can be too detailed and flexible for general use. Engineering level accuracy is also expensive countywide. Beyond the cost issue, there is a bigger issue. Cities and counties deal with parcels and addresses, not watersheds. In fact, nearly all transactions in local government deal with addresses and parcels. GIS software tools used in a daily local government workflow need to be simple. The purpose of this paper is to show that building a simple GIS stormwater runoff calculator can be done on a limited budget (Figure 1.) The one presented here is called: 'CAGIS runoff calculator'. You can zoom into any area on the county map, hit one button and get the stormwater runoff volume estimates for any parcel. You can also enter a proposed land-cover change and get before/after stormwater runoff estimates. The calculator can be used to quantify changes in run-off due to proposed development.

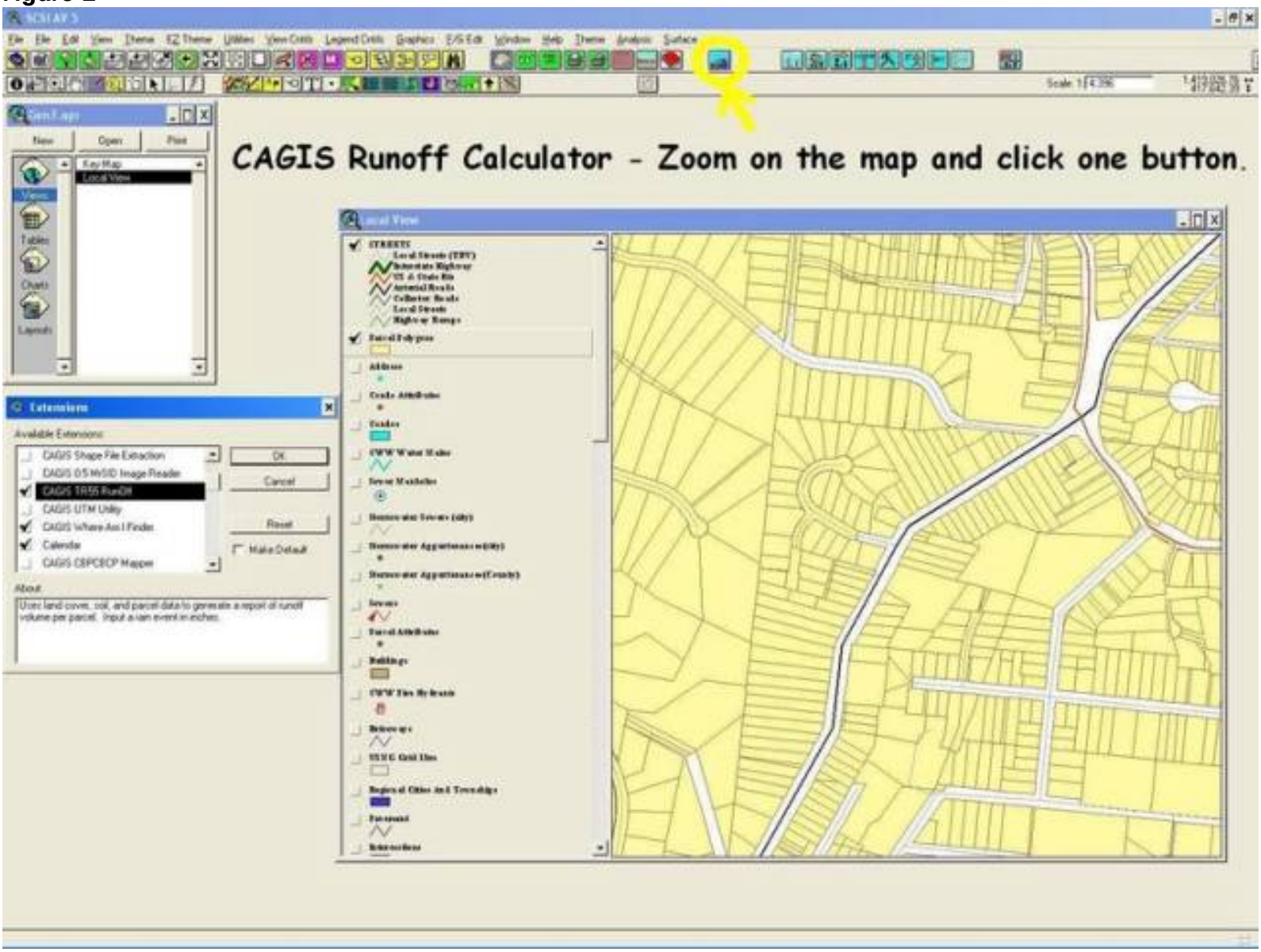
The Cincinnati Area Geographic Information System (CAGIS) is a central group of GIS professionals who coordinate and unify GIS efforts in about 40 different county and city departments. Generally, what we do is look at paper workflows or non-optimal workflows and design software that makes the work easier and simultaneously updates centralized GIS databases. Our goal is to imbed GIS on the desks of people doing city business, so that they use and update the digital map as part of their job. In addition, the updated digital map makes their jobs run faster and more accurately. However, this stormwater calculator is different because there is no existing step in the permitting process that calculates stormwater runoff impacts on the watersheds. This work is an attempt to fit a growing need rather than re-engineer an existing workflow.

Most stormwater modeling tools in GIS are geared towards hydrologists and engineers. Most of them deal with hydraulic modeling; hydrological modeling or NPDES phase II stormwater permitting and reporting. Hydraulic modeling tools calculate where in a sewer pipe network the pipes should be replaced. Trying to do water flow mass balance equations for an entire county would be very expensive. As the analysis area increases, it's difficult to get accuracy that engineers feel comfortable with, because stormwater runoff calculations have many variables and unknowns. In the permitting process, we only need ballpark numbers to indicate if the proposed development could add significant amount of runoff to overloaded 'sewer-sheds' and watersheds.

Cincinnati area already has departments doing precise hydraulic modeling on sewer pipes and another developing a system to deal with NPDES Phase 2 permits. Several departments capture stormwater infrastructure information, and perform hydrologic calculations. Still other area agencies are concerned with watershed plans and hydrologic modeling on larger watersheds. These efforts tend to run in parallel, and they are not as unified as is desirable. The goal is that someday these agencies can work together

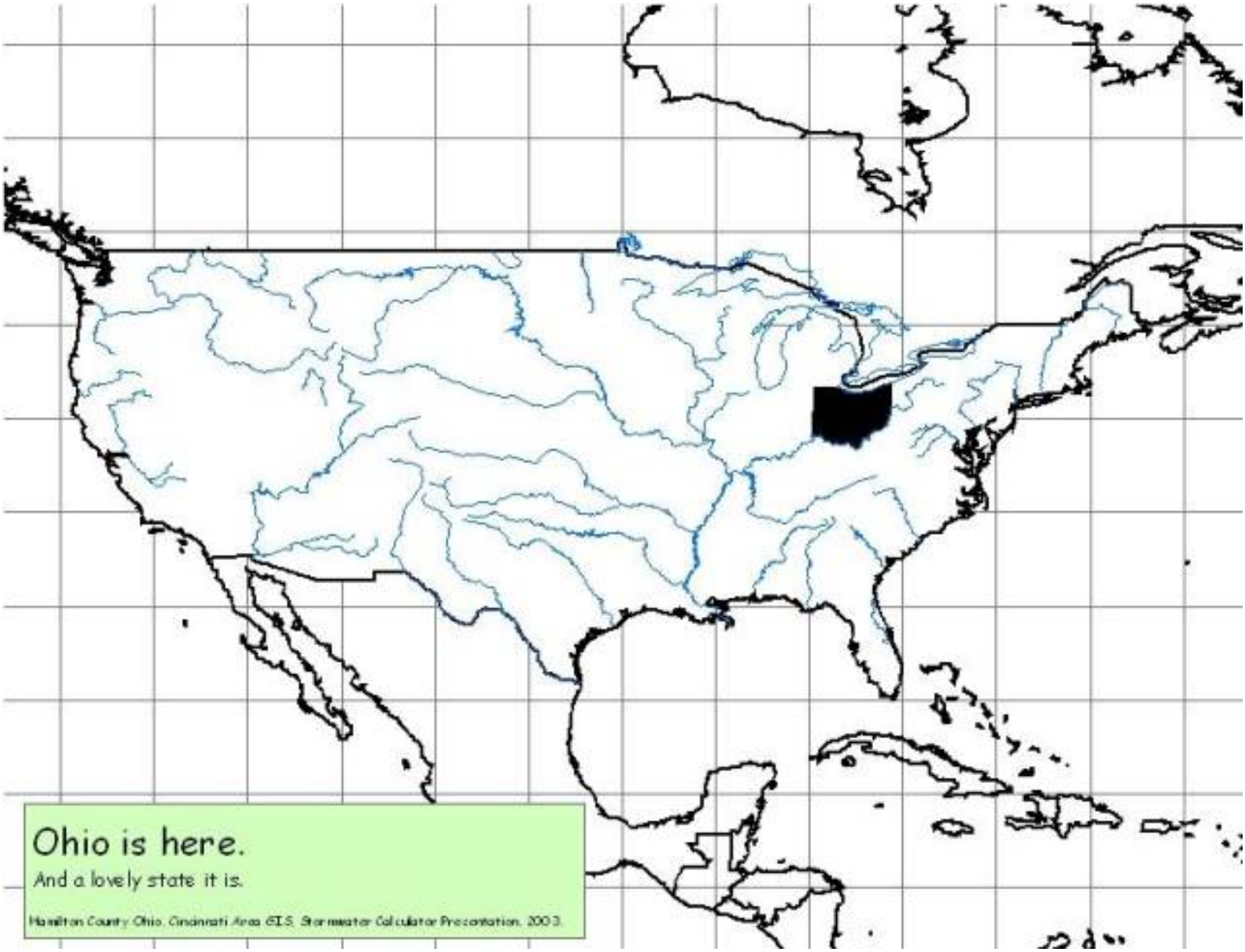
more efficiently, however, different departments have different missions, different goals, and different jurisdictions.

Figure 1



CAGIS software and data is already distributed across about 1000 desktops. This runoff calculator would be one extra button on a highly customized GIS. (Figure 1, top.)

Figure 2



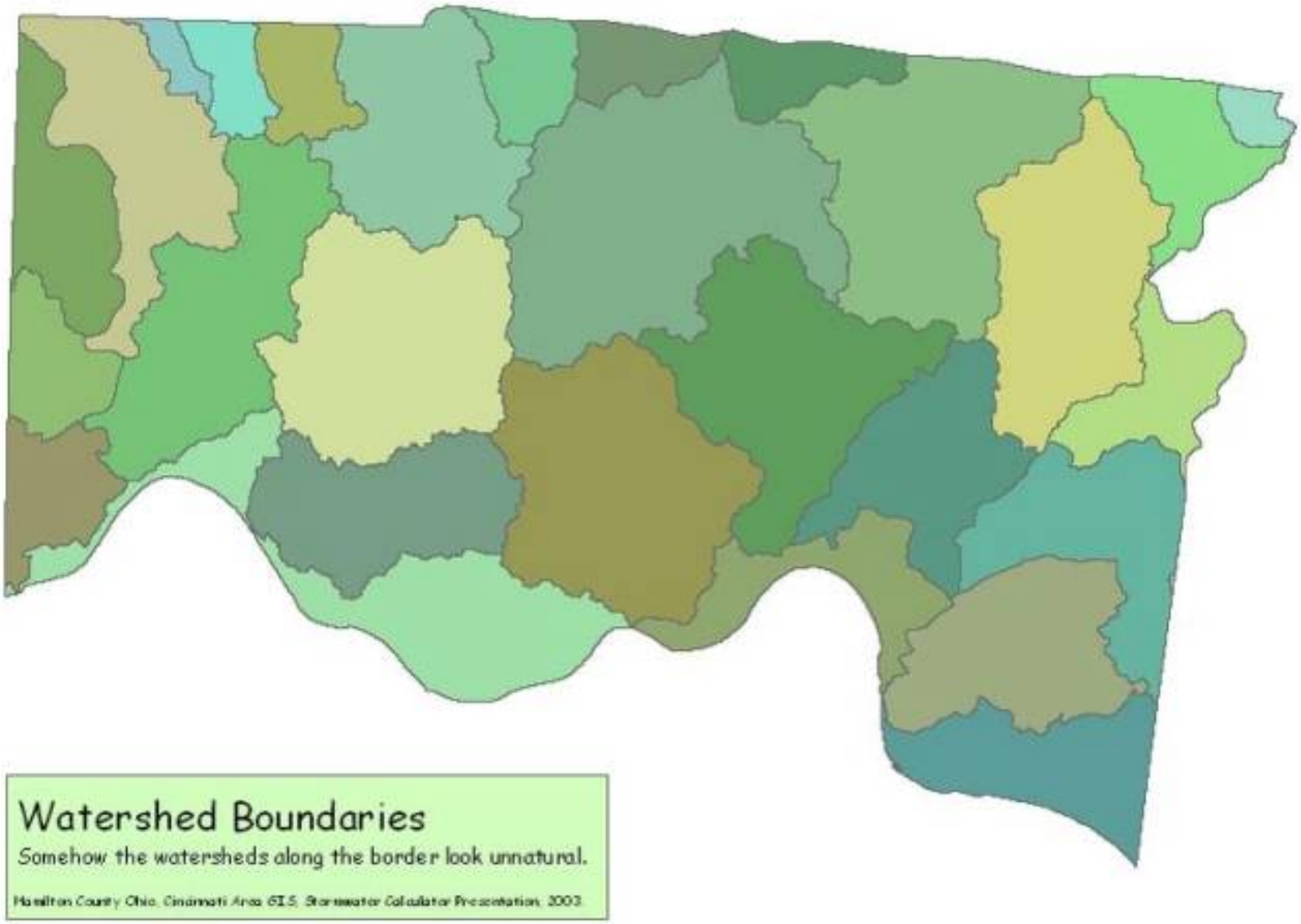
For reference, Ohio is shown in figure 2. The Ohio River borders the state to the south.

Figure 3

The City of Cincinnati is in Hamilton County, Ohio. (Figure 3.) Cincinnati is widely recognized as a nice place. As with many mid-western cities however, Cincinnati struggles with the human and environmental impacts of sprawl. Flooding and combined sewer overflows are among these problems.

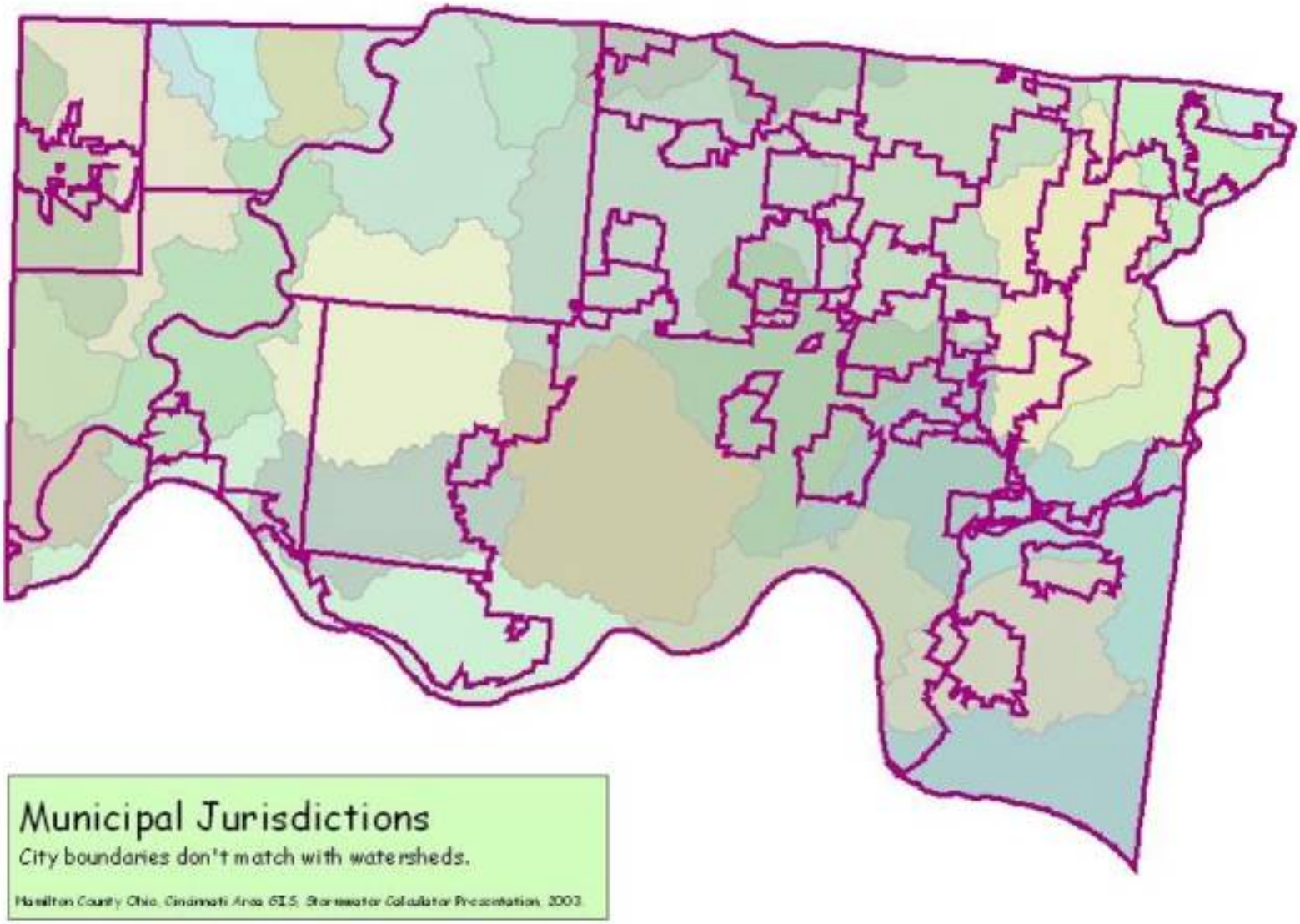
Data Creation

Figure 4



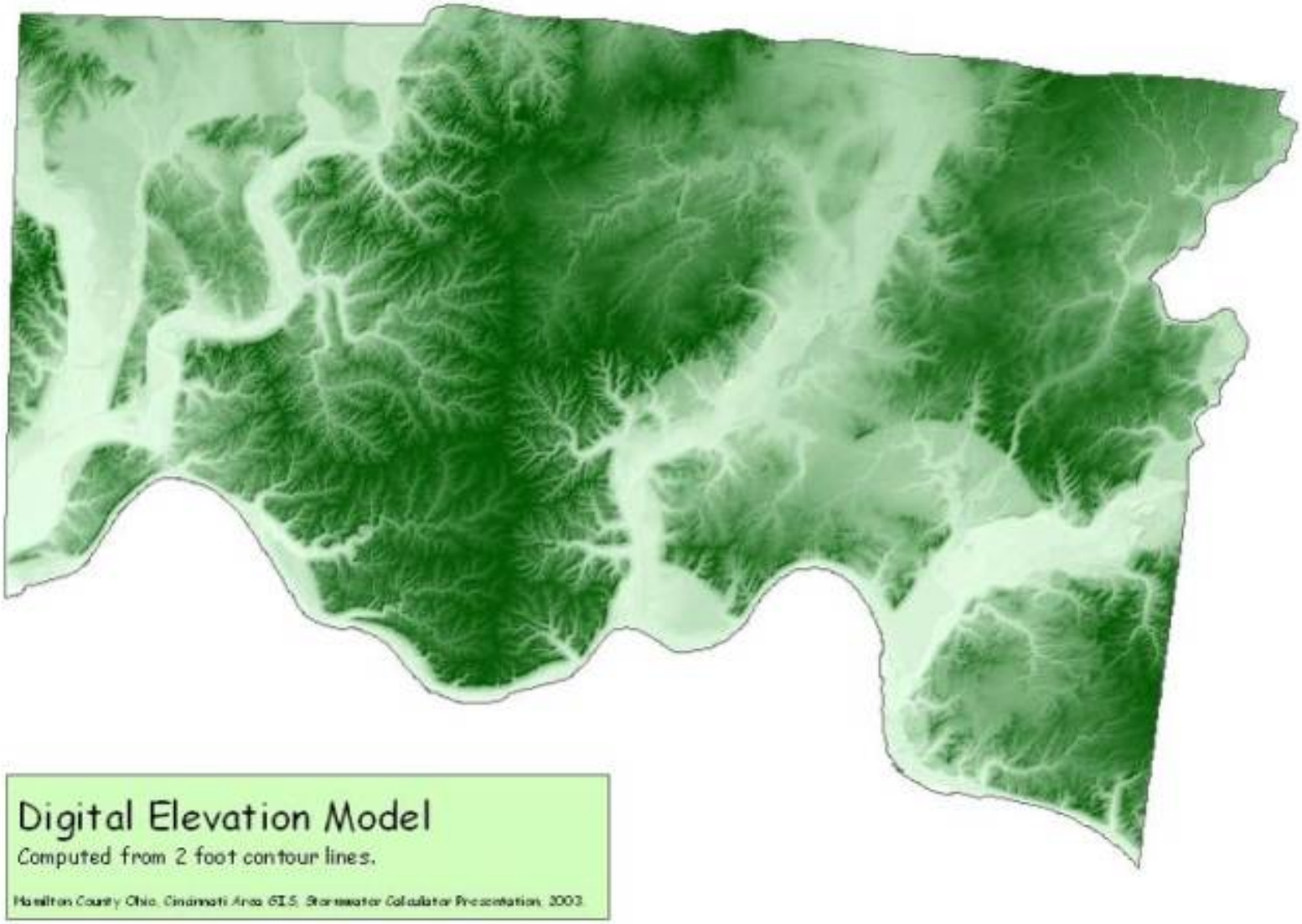
The runoff calculator requires detailed GIS data. In addition to making the calculator, we had to develop additional GIS data layers for our county. Notice that the watershed boundaries in Figure 4 seem to match exactly with the county boundary. They've been clipped, because county folks aren't responsible for decisions or infrastructure in other counties. Data is expensive and resident taxpayers don't want to pay to collect data for other counties. The fact is we don't have much useful hydrologic GIS data for the surrounding counties. Regionally people are still deciding if and how to share data. Without standardized regional data, it's difficult to do anything approaching an accurate hydrologic analysis.

Figure 5



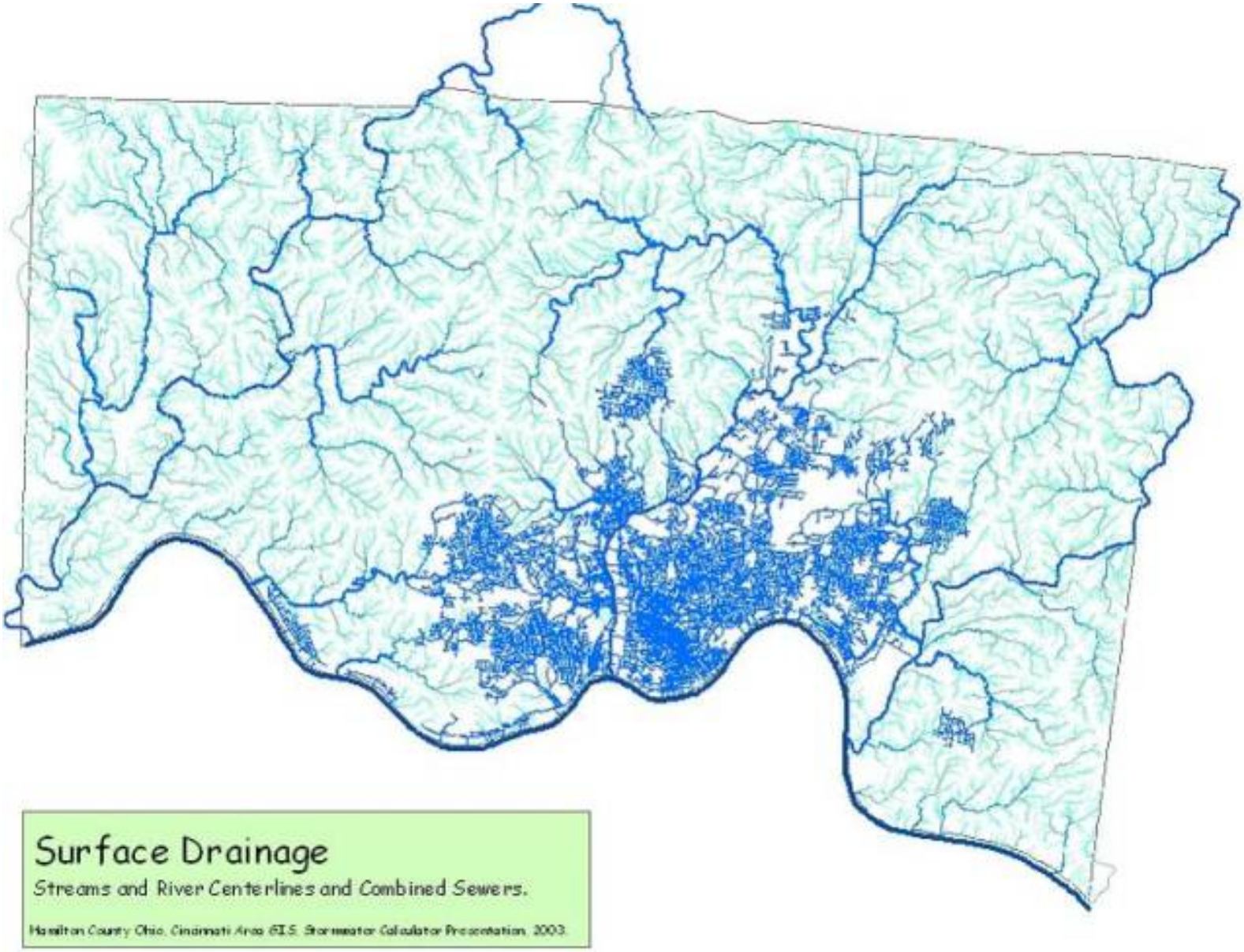
Public planners need tools that deal with the land they manage. A common problem for planners nationwide is illustrated here. The watersheds do not coincide with the political jurisdiction boundaries. One watershed has multiple agencies responsible for land planning and infrastructure. Each agency contains pieces of various watersheds. This will be a key point. Watershed boundaries do not match with national, state, county, city, or township boundaries. Individual parcel boundaries don't match with small sub-basin boundaries either. This is a fundamental problem with trying to do meaningful hydrologic calculations for political areas.

Figure 6



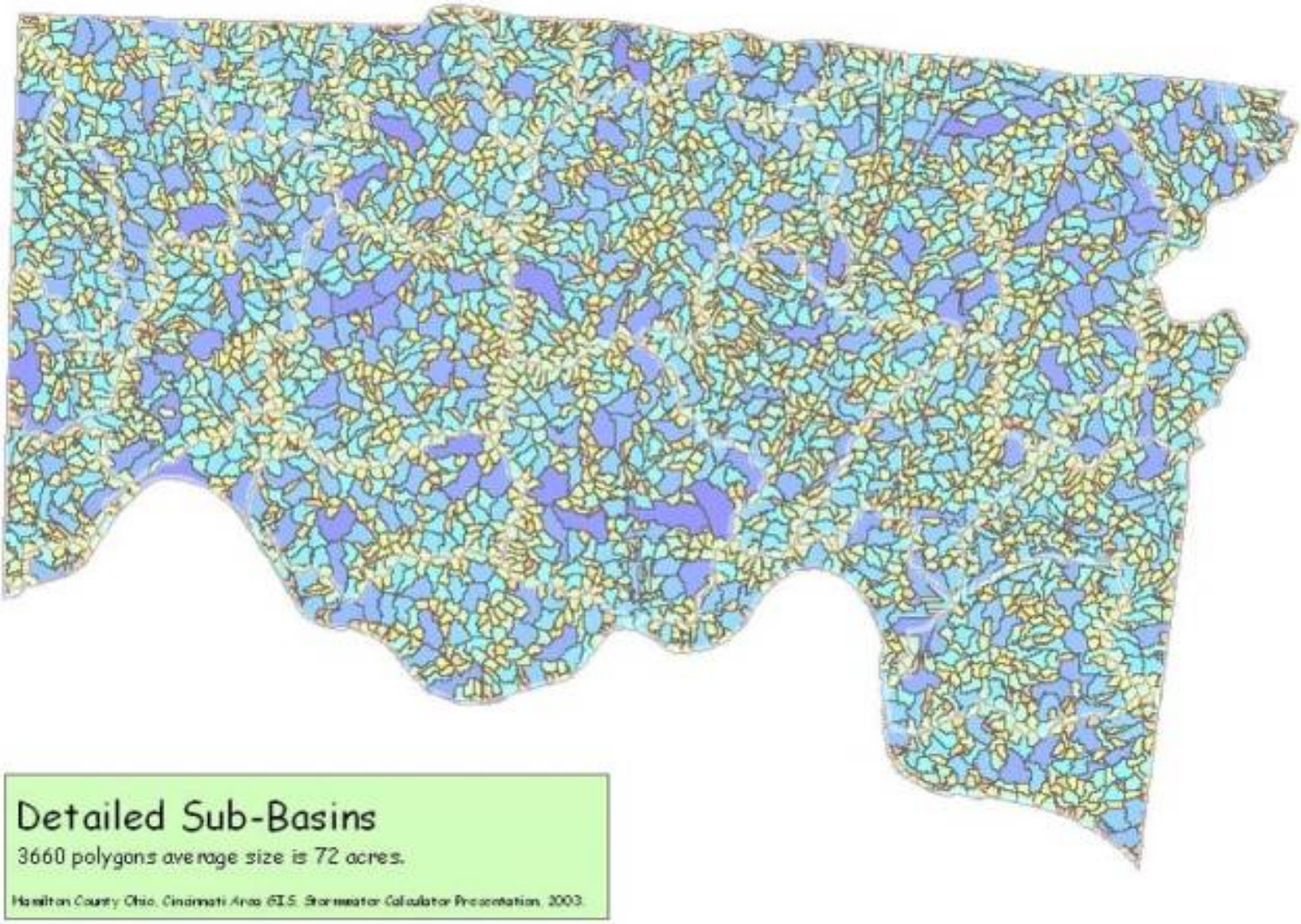
In addition to adding a stormwater calculator to our software, we needed to create data detailed enough to do hydrologic calculations on small areas. First, we built the typical GIS layers: an accurate hydrological DEM, a linear network of stream centerlines, soils data, detailed watershed boundaries and land-cover (impermeable surface) data. We used 2-foot contour lines to make a DEM (Figure 6) and we removed the sinks.

Figure 7



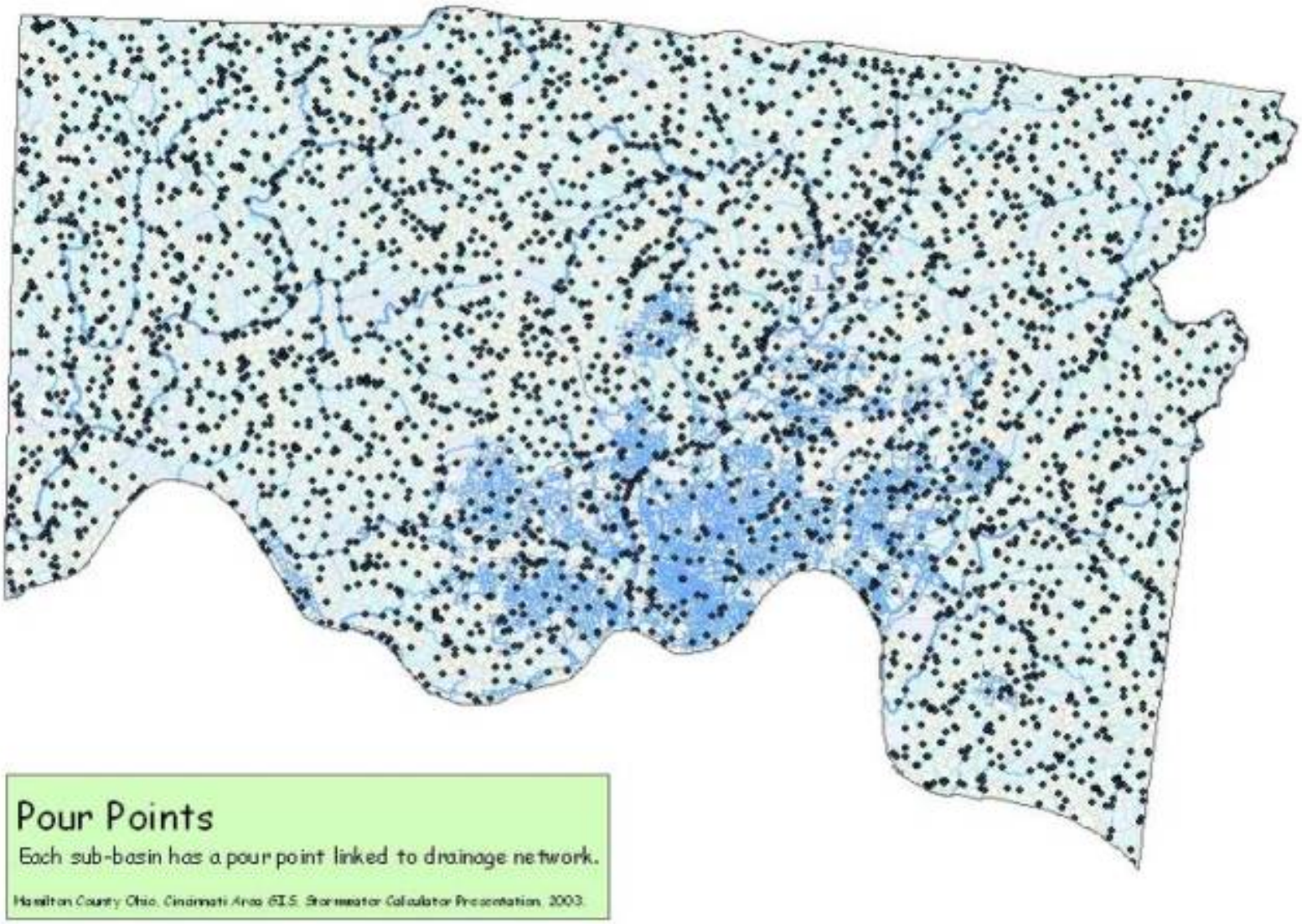
From the hydrological DEM we generated flow lines as stream centerlines (Figure 7). Redirecting stream centerlines through culverts and major storm sewers required extensive hand editing. A linear network requires all the arcs to be connected at nodes. We ran a program to test connectivity and flip all the vectors so that they flow downstream and into the Ohio River at the right place. We used half-foot orthophotos as a base layer for quality control on stream centerlines. In dense urban areas, the natural streams are replaced almost totally by roads and storm-sewers. We added in major combined storm-sewers to the stream network to fill in some missing areas of drainage patterns.

Figure 8



We recreated the DEM, in order to make more detailed sub-basin boundaries (Figure 8) that match the stream network. We went back to the contour lines with the hand-edited, stream network as an additional input to the ArcInfo function 'topogrid' and regenerated the hydrological DEM. We ran into some software limitations and had to tile the job into workable chunks by watershed boundaries. We used very general USGS watersheds to start with. Then we made a more accurate watershed layer using the second version of the hydrological DEM.

Figure 9



The layer of pour-points required to create detailed watershed boundaries is shown in Figure 9. The one and three valent nodes from stream network lines worked well as input pour-points. We used some conflation to relate the stream names and data from the EPA reach files to attribute larger streams. The ESRI help files describe the process of how to build hydrologic GIS data, but it's not automatic. Labor-intensive hand-editing was required on both the streams and watershed boundaries.

Hydrologic Model Selection

It took a couple years to build these layers with one staff person working a few hours a week and several university interns working half time. We also had to make a choice about hydrologic models. For our calculator we chose to use TR55 model. Engineers and hydrologists generally agree that SWMM or HEC based software would be more accurate. Technically, they are right. However, these tools are too complex for planners to use for screening purposes. TR55 is a simple empirical model that allows us to do runoff volume calculations on political boundaries, like parcels. Drainage areas tend to be teardrop shaped polygons. Administrative boundaries tend to be rectangular. To make a hydrograph, we would have to do the calculations on drainage areas. Local governments cannot use watersheds to manage land, unless they re-engineer workflows, software and databases. The TR55 calculations can be run on parcels, cities, or neighborhoods. It doesn't matter, to the equations where the water flows after it runs off. New stormwater is added to the landscape by new development within an agencies jurisdiction, we can now easily estimate its volume for a given precipitation event.

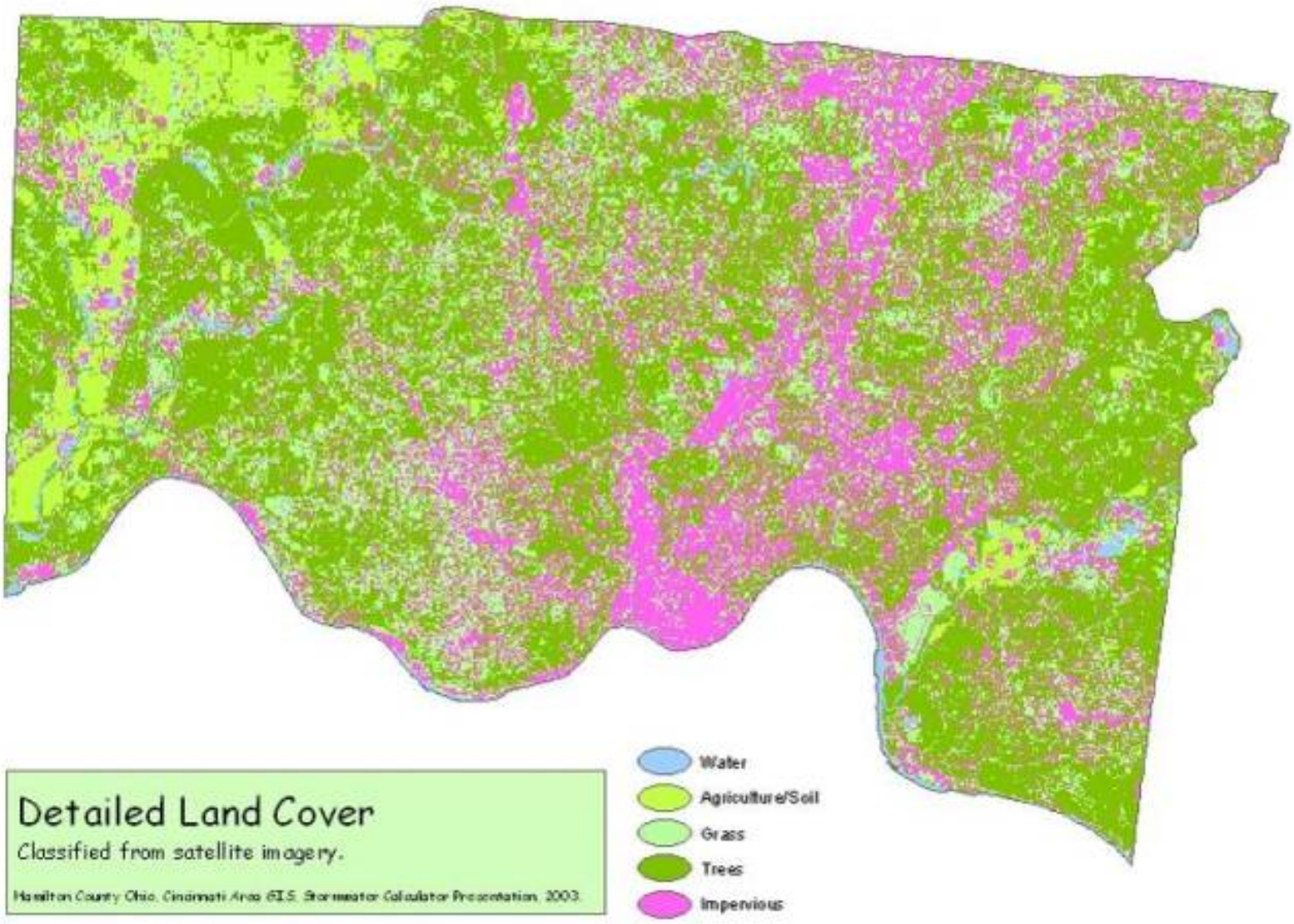
Community leaders want to be able to predict flooding problems. Many modeling software's are available for flow modeling. The missing piece is not really the software but the data. Detailed flood modeling requires detailed and up-to-date GIS data over large watershed areas. A detailed, up-to-date, GIS database of pipes, streams, roads, and watersheds can only be achieved if agencies pool their efforts to update the data, as part of daily workflows. That means that agencies must discuss and agree on a database design for how to model streams, stormwater, and sewer infrastructure in GIS. Agencies need to work together to share data, and coordinate the processes that update the data. This seems like a simple point, but it is not. The quality of networks, computers, software and databases is increasing. The technical barriers to sharing both data and workflows are dropping.

Figure 10

After making a stream network and sub-basin GIS layers, we realized that these datasets wouldn't be immediately useful or necessary for our stormwater calculator. The TR55 model needs land-cover and soil data (Figure 10.) Our county soil surveys had already been polygonized into GIS data. Still, we had

to download attributes for general soil groupings. Some data cleanup on this soils data was necessary to make it work with TR55.

Figure 11

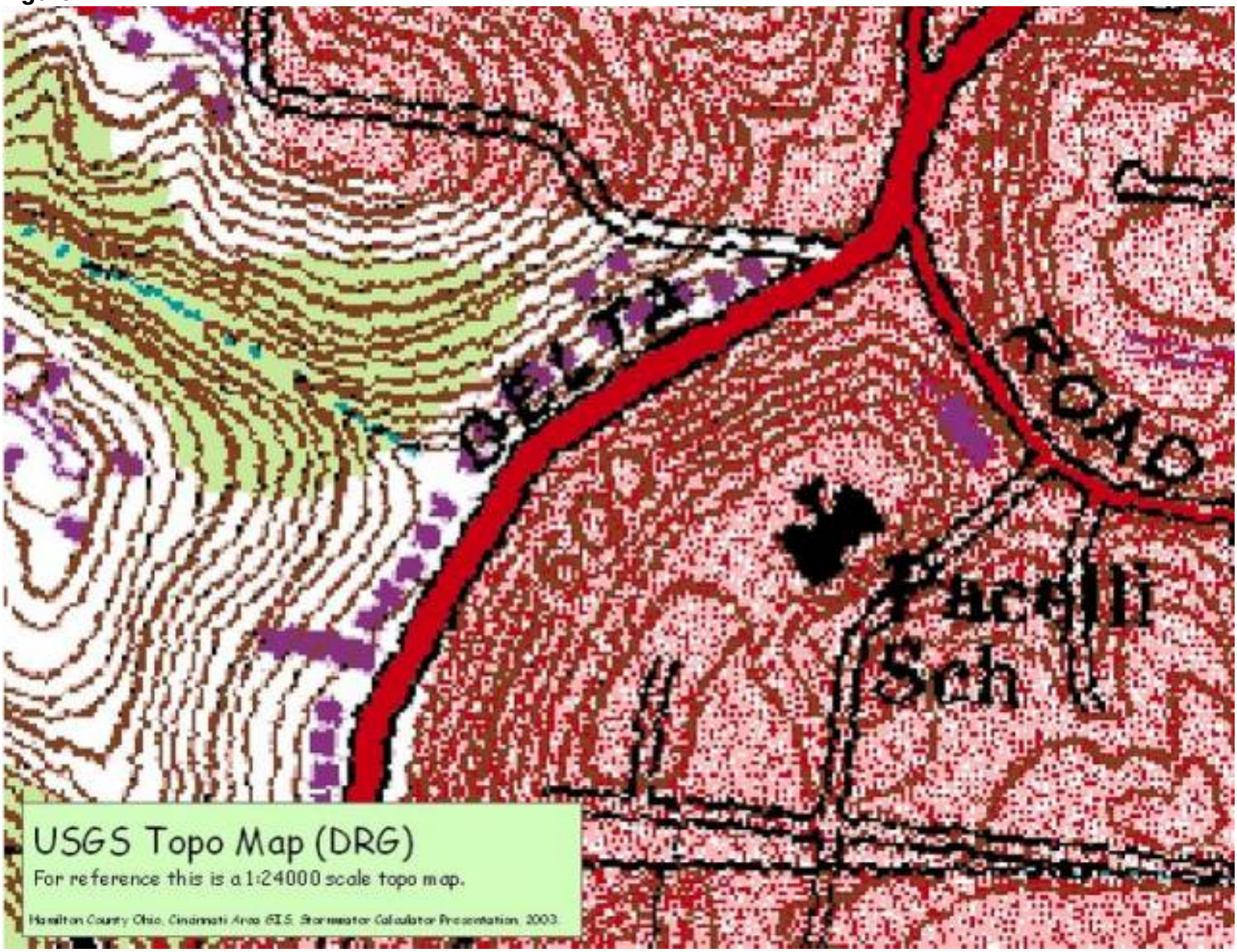


When using the TR55 model to do runoff volume calculations, the accuracy depends mostly on the quality of the land-cover data. Stormwater models are very sensitive to the percent impervious surface area. We know of two ways to get decent land-cover data. One is remote sensing using 4-meter resolution classified satellite imagery. The other option is to trace the boundaries of all the paved surfaces and buildings from large-scale orthophotos. These two products look very different. At 1:500 scale the raster GIS data from classified satellite imagery has a 'blocky' look. Digitizing accurate impervious surface polygons looks better to the eye, but can be expensive. We chose to purchase 4-meter satellite imagery to make a land cover layer (Figure 11.)

(One additional option to build the land-cover layer is to use survey GPS, but the cost would be prohibitive. Once we built the calculator, we explored some of the other options for land-cover data by testing it on data from several different sources and compared the results. We compared 4 data sources: public domain USGS MRLC data, auditors land-use codes attached to parcel polygons, remotely sensed and classified satellite imagery, and hand digitized, detailed impervious surface

polygons.)

Figure 12



People working in permitting and zoning deal with parcels, so they need relatively detailed GIS data because they usually work on a small area of the map. For example if we zoom into a typical city subdivision on a USGS 1:24000 scale topo map (Figure 12), we can get an idea of what the subdivision looked like 30 years ago. Many people are familiar with these maps so Figure 12 is included for a sense of scale.

Figure 13

The same area of land now has more parcels and more houses. Figure 13 average parcels in a typical city neighborhood. The colors represent land use codes for the parcels and zoning rules. Most of the parcels are single family, multi-family or commercial. Parcel land-use codes, or even census tracts, could be used in TR55 instead of detailed land cover data. For large watersheds aggregating land-use polygons works, but at the parcel level it is not acceptable.

Figure 14

At this scale (1:5000), notice that the ownership boundaries do not match with the sub-basin boundaries (pink jagged lines). The permitting and zoning process is carried out at the parcel level, and CAGIS has already integrated GIS databases to this process. Workers making zoning and permitting decisions do not have time to run complicated hydraulic models. Moreover, they need tools that work on parcels. By using the TR55 model, we can calculate runoff volume by parcel. We don't need to modify sub-basin boundaries to match parcel boundaries. Nor do we have to run calculations on larger watersheds and then apply values to parcels.

Figure 15

The classified satellite data provides a good estimate of impervious surface area; tree and grass cover per parcel. (Pink areas in figure 15). It is not as precise as hand-digitized impervious polygons. Still, we get reasonable runoff volume estimates at a much lower cost. However, the blocky, rasterized look of the data does give people the impression that the layer is inaccurate. This has been a barrier to implementing the run-off calculator.

The choice of methodology for land-cover data layer creation will depend on the ultimate use of the run-off calculator. In the current application, remote sensing proved the best approach for land-cover data. Our pavement data was captured as disconnected lines a long time ago. Polygonizing it would have been expensive. If an organization has a strong need for accurate vector GIS polygons of pavement and buildings, then maybe remote sensing is not the best way.

Figure 16

We have received positive reaction to demonstrations of this CAGIS runoff calculator, despite concerns about accuracy. Most of our users expect to see a land-use base map of half-foot color orthophotos as shown in Figure 16. We maintain, however that given the variation in stormwater modeling calculations, total accuracy is not realistic. The calculator is useful for easy 'what-if' calculations.

Figure 17

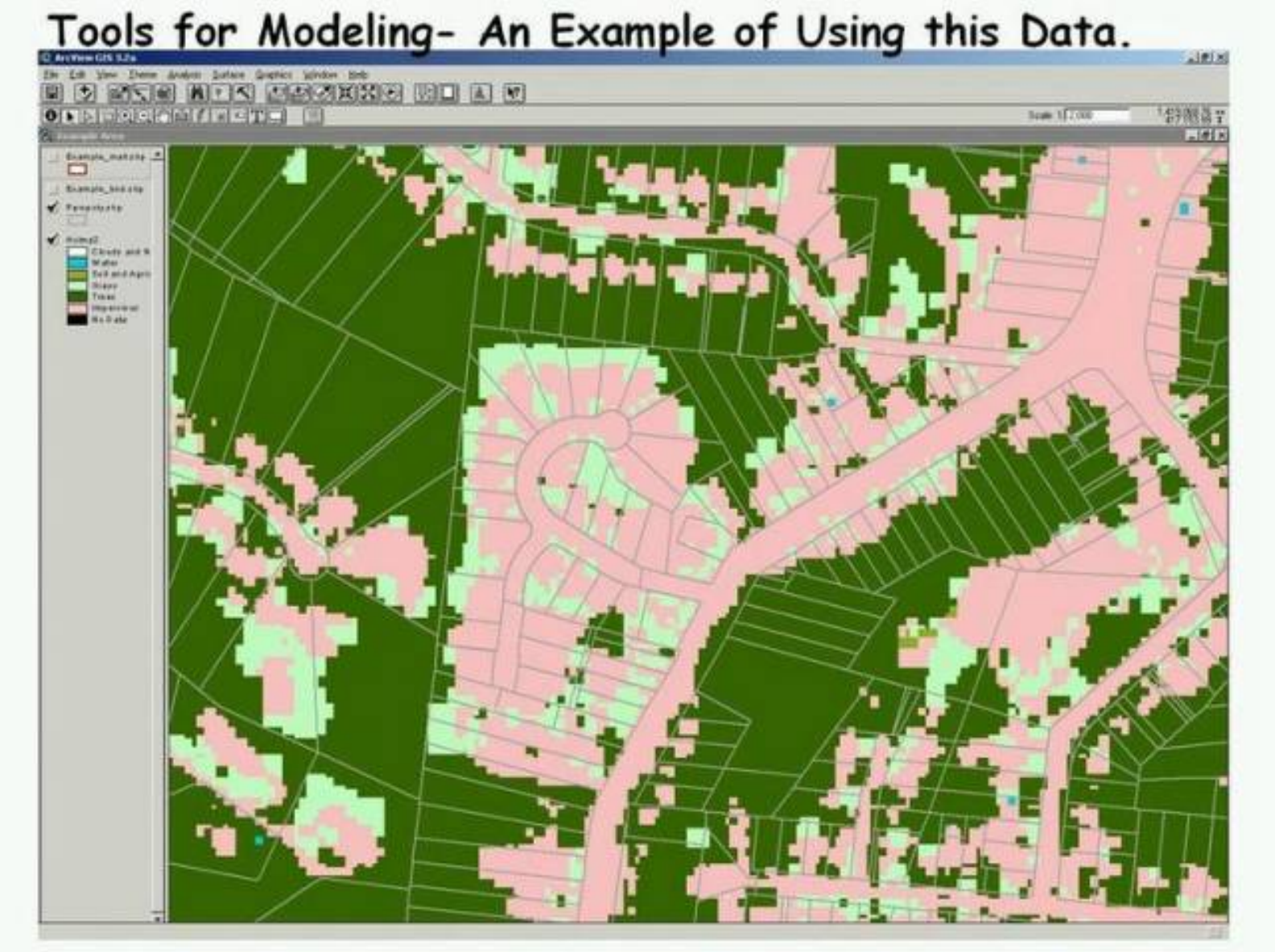
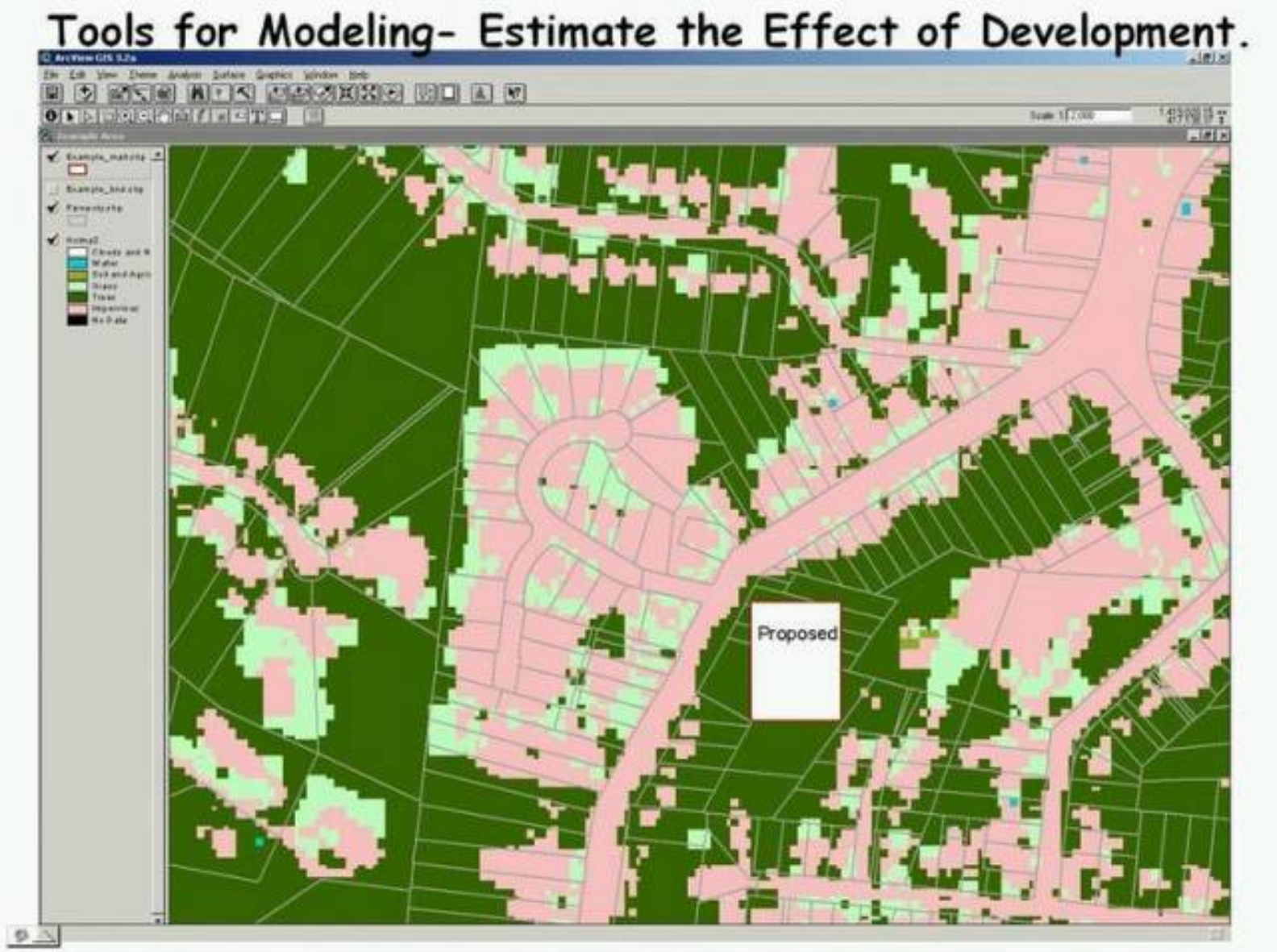


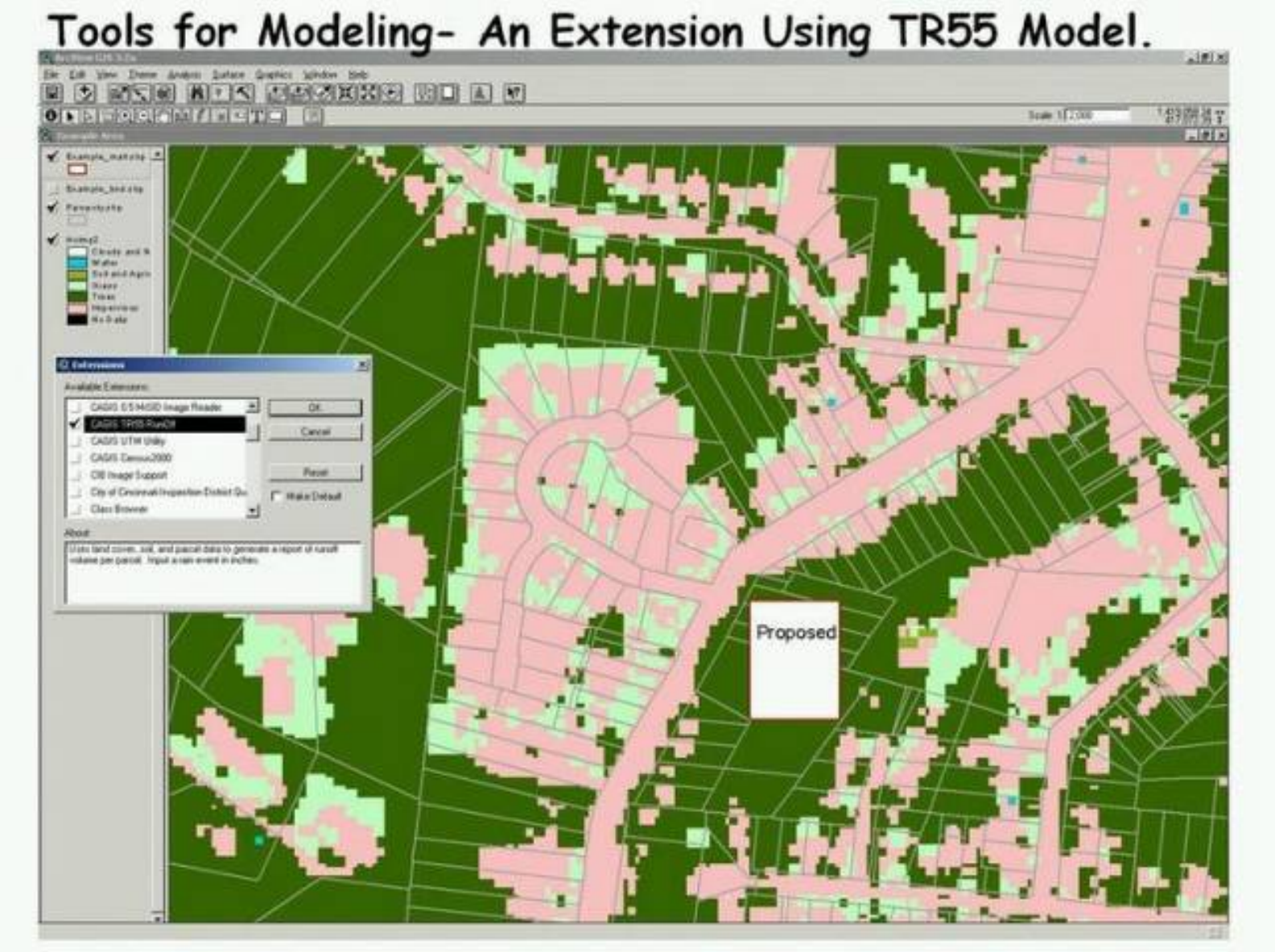
Figure 17 shows the area of interest for a 'what-if' scenario.

Figure 18



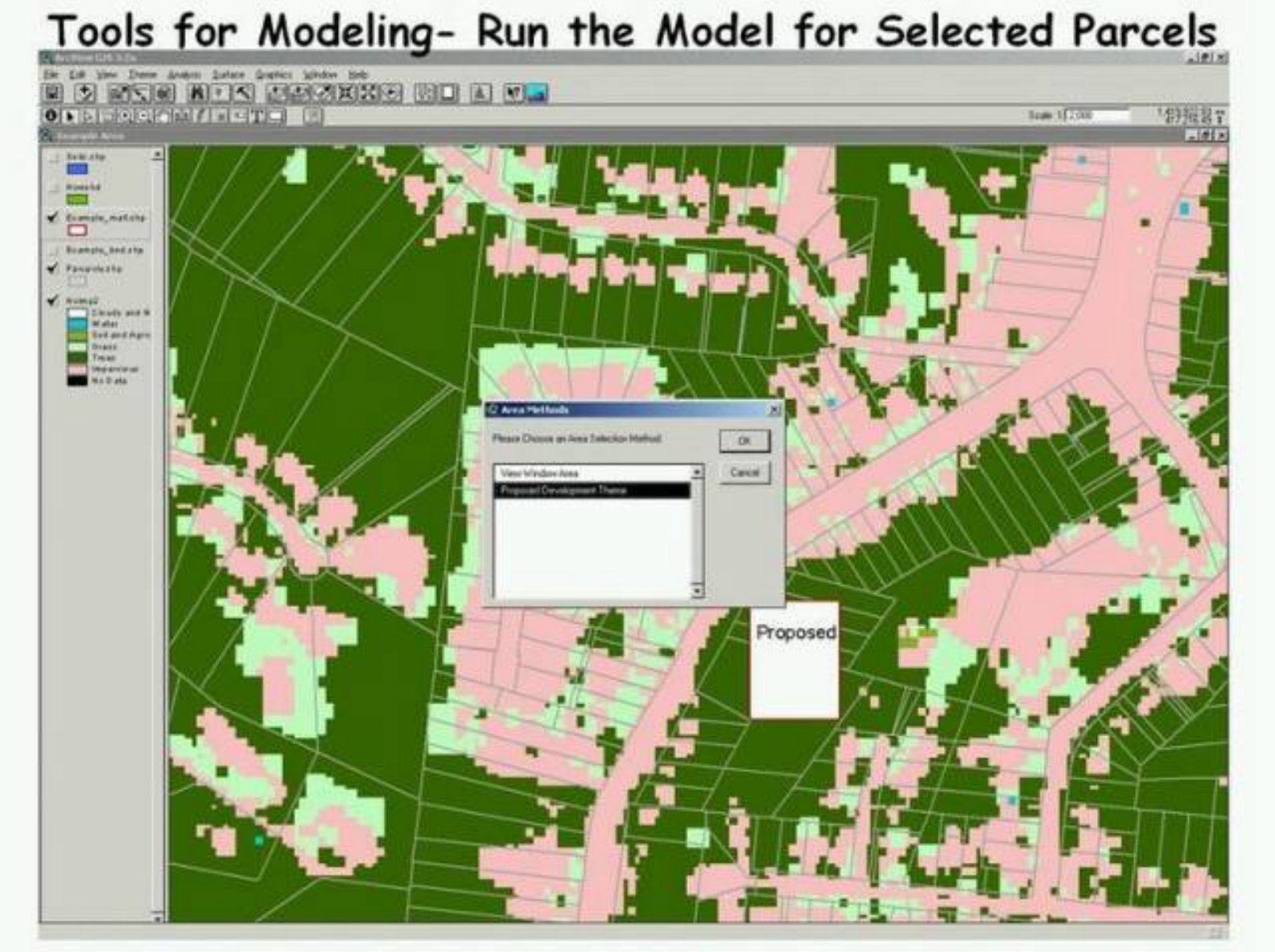
We add shapes to the map representing the changed land cover. For example, consider a proposal to add a parking lot over top of some trees. In Figure 18, the pink areas are impervious surfaces, light green areas are grass, dark green areas are trees and the white box is a proposed new impervious surface.

Figure 19



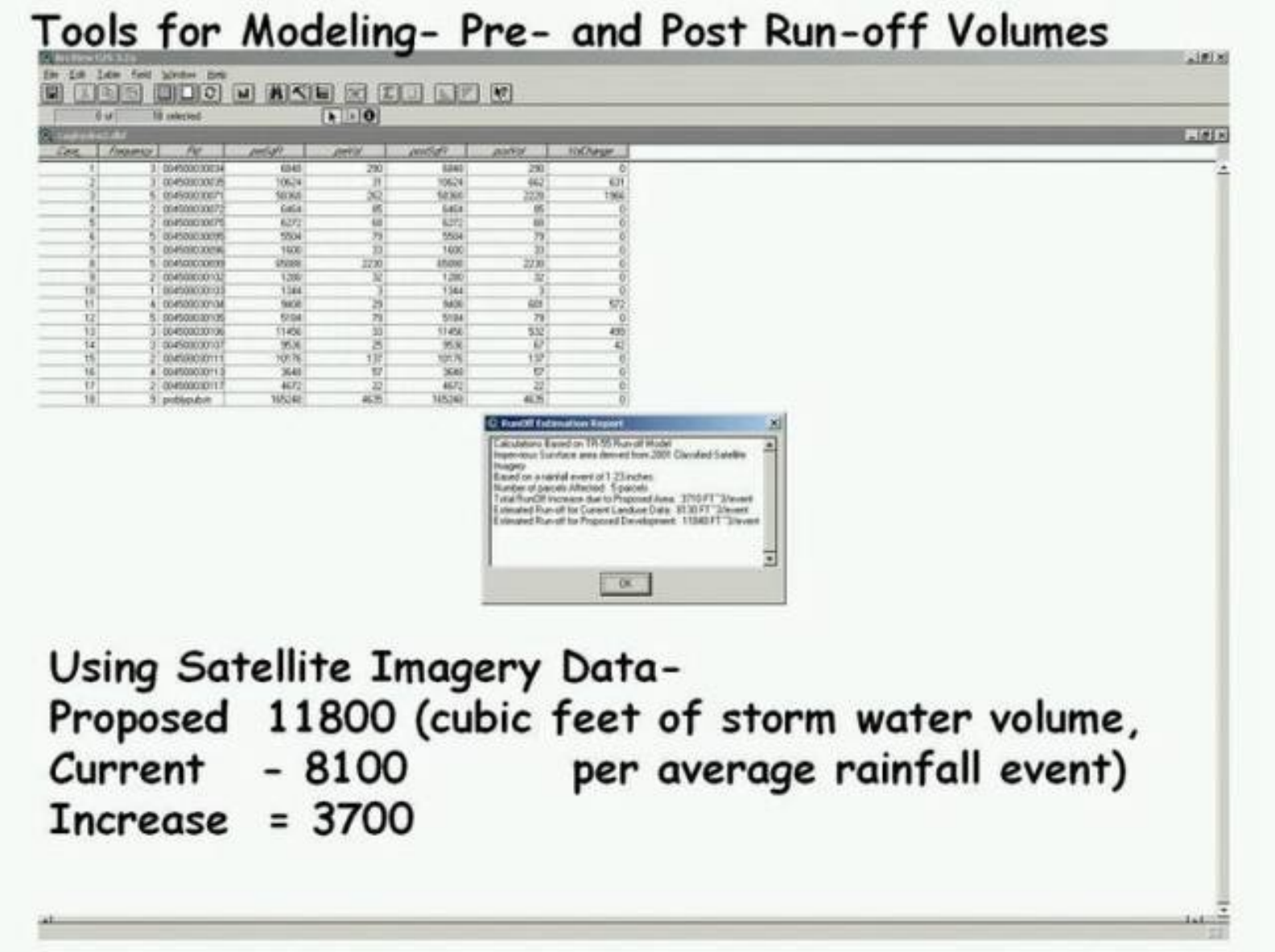
This tool is an ArcView extension that can be turned on easily when needed (Figure 19.)

Figure 20



The ease of use of the calculator is illustrated in Figure 20, the user is asked a single question.

Figure 21



The calculator produces a summary of estimated stormwater runoff volume due to this development, in this case 3700 (Figure 21.) The significance of the output is straightforward. The program calculates the stormwater runoff for each parcel based on existing land use layer. Then it runs the same calculation with the proposed land use layer. The difference in the two calculations is equal to the change in runoff volume due to the proposed development. By default, it uses an average rain event of 1.23 inches of precipitation. The answers are reported by parcel. 'X' number of cubic feet would run off this parcel for an average storm. 'Y' cubic feet would run off if this parking lot were added. Y-X=Z. Therefore, Z cubic feet of new stormwater has been created by this parking lot.

This runoff calculator doesn't produce flow information, or hydrographs. Other software could be used to do more landscape scale hydrologic modeling. What the runoff calculator does do is allows for a quick look at potential ramifications of various development scenarios. This information could be used by planners for a variety of functions. For example, fragile watersheds could be tagged to limit new additions of stormwater. These limits could be enforced in a standardized way by all local permitting agencies. A long term, regional land-use plan could be developed across counties. Each county could enforce that plan with its own zoning and permitting process. Drainage pipes could be better designed and upgraded if a firm regional development plan was enforced by a regionally coordinated zoning and permitting effort.

Policy and Implementation Issues

Excess stormwater runoff from urbanizing areas is increasingly being recognized as a serious threat to the public in the form of increased flooding. The recently implemented Phase 2 of EPA's NPDES Stormwater permit program focuses attention on stormwater in local governments. Nevertheless, the general trend is towards reducing permitting red tape related to new development. The ability of the storm water runoff calculator presented here to easily, quickly calculate a list of run off volumes by parcel in a chosen area makes it an attractive tool for local policy makers.

Local flooding, CSO problems and erosion problems are increasing. People are concerned about flooding and the connection in the public's mind between urban sprawl and flooding can be strengthened by tools such as the runoff calculator. The runoff calculator could be used to inform policy decisions such as the assignment of stormwater fees based on actual runoff estimates, rather than just using parcel size, or uniform stormwater fees.

Recently our city just dissolved the entire planning department, and moved the people into what was the economic development department. The name of the new department is 'Community Development and Planning.' Notice. The new name is not 'Community Planning THEN Development'. The general trend of local governments nationwide is to attract development by cutting red tape and offering incentive packages. At the same time, from 1980-2000, the proportion of developed land in the region increased by an astounding 141%, while population increased by just 15%. (sierraclub.org) Local urban population declined during that period.

The public wants a strong economy but there is a growing awareness about problems related to urban sprawl. For example, here is a comment from a neighboring county leader. "*All you gotta do is turn on the television at night and listen to how things are in Hamilton County, in Cincinnati... No one wants to live down there anymore, guys. They all want to have the good life like we've got here in Warren County ... I don't want to turn Warren County into one solid sheet of concrete.*" (Mike Kilburn, Warren County Commissioner)

Our city faces other problems besides flooding and sewer overflows. It is not the software developers, or the hydraulic engineers, or the public, or the planners, or the permitting people who really make development decisions. Neither is it only up to politicians and business people. There is a complicated mix of political, economic and environmental issues. Here is another software tool and some ideas to throw into the mix.

Conclusion

GIS software tools that estimate the volume of new stormwater runoff can be made in-house on a limited budget.

With the TR55 model, we can calculate stormwater runoff volumes, for parcels, and political boundaries without adding the unnecessary complexity of hydrographs.

One main benefit of this runoff calculator is that it is simple to use. The drawback to being simple is that it looses flexibility and accuracy. Yet, the simplicity is not really a drawback. It's a step in the right direction. We often use the phrase 'progressive functionality'. The current permitting process has no push-button step for estimating the addition of new runoff. It's best to add a simple tool first to get ballpark numbers. Some simple tools are better than nothing. In the future, if there is a need for more accuracy, we can add more accurate hydrologic tools and data.

The complexity of GIS software is not always the best measure of its value. Before spending a lot of

money on stormwater modeling, I'd urge GIS folks in other local governments to sit down and consider how the software they are buying or developing is to be integrated across workflows. We tend to gauge success of software on how well it streamlines a workflow and integrates data across agencies. NPDES Phase 2 reporting, sewer system hydraulic modeling, stormwater infrastructure management, land-use planning, zoning, and permitting are related workflows. Therefore, they should be using and updating the same GIS databases.

Acronyms

CSO = Combined Sewer Overflow

GIS = Geographic Information System

CAGIS = Cincinnati Area GIS

NPDES = National Pollutant Discharge Elimination System

TR55 = Technical Release 55

SWMM = Storm Water Management Model

HEC = Hydrologic Engineering Center

USGS = US Geological Survey

DEM = Digital Elevation Model

GPS = Global Positioning System

MRLC = Multi-Resolution Land Cover

Acknowledgments

Thanks to the following people for ideas and discussions about this software: Barbara Quinn, Shaoli Huang, Ed Weber, Bob Babbs, Paul Kreimer, Steve Donovan, Susan Moisio, Hale Thurston, David Szlag, Bill Shuster and Beth Lemberg.

Thanks to these interns for their work on the project: Susanne Wimmer, Mike Ellis, Khalid Hasan, Hu Wei, David Jirousek, Vrushali Dixit, Puchun Cai, and Qinghong Wei.

Thanks to the Purdue University LTHIA project for ideas about how to use TR55 in ArcView.

Thanks to Kass Green and Nancy Thomas from Space Imaging Services for knowledge and advice about classifying Ikonos Satellite Imagery.

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Author

Andrew Swift is a programmer for CAGIS, the Cincinnati Area GIS. He received a Masters in Environmental Science from Indiana University in 1996. E-mail: andy.swift@cincinnati-oh.gov