Pilot Study

for

Shallow Groundwater Maps for On-Site Evaluation

Draft Final Report

To the

Texas On-Site Wastewater Treatment Research Council

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Introduction

This study addresses the issue of accurate assessment of shallow groundwater for site evaluation purposes under the On-Site Sewage Program guidelines of the Texas Natural Resources Conservation Commission. The question addressed here is whether a map-based system could be used to substitute on-site evaluations of shallow groundwater made by county health personnel or other designated representatives.

Current regulations in Texas call for an on-site evaluation for the presence of shallow groundwater (TAC30, Chapter 285.30). The ability to accurately assess the presence of seasonal groundwater depends on the ability to correctly interpret soil drainage mottles and landscape drainage patterns. When properly interpreted, drainage mottles are an excellent indicator of shallow groundwater. The problem is that the ability to correctly interpret mottles requires a fair amount of sophistication in soil science, a skill not well distributed among county health departments. A more difficult problem is that the period required for mottle formation in some soils may be much longer than any reasonable margin of safety in terms of length of soil saturation. Some red soils on the Texas Gulf Coast for example experience saturation periods of up to 4 months without the formation of mottles (see Jacob, 1999). Significant error that could result in serious public health exposures is clearly inevitable under the current arrangement.

Requiring on-site evaluations by professionally-trained soil scientists is one solution to the above problem. Such a requirement is not politically feasible for the present, in part due to insufficient numbers of trained soil scientists that would be required to perform the more than 50,000 evaluations that are conducted annually in Texas.

Maps of the distribution of shallow groundwater are a potential solution to the evaluation issue. The problem here is one of accuracy. We have no quantitative sources that would allow us to develop a map with any reliable degree of accuracy (i.e., without error). Considerable resources would be needed to be able to precisely model the landscape to the degree needed for an accurate map, and almost any map thus developed would still be subject to significant error.

In spite of a lack of quantitative data, soil scientists do know enough about the landscape to make some fairly accurate assessments about where seasonal shallow groundwater may occur. At the very least, a line can be drawn sufficiently high in the landscape above which we can be reasonably sure there is little chance for the presence of shallow groundwater. There would of course be considerable error in the sense that we would have to draw the line quite a bit above the true location because of our lack of precise information.

Error is inevitable. The error that exists in the current system is not controllable. It is entirely dependent on the ability of non-soil scientists to make fairly sophisticated judgments about soil saturation events. On the other hand, with available information we can construct maps of the occurrence of shallow groundwater that contain quite a bit of error, but error that is predictable and biased toward benefiting the public health. The question we are attempting to answer here is whether or not such a map would be useable at the scale of a county permit program.

The existence of a suitability map could be important to county-level programs in that it would provide a consistent means of identifying groundwater problem areas. In addition, it would also provide a scientific standard which could be appealed to in disputed cases. Because of the inherent error in the map, counties could allow variances based on an in-the-field site evaluation of a Certified Professional Soil Scientist.

We contracted with the Texas On-Site Wastewater Treatment Research Council to develop provisional shallow groundwater maps for five Texas counties in urban fringe areas subject to high population growth. Because of funding limitations, we developed a detailed map for only one county, Montgomery, and provisional maps for four others (Guadalupe, McClennan, Denton, and Williamson). The provisional maps are based solely on USDA soil surveys available for those counties. The Montgomery County map is based on a more sophisticated approach using soil landscaping modeling.

The maps were developed in ARCVIEW 3.2 geographic information system software. Complete documentation of all software development is contained in Appendix A.

The map presented here (on accompanying CD) has a simplified user interface that facilitates access. Map location can be determined from aerial photographs (part of the GIS on the CD) or map clues such as streets, or by entering coordinates from a GPS. If the map proves useable, we will incorporate address locator software such as that used by county 911 systems. In addition to the suitability status of the soil at a given site, users can obtain information on soil type, slope, and elevation. Printouts of any or all of this information at any given site can easily be executed.

The software requires that the user have ARCVIEW 3.2 installed on a computer. Montgomery County is currently operating under our site license as an experimental project. The software itself costs about $800.00. Most counties have sufficiently powerful computers to run ARCVIEW.

Conclusions

The Montgomery County map is currently undergoing field testing by the County Public Health department. The field staff have reported that the digital GIS map is easy to use.

Initial reports indicated that the field staff is using the map primarily in disputed cases rather than using the map as the initial determination of groundwater status. We chose Montgomery County because it is the closest county where we could begin to find significant landscape relief. Most of the County is quite flat and poorly drained, but it has much more relief in the NW quadrant than in all of Harris County, for example. The County staff already recognizes that most of the county is poorly drained, although interestingly they cite a value of about 25% suitable soils with respect to groundwater, whereas our model shows only 10-15% of the soils as suitable.

There are two errors we can make with the map. We might call the first Type 1 error: classifying an area as dry that in reality has seasonal ground water in the treatment zone. Type 2 error would be classifying as area as wet or seasonally wet that is actually dry all of the time. A conservative map will minimize Type 1 error at the expense of Type 2 error.

Table 1. Potential Errors in Shallow Groundwater Determination

Determination → / Actual state ↓	Unsuitable	Suitable
Unsuitable	No error	**Type 1 Error (Public health threat)**
Suitable	**Type 2 Error**	No error

The success of our map can be measured on two fronts. First, that it is actually a conservative map, with minimal Type 1 error; that is, one can be reasonably sure that any area indicated as suitable on the map actually is suitable, regardless of the converse error (suitable areas identified as unsuitable). A map that identified the entire county as unsuitable would obviously meet this criteria, but would have no value as a diagnostic tool. So there has to be enough discrimination to make the map useable.

Preliminary results (feedback from the County staff) indicate that the map is conservative, i.e., that it is not likely to contain errors contrary to public health interests (Type 1). As to whether it discriminates sufficiently between suitable and unsuitable areas has not been determined.

We plan to test the fitness of this map by comparing past determinations by the County staff with the map classification. We will make an independent field determination of the drainage status at selected sites, preferably by a soil scientist not associated with this project. If professional determinations show that significant Type 1 error has been made by county staff, and that the map determinations would have eliminated this error, then the map will be deemed to be fit, even if significant Type 2 error is introduced by the map.

We developed preliminary maps for four additional counties. Because these counties have much greater relief, the maps for these counties will be perceived to have greater diagnostic value, given that there is a much greater percentage of suitable soils in each county. In reality, the map for Montgomery County is just as powerful, but the truth is that most of the county is unsuitable with respect to groundwater. A map for Harris County would show that well over 98% of the county is unsuitable with respect to groundwater for standard systems. That is one reason we did not choose Harris County as a pilot project.

The preliminary maps are based on soil surveys only. Additional analyses of profile curvature and slope are needed to develop final maps. These analyses will probably add 5-25% additional unsuitable areas to each map. The GIS interface for the preliminary maps does not have the simplified format that was developed for Montgomery County. Criteria for the unsuitable soils for the four preliminary maps is in possession of Texas Cooperative Extension staff in Houston, TX.

Examination of the maps (Figures 1-5) reveals a clear pattern in all of the counties. Unsuitable areas are restricted to drainage areas or associated with geologies that have planar surfaces. Gulf Coast counties are going to be dominated by unsuitable soils, with suitable areas becoming more dominant as one moves inland to areas of greater landscape relief.

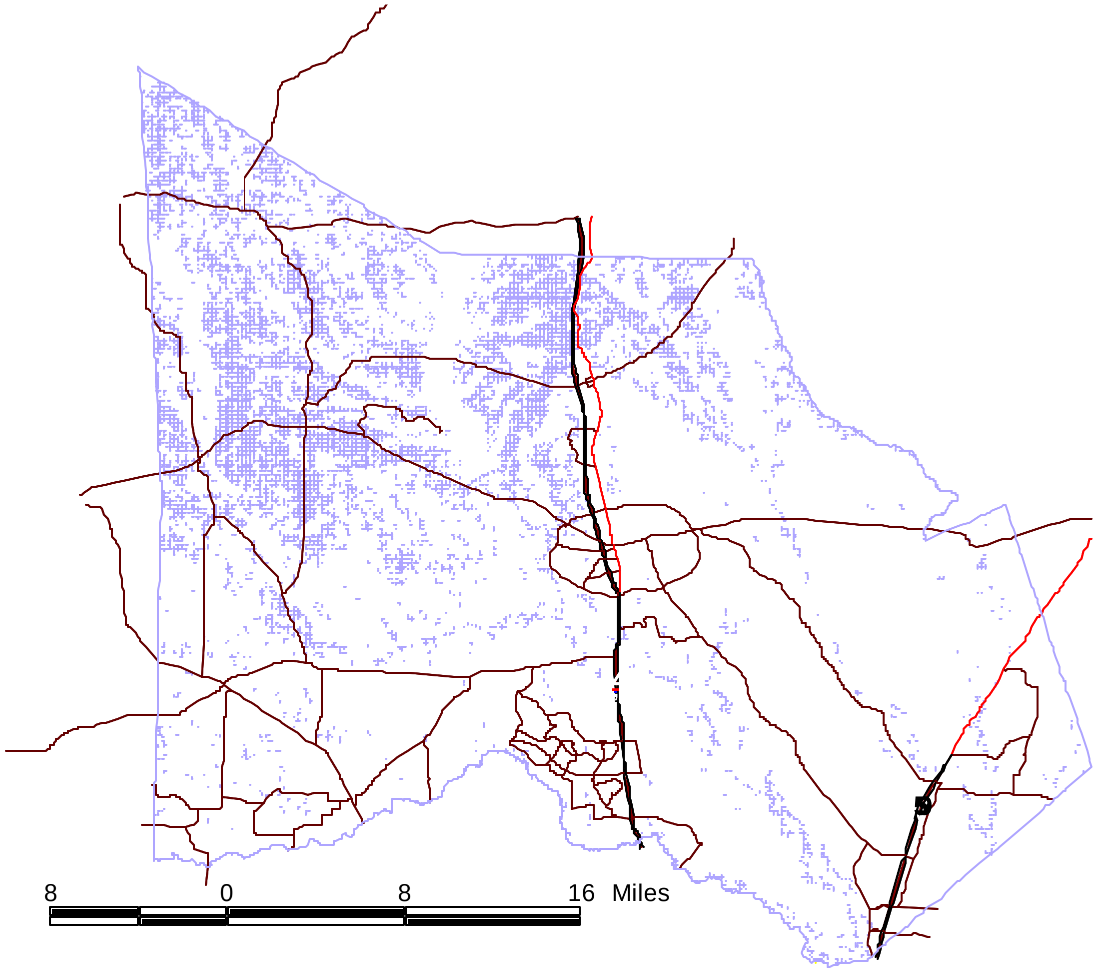


Figure 1. Suitable soils (dark shaded areas) with respect to groundwater in Montgomery County, Texas. (Based on soil landscape model supplemented with

soil survey information).

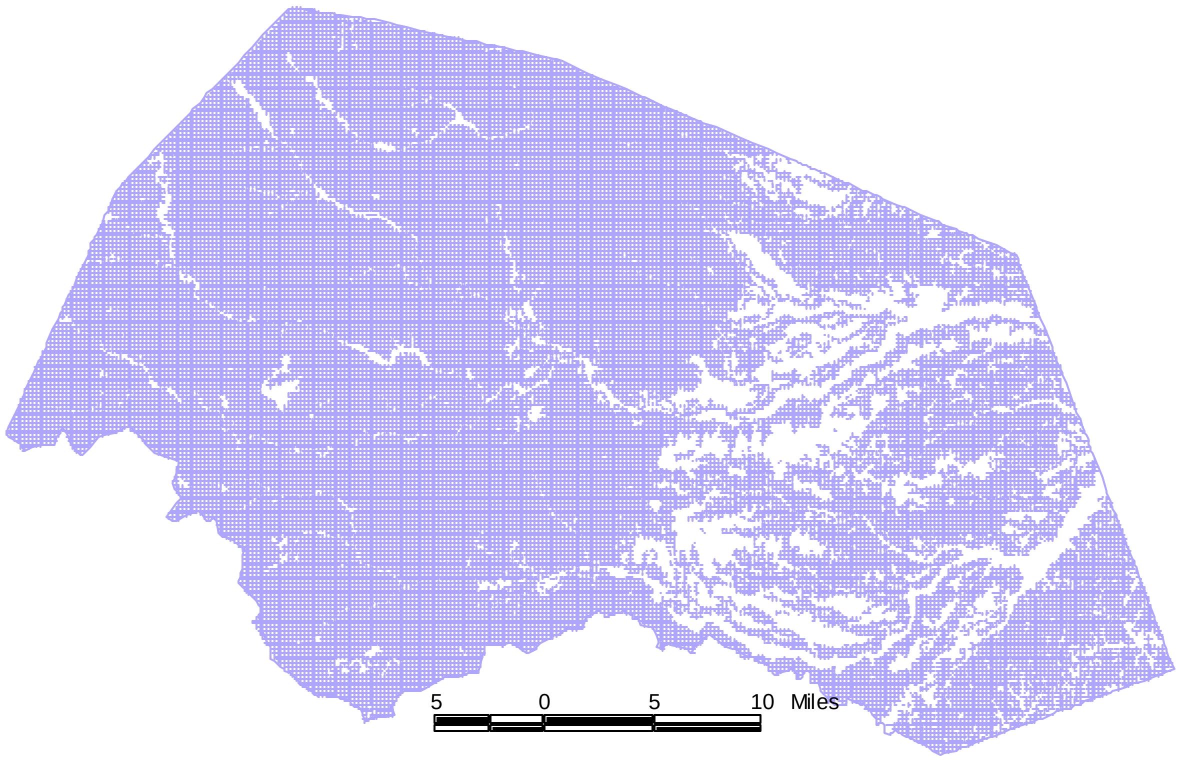


Figure2. Suitable soils (dark shaded areas) with respect to groundwater in Williamson County, Texas. (Preliminary map based on soil survey information only).

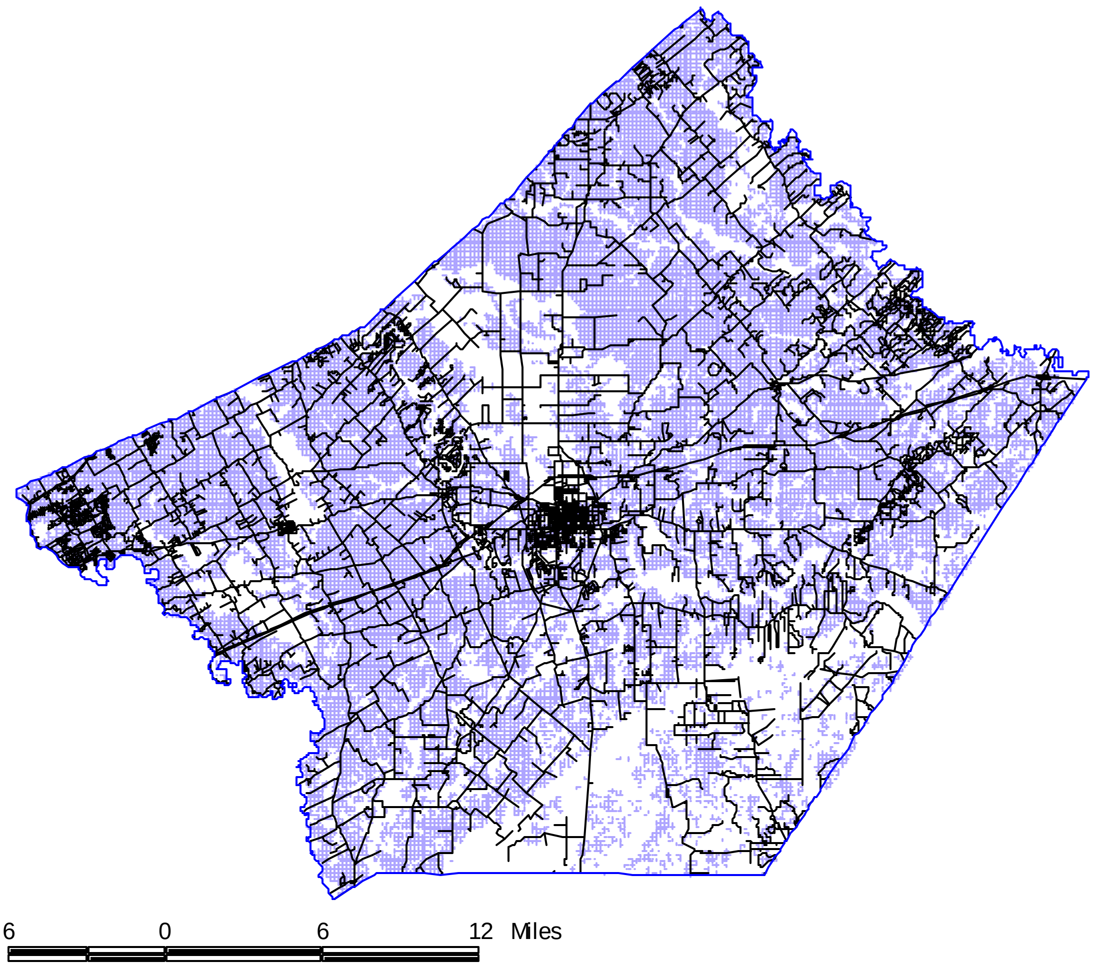


Figure 3. Suitable soils (dark shaded areas) with respect to groundwater in Guadalupe County, Texas. (Preliminary map based on soil survey information only).

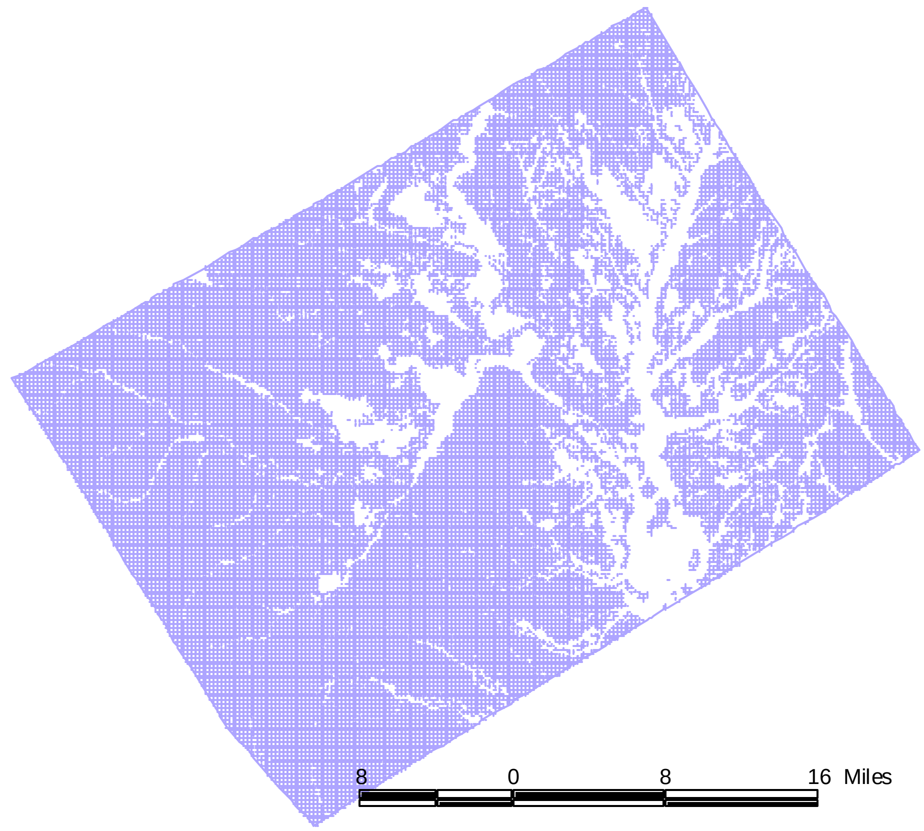
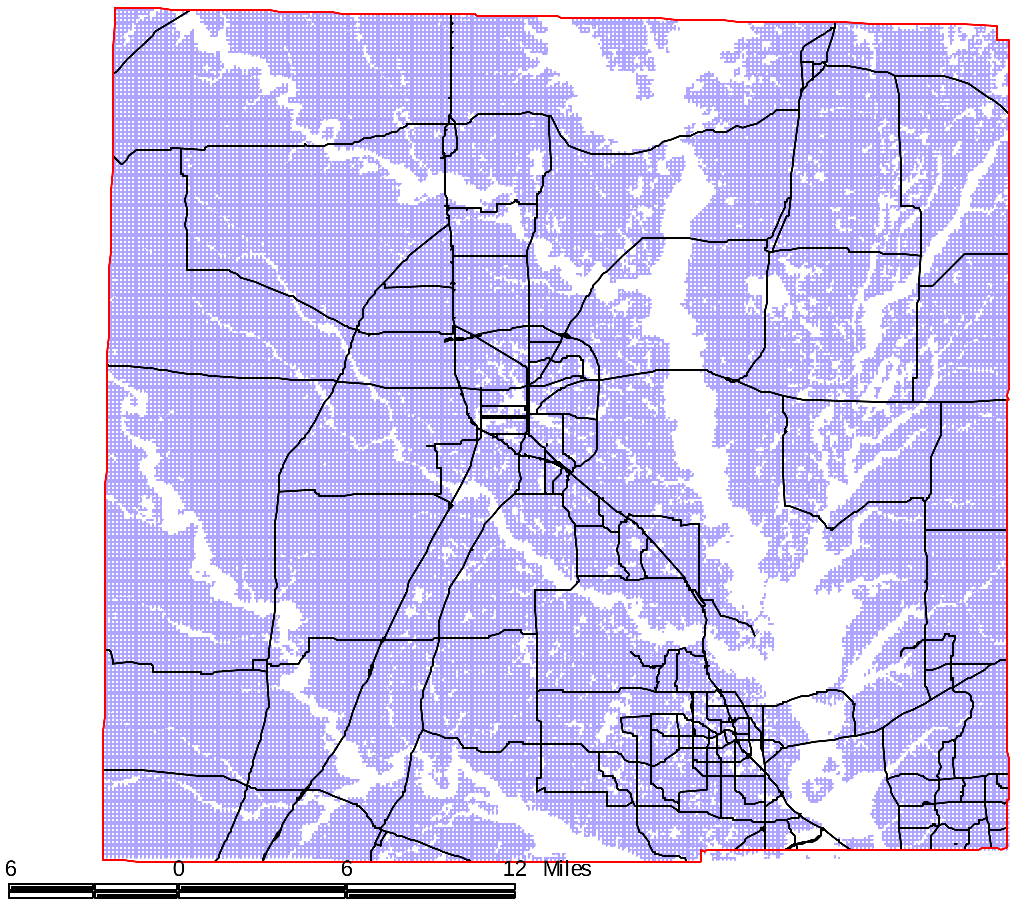


Figure 4. Suitable soils (dark shaded areas) with respect to groundwater in McClennan County, Texas. (Preliminary map based on soil survey information only).



6
0
6
12 Miles

Figure 5. Suitable soils (dark shaded areas) with respect to groundwater in Denton County, Texas. (Preliminary map based on soil survey information only).

APPENDIX

Development of the Landscape Model

The guiding principal for developing this model was that landscapes with slopes less than 3-5% and/or with concave landscape positions would be unsuitable, with respect to shallow groundwater, for standard septic systems.

The first iteration of the landscape model was to select soils from the Montgomery County Soil Survey (USDA Soil Survey Staff, 1972). The soil survey provided a good first cut at unsuitable areas, but because landscape position was not the ruling paradigm when this survey was completed, many flat and concave areas appeared as suitable on the suitability map.

The second and subsequent iterations of the landscape model involved quantification of landscape features using ARCINFO software in conjunction with the Soil Landscape Analysis Laboratory at the University of Minnesota.

Terrain Analysis

A series of DEMs were created from USGS hypsography data at 10-m, 15-m, 20-m, and 25-m resolutions. Hypsography data was assembled, merged, and then clipped to the Montgomery County boundary for processing and analysis. An iterative finite difference interpolation technique (Hutchinson, 1996) within ARC/INFO's TOPOGRID command (Environmental Systems Research Institute, 1994) was used to interpolate elevation from the 10-ft contour isolines. The 20-m DEM was selected for further analysis due to the tradeoff between computational efficiency and grid cell size. Approximately 17000 attributed contour arcs were interpolated to a regular grid DEM of roughly 12 million points (3399 by 3469). This method is an improvement from previous finite difference DEM interpolation algorithms (Hutchinson, 1988) by preserving the mechanical efficiency of 'local' interpolation methods, without losing the surface continuity of global interpolation methods such as krigging. Although this technique allows a DEM to follow abrupt changes in terrain, such as streams and lakes, drainage enforcement was not used due to the lack of high quality ancillary data for Montgomery County.

Selected primary terrain attributes (Table 1) were calculated using GRID in ARC/INFO. The GRID processing parameters are described in the Environmental Systems Research Institute (ESRI) User's Guide (ESRI, 1994), and specific algorithms used are detailed by Jensen and Domingue (Jensen and Domingue, 1988) and Moore (Moore et al., 1991, 1993, 1994). Profile curvature measures curvature in the downslope direction, whereas plan curvature calculates cross-slope curvature. Specific catchment area is the area that contributes flow to a point on the landscape, and is calculated by accumulating the weight for all cells that flow into each downslope cell (flow direction). Catchment area is also described as the area per unit width orthogonal to flow direction. In this case, the $\log_{10}$ was taken to distribute flow accumulation over a smaller range of values.

Table 1. Primary and secondary terrain attributes calculated from a digital elevation model.

Primary terrain attributes	Secondary terrain attributes
Slope gradient, *S*, %	**Compound Topographic Index (CTI)***
Profile curvature C_{pro}, mm^{-2}	**Stream Power Index (SPI)**
Plan curvature C_{plan}, mm^{-2}	
Specific catchment area, A_S, m^{2}m^{-1} §	

§ Also referred to as flow accumulation (ESRI, 1994).
* Also referred to as the steady-state wetness index (Moore et al., 1991).

Secondary terrain attributes (Table 1) were derived from linear combinations of two or more primary attributes (Moore et al., 1991, 1993). CTI and SPI are defined as:

$$\text{Log}_{10}\,(A_S \,/\, S) \qquad [1]$$

$$A_S * S \qquad [2]$$

Both of these secondary terrain attributes are hydrologically based indexes that quantify interactions between primary attributes and characterize aspects of water flow on hillslopes (Moore et al., 1993). CTI takes into account both a local slope geometry and spatial location on the landscape, combining data on gradient and specific catchment area. As specific catchment area and gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increases, hence stream power index and erosion risk increases (Moore et al., 1991).

Slope (S) and profile curvature (C_{pro}) were the terrain attribute inputs in the model, with other terrain attributes explaining very little in terms of site suitability.

Pre-processing of the terrain attributes included smoothing of both slope and profile curvature with a 3 X 3 filter to make the dataset more continuous. After several iterations of the model between the Minnesota and Houston project staff, it was determined that a site would be suitable if a given landscape position met either of the following:

- slopes were over 3%
- profile curvature had a value less than – 0.05

These values provided a smooth map that captured water gathering areas on the landscape quite well.

Claypan soils, however, are notoriously problematic in terms of perching water above the claypan. We decided to include claypan soils up to 5% slopes as unsuitable. We used claypan soils with claypans between 15 and 60 inches deep. These polygons were selected from the SSURGO database. The resulting map thus has both smooth lines (from SSURGO) and pixilated lines (from the terrain analysis).

We also considered that small ridgetops with planar slopes would not have the same hydrologic impacts as broader areas (the famous “red-edge” effect documented by Daniels). It is not possible at present in ARCINFO to remove areas because of their narrowness. As a compromise, we removed all unsuitable polygons less than 15,000 m^2 in size.

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