DERIVATION OF A PHYSIOGRAPHICALLY-BASED DEPTH TO GROUNDWATER MAP FOR THE STATE OF PENNSYLVANIA

Technical Report
for DEP Task 11

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June 1997

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1.0 INTRODUCTION

As part of an earlier project done for DEP, Penn State developed a statewide "depth-to-groundwater" map that was subsequently used as one of the input layers for a groundwater pollution potential (DRASTIC) map. This groundwater depth map was created using a digital water well location map (in fact, an ARC/INFO coverage) that contained as attribute information, among other things, the depth below the surface at which drinking water is withdrawn. At the time, because of the particular focus of the study (drinking water supply protection) and the lack of better data, a decision was made to create the depth-to-groundwater map from this well data set using GIS-based spatial interpolation techniques.

Since the time this project was completed, however, it has been recognized that a different type of depth-to-groundwater map would be more useful for most statewide planning efforts related to the protection of groundwater resources. In particular, a better map would be one that represents the uppermost level of the groundwater table rather than the level at which drinking water supplies might be withdrawn. Described below are the procedures utilized to create such a map.

2.0 METHODOLOGY AND RESULTS

It has long been recognized that, in most situations, depth to groundwater is very closely associated with surface topography, geology and physiography (Freeze and Cherry, 1979). Although land and water table surfaces are examples of highly complex, continuous surfaces, it is possible to classify similar areas into regions of less variability. Similar to the way soil scientists use directly observable characteristics of topography, geology, vegetation, and climate to interpret and map soil properties, hydrogeologists often use similar techniques to estimate depth to groundwater in the field. With this approach, an attempt is made to map the groundwater surface for large geographic areas by classifying discrete "landscape units" that reflect fairly predictable ranges of average annual water table depth. Based on "conceptual models" of this type, it is possible to develop more formalized "decision rules" that can be used to predict the spatial occurrence of water table depth on a "point-by-point" basis within a GIS environment. Such a methodology has been successfully used by Fels and Matson (1996) to map water table depth in North Carolina.

For this study, water table depth throughout Pennsylvania was estimated using a combination of two physiographicaly-based approaches. The results of each effort were than reviewed and critiqued by central and regional office staff of the Bureau of Drinking Water Management. Based on such input, the map was then iteratively revised until a final map was developed that appeared to be reasonable given the scientific basis of the algorithms used and the professional judgement of the technical staff around the state. While this map is considered to be "final" in the context of this report, it is, in actuality, a map that will likely be modified from time to time as more useable, precise, and/or otherwise appropriate data becomes avaliable.

Development of Preliminary Terrain Maps

As described above, the focus of this study was to predict and map depth to groundwater based on the spatial occurrence of different combinations of surface features or terrain types. In this case, the three primary GIS data layers used were those which depicted landscape position, distance to surface water and physiographic region.

The map of landscape position was created by first developing a land surface "curvature" map by applying the CURVATURE function in ARC/INFO GRID to a statewide elevation (DEM) data set to produce a new map called PACURVE. A positive curvature indicates that the surface is upwardly convex, a negative curvature indicates that the surface is upwardly concave, and a value of zero indicates a flat surface. Based upon a visual examination of the results, this layer was then recoded to produce a new map (LANDSCAPE) depicting hill crests, mountain/hill slopes, and valleys or plateaus (see Figure 1).

The distance-to-surface water map (called DISTANCE) was created by applying the ARC/INFO GRID function DISTANCE to a specially-derived surface water body map. This latter map was created by combining gridded versions of the county-based PennDOT stream coverages with surface water information from an available statewide land use/cover layer (PALUMRLC). With DISTANCE, a new map was created showing distance to nearest water bodies in increments of 30m (which was the cell size used). As shown in Figure 2, this new map was subsequently recoded (to RECDIST) to reflect distance ranges from 1-100m, 100-500m, 500-1000m, 1000-2000m, and >2000m.

The physiographic region layer used (PHYSPROV) was originally obtained from the Pennsylvania Topographic and Geologic Survey. As shown in Figure 3, this map represents the major physiographic regions of the state. For the purpose of this project, a gridded version of the map was utilized.

Depth-to-Groundwater Map: Version 1

The initial version of a revised depth-to-groundwater (i.e., water table) map was developed primarily using descriptive information on physiographic and hydrogeologic settings provided in the DRASTIC user's manual (USEPA, 1987), although information gleaned from an existing environmental geology reference (Geyer and Wilshusen, 1982) and other sources were also used. For this version, depth-to-groundwater classes were based on different combinations of landscape curvature, slope, distance to surface water, and physiographic province. A text copy of the GRID macro used to create this map (shown in Figure 4) has been included in the Appendix.

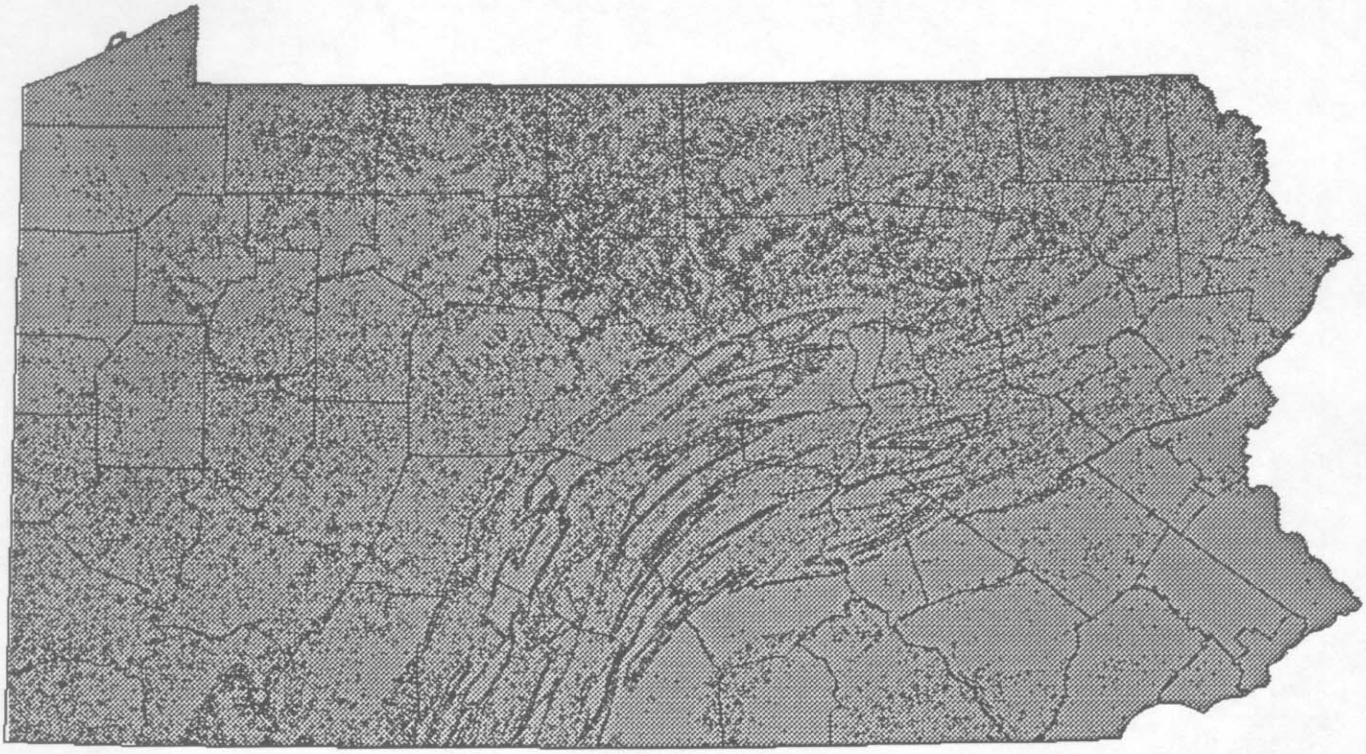

Figure 1. Landscape units of Pennsylvania. Darker shades depict hill crests and sideslopes; lighter shades depict valleys and relatively flat upland areas.

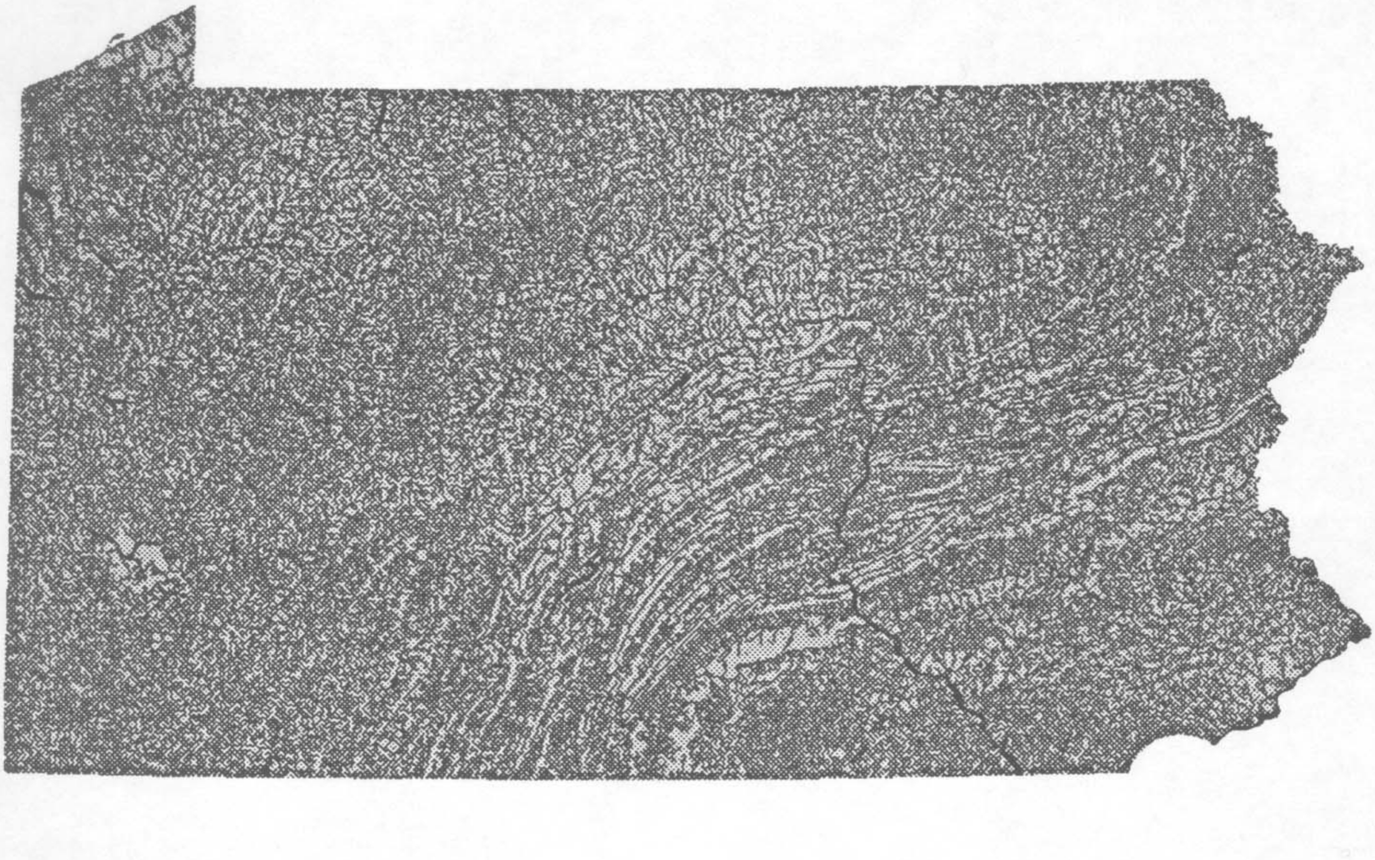

Figure 2. Recoded distance-to-stream map. In this image, cells closer to surface water are darker than cells that are farther away.

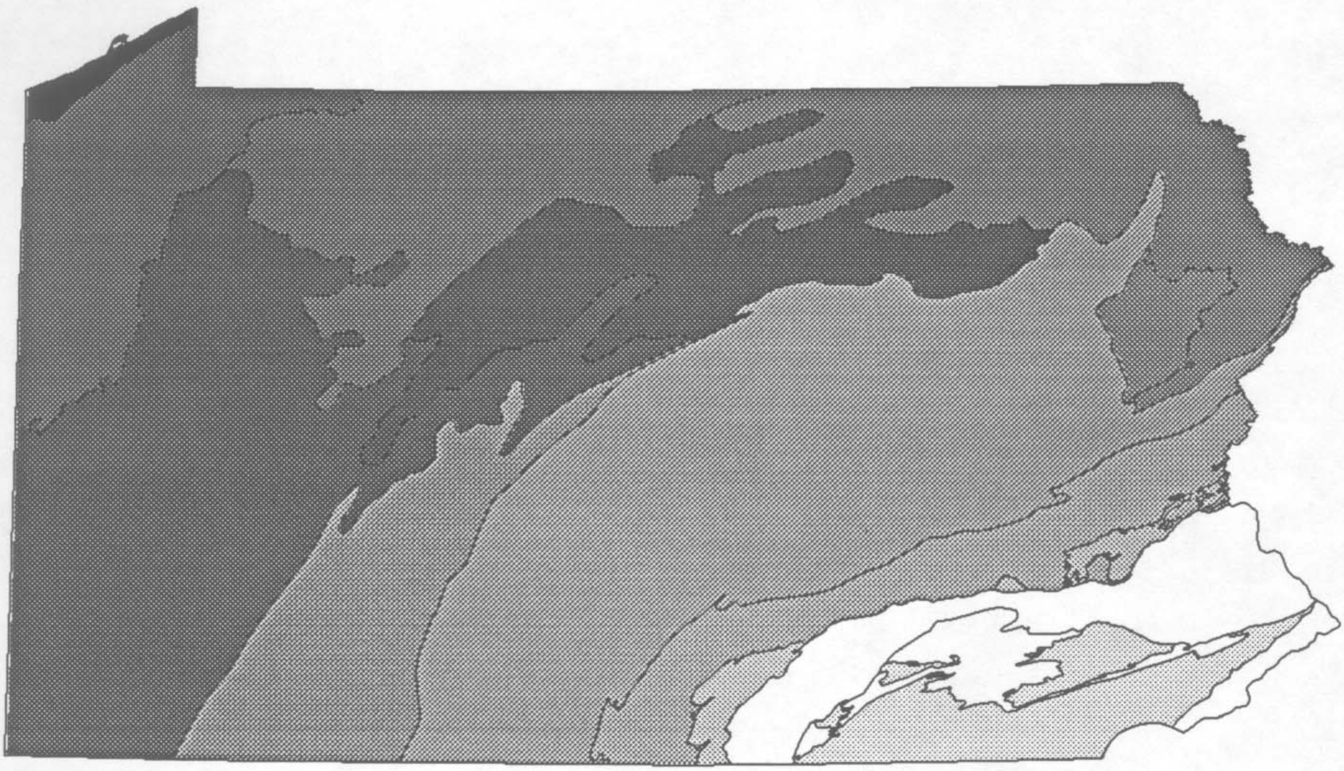

Figure 3. Physiographic province map.

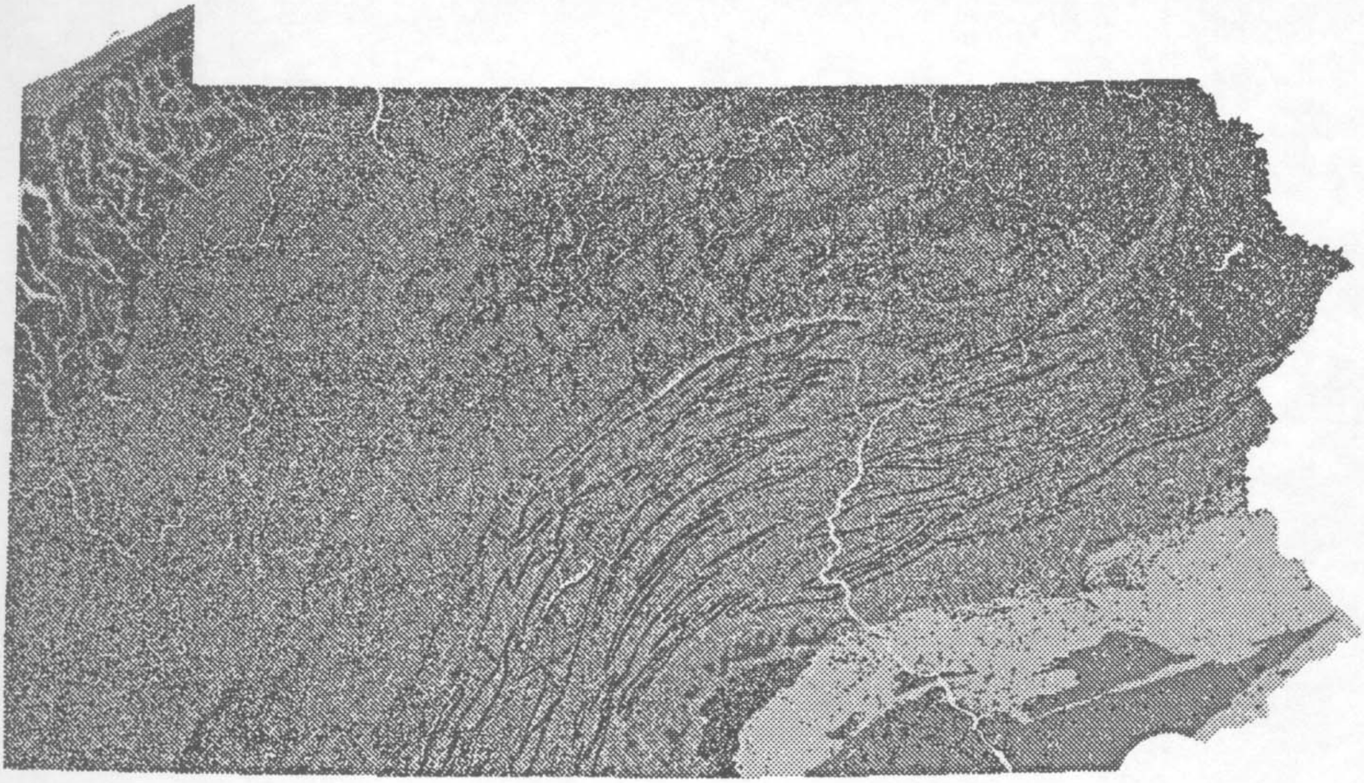

Figure 4. Depth-to-groundwater map: Version 1. Note that lighter shades indicate shallower depths to groundwater.

Depth-to-Groundwater Map: Version 2

In this second version, an attempt was made to define different water level ranges using USGS well sample data provided by DEP. One of the attributes included with this data set is static water level. For this project, an ARC/INFO grid layer was generated from this data set, with the grid data values representing the static water level. This layer was subsequently "crosstabulated" against an integrated terrain unit map which was created by compositing several of the surface feature layers described above. The objective in this case was to determine average values of depth to groundwater for different combinations of landscape position, distance to surface water, and physiographic region.

The new integrated terrain unit map (called LANDUNIT) had almost two hundred distinct combinations of these three factors. As might be expected, due to the absence of well sample locations in some areas of the state, average depth-to-groundwater estimates could not be derived for every possible terrain unit combination. In such cases, a best estimate of depth was made based on similarity to other terrain unit combinations, depth values at nearby well locations, and prior knowledge about the area. Figure 5 depicts this particular version of the map. As with the previous version, the macro used to produce it has been included in the Appendix.

Depth-to-Groundwater Map: Final Version

After being developed, copies of the two map versions described above were sent to DEP regional office staff for their review and comments. Based upon this review, a "final" version of the map was produced (see Figure 6). In many respects, this newest version is a composite of the two earlier renditions. In some cases, values from version 1 were used, and in other cases the version 2 values were used. In still other cases (particularly in the northwest and southeast portions of the state), heavier reliance was placed on depth ranges recommended by DEP staff based on their local experience. However, as cautioned earlier, this map is still to be viewed as a "work in progress", and as such, is subject to change pending further input from DEP staff members and other interested parties. In any case, this newest version is considered to be more representative of ground water levels in the state than the version used to produce the first DRASTIC map of the state. For comparison purposes, the initial DRASTIC map and a revised version using this newest depth-to-groundwater map are shown in Figures 7 and 8, respectively.

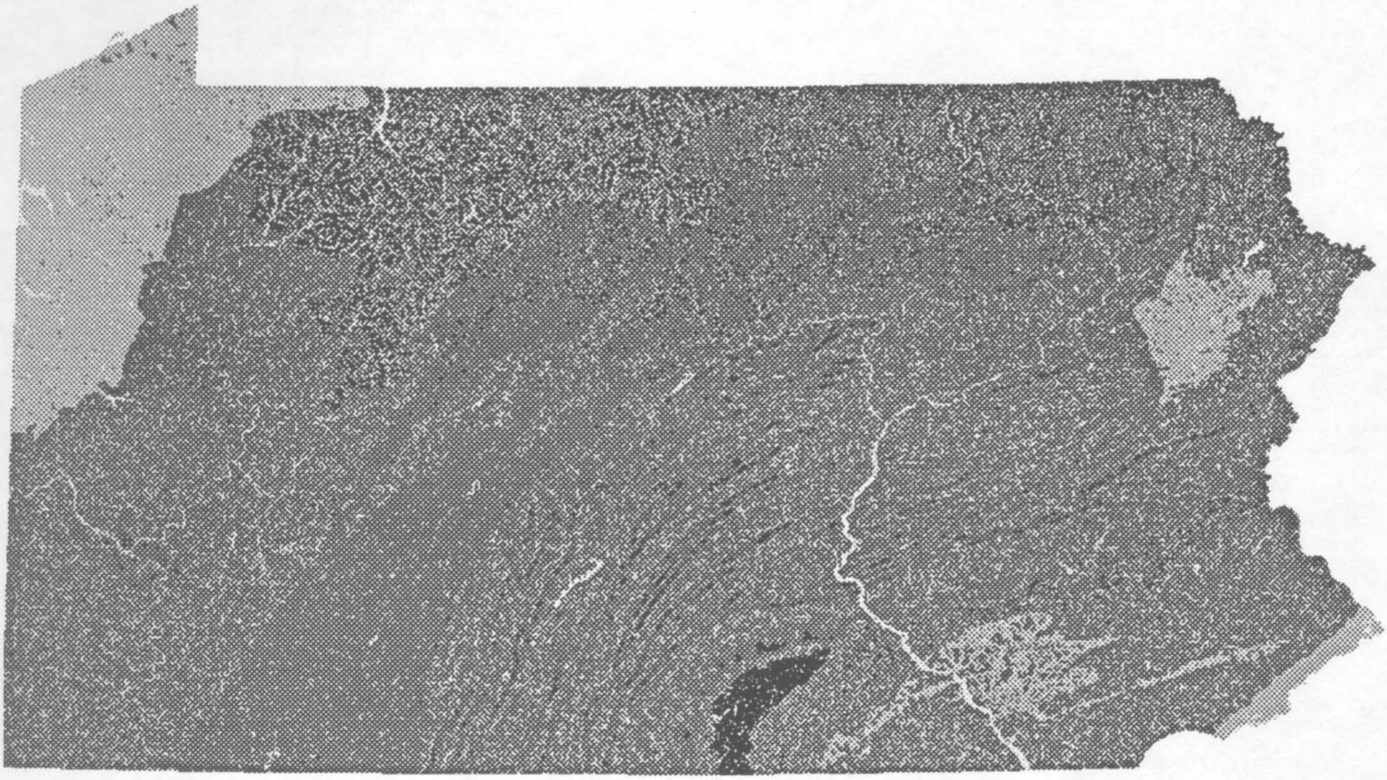

Figure 5. Depth-to-Groundwater Map: Version2

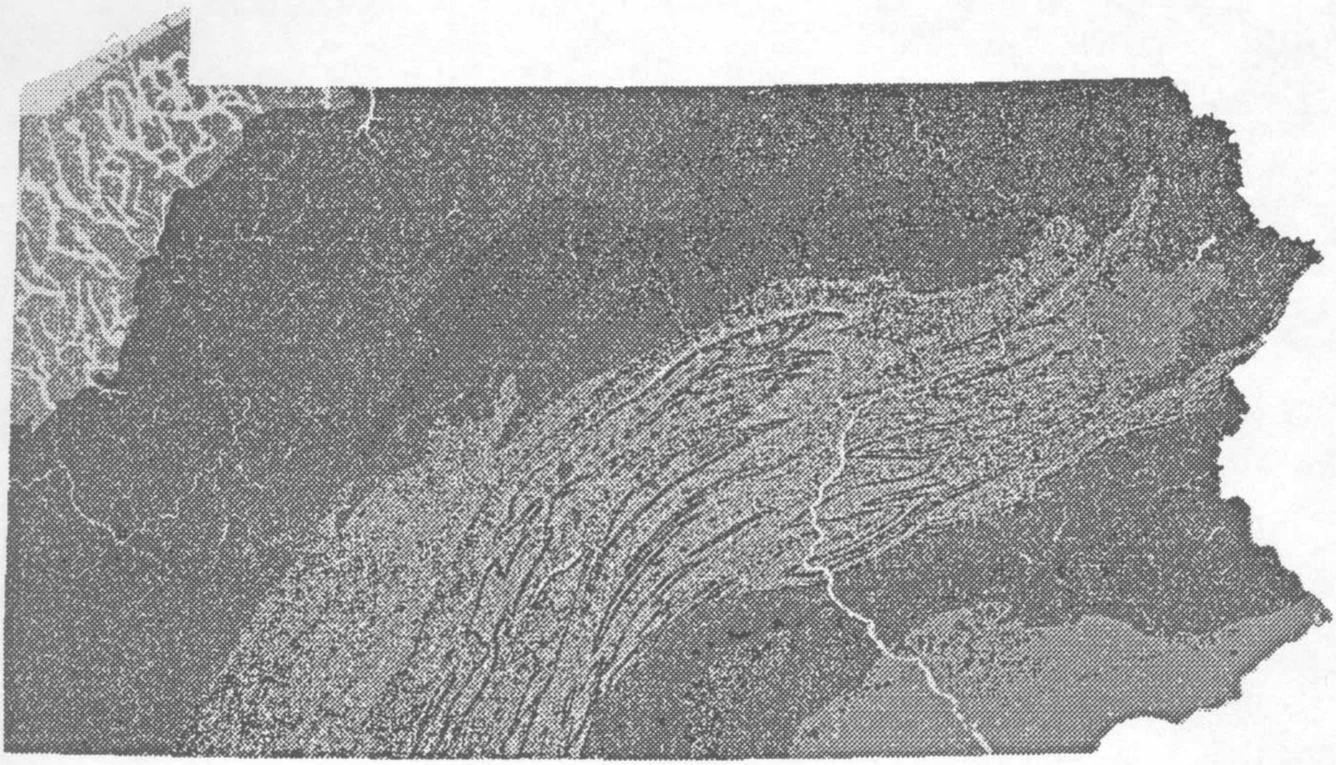

Figure 6. Depth-to-Groundwater Map: Final Version

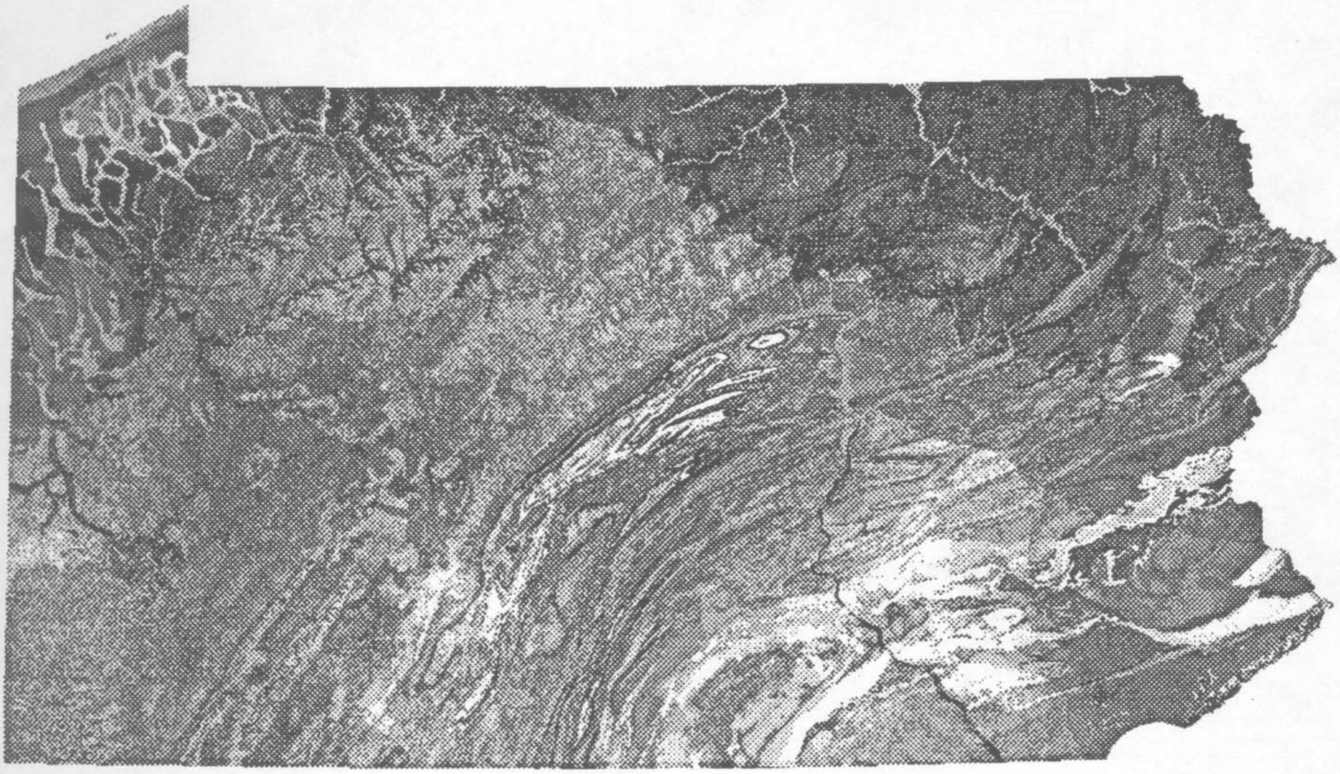

Figure 7. DRASTIC map produced from initial depth-to-groundwater layer. In this image, lighter shades indicate higher groundwater pollution potential.

Figure 8. Revised DRASTIC map using new depth-to-groundwater layer.

3.0 LITERATURE CITED

Fels, J.E. and K.C. Matson, 1996. A Cognitively-Based Approach for Hydrogeomorphic Land Classification Using Digital Terrain Models. In: Proc. Third International Conf. / Workshop on Integrating GIS and Environ. Modeling, Sante Fe, NM.

Freeze, R.A. and J. A. Cherry, 1979. Groundwater. Pub. By Prentice Hall, Inc., Englewood, NJ, 604 pp.

Geyer, A.R. and J.P. Wilshusen, 1982. Engineering Characteristics of Rocks of Pennsylvania. PA Bureau of Topographic and Geologic Survey, 300 pp.

USEPA, 1987. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings. EPA-600/2-87-035, 455 pp.

APPENDIX

```
/*
/*  MACRO FOR CALCULATING DEPTH TO GROUNDWATER
/*  BASED ON PHYSIOGRAPHIC AND DISTANCE ATTRIBUTES
/*
setwindow drastic
setcell 100
docell
/*
/*  Decision rules for Nonglaciated Central region
/*        (High and Low Plateau Sections)
/*
 if ( physprov == 3 or physprov == 5 )
   if ( water gt 0 ) gwdepth = 10
   else if ( pacurve ge 0.1 ) gwdepth = 3
   else if ( paslope ge 11 ) gwdepth = 5
   else if ( distance lt 100 ) gwdepth = 9
   else gwdepth = 7
/*
/*  Decision rules for Nonglaciated Central region
/*        (Mountainous sections)
/*
 if ( physprov == 2 or physprov == 8 )
   if ( water gt 0 ) gwdepth = 10
   else if ( pacurve ge 0.1 ) gwdepth = 3
   else if ( paslope ge 11 ) gwdepth = 5
   else if ( distance lt 100 ) gwdepth = 9
   else gwdepth = 7
/*
/*  Decision rules for Ridge and Valley region
/*
 else if ( physprov == 9 or physprov == 10 )
   if ( water gt 0 ) gwdepth = 10
   else if ( pacurve ge 0.1 ) gwdepth = 2
   else if ( paslope ge 11 ) gwdepth = 5
   else if ( distance lt 100 ) gwdepth = 9
   else if ( distance lt 1000 ) gwdepth = 7
   else gwdepth = 5
/*
/*  Decision rules for Glaciated Central region
/*
 else if (physprov == 1 or physprov == 4 or physprov == 6 or physprov == 7 )
   if ( water gt 0 ) gwdepth = 10
   else if ( pacurve ge 0.1 ) gwdepth = 3
   else if ( distance  lt 100 ) gwdepth = 9
   else if ( physprov == 1 ) gwdepth = 7
   else if ( /bme1/grndwtr/dvadose == 8 ) gwdepth = 7
   else gwdepth = 5
/*
/*  Decision rules for Piedmont/Blue Ridge region
/*      (Reading Prong and Lowland Section)
/*
 else if ( physprov eq 11 or physprov eq 15 or physprov eq 14 )
   if ( water gt 0 ) gwdepth = 10
```

```
    else if ( pacurve ge 0.1 ) gwdepth = 1
    else if ( paslope ge 11 ) gwdepth = 3
    else if ( distance lt 1000 ) gwdepth = 9
    else gwdepth = 7
/*
/* Decision rules for Piedmont/Blue Ridge region
/*        (South Mountain Section)
/*
  else if ( physprov eq 12 )
    if ( water gt 0 ) gwdepth = 10
    else if ( pacurve ge 0.1 ) gwdepth = 1
    else if ( paslope ge 11 ) gwdepth = 3
    else if ( distance ge 300 ) gwdepth = 7
    else gwdepth = 5
/*
/* Decision rules for Piedmont/Blue Ridge region
/*        (Upland Piedmont Section)
/*
  else if ( physprov eq 13 )
    if ( water gt 0 ) gwdepth = 10
    else if ( pacurve ge 0.1 ) gwdepth = 1
    else if ( paslope ge 11 ) gwdepth = 3
    else if ( distance lt 1500 ) gwdepth = 7
    else gwdepth = 5
/*
/* Decision rules for Coastal Plain region
/*
  else if ( physprov == 16 )
    if ( water gt 0 ) gwdepth = 10
    else if ( pacurve ge 0.1 ) gwdepth = 5
    else if ( distance lt 1000 ) gwdepth = 9
    else gwdepth = 7
  endif
end
/*
/* Explanations/Definitions
/*
/* GWDEPTH VALUES
/*     10: 0-5 ft.
/*      9: 5-15 ft.
/*      7: 15-30 ft.
/*      5: 30-50 ft.
/*      3: 50-75 ft.
/*      2: 75-100 ft.
/*      1: >100 ft.
/*
/* "PASLOPE GE 11" means "slope greater than or equal to 11 degrees (~24.4 %)"
/*
/* "DISTANCE LT _____" means "distance from surface water less than (value in meters)"
/*
/* "PACURVE GE 0.1" means hill crest or top of ridge
/*
```

```
/*  PHYSPROV VALUES (SECTIONS)
/*   1 - Eastern Lake Section  (Central Lowland Province)
/*   2 - Mountainous High Plateau Section (Appalachian Plateau Province)
/*   3 - Pittsburgh Low Plateau Section (APP)
/*   4 - Glaciated Pittsburgh Plateau Section (APP)
/*   5 - High Plateau Section (APP)
/*   6 - Glaciated Low Plateau (APP)
/*   7 - Glaciated Pocono Plateau Section (APP)
/*   8 - Allegheny Mountain Section (APP)
/*   9 - Appalachian Mountain Section (Ridge and Valley Province)
/*  10 - Great Valley Section (R/V P)
/*  11 - Reading Prong Section (New England Province)
/*  12 - South Mountain Section (Blue Ridge Province)
/*  13 - Piedmont Upland Section (Piedmont Province)
/*  14 - Piedmont Lowland Section (PP)
/*  15 - Gettysburg-Newark Lowland Section (PP)
/*  16 - Lowland and Intermediate Upland Section (Atlantic Coast Province)
/*
/*  "VADOSE==8" signifies glacial outwash in the Glaciated Central region
/*
/*  "WATER GT 0"  signifies surface water feature
```

```
/*
/* MACRO FOR CALCULATING DEPTH TO GROUNDWATER
/* BASED ON INTEGRATED TERRAIN UNITS (Version 2)
/*
&echo &on
setcell 100
setmask physprov
/*
/* Decision rules based on cell values in LANDUNIT grid, which are
/* a combination of RECDIST, LANDSCAPE and PHYSPROV
/*
if ( water gt 0 ) gwdepth3 = 10
else if ( landunit == 1 ) gwdepth3 = 7
else if ( landunit == 2 ) gwdepth3 = 7
else if ( landunit == 3 ) gwdepth3 = 5
else if ( landunit le 5 ) gwdepth3 = 7
else if ( landunit == 6 ) gwdepth3 = 5
else if ( landunit == 7 ) gwdepth3 = 7
else if ( landunit le 9 ) gwdepth3 = 5
else if ( landunit le 14 ) gwdepth3 = 7
else if ( landunit == 15 ) gwdepth3 = 5
else if ( landunit == 16 ) gwdepth3 = 7
else if ( landunit == 17 ) gwdepth3 = 5
else if ( landunit == 18 ) gwdepth3 = 7
else if ( landunit == 19 ) gwdepth3 = 2
else if ( landunit == 20 ) gwdepth3 = 3
else if ( landunit le 23 ) gwdepth3 = 5
else if ( landunit == 24 ) gwdepth3 = 2
else if ( landunit == 25 ) gwdepth3 = 5
else if ( landunit le 28 ) gwdepth3 = 3
else if ( landunit == 29 ) gwdepth3 = 9
else if ( landunit le 31 ) gwdepth3 = 3
else if ( landunit == 32 ) gwdepth3 = 5
else if ( landunit == 33 ) gwdepth3 = 3
else if ( landunit == 34 ) gwdepth3 = 5
else if ( landunit le 37 ) gwdepth3 = 7
else if ( landunit == 38 ) gwdepth3 = 5
else if ( landunit == 39 ) gwdepth3 = 7
else if ( landunit == 40 ) gwdepth3 = 5
else if ( landunit == 41 ) gwdepth3 = 7
else if ( landunit == 42 ) gwdepth3 = 5
else if ( landunit == 43 ) gwdepth3 = 3
else if ( landunit == 44 ) gwdepth3 = 5
else if ( landunit le 47 ) gwdepth3 = 3
else if ( landunit == 48 ) gwdepth3 = 7
else if ( landunit le 52 ) gwdepth3 = 5
else if ( landunit == 53 ) gwdepth3 = 3
else if ( landunit le 55 ) gwdepth3 = 7
else if ( landunit le 58 ) gwdepth3 = 5
else if ( landunit le 60 ) gwdepth3 = 3
else if ( landunit == 61 ) gwdepth3 = 5
else if ( landunit le 63 ) gwdepth3 = 7
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else if ( landunit le 74 ) gwdepth3 = 5
else if ( landunit == 75 )  gwdepth3 = 3
else if ( landunit le 81 )  gwdepth3 = 5
else if ( landunit == 82 ) gwdepth3 = 3
else if ( landunit == 83 ) gwdepth3 = 7
else if ( landunit == 84 )  gwdepth3 = 3
else if ( landunit le 86 ) gwdepth3 = 7
else if ( landunit == 87 )  gwdepth3 = 5
else if ( landunit == 88 ) gwdepth3 = 7
else if ( landunit == 89 ) gwdepth3 = 3
else if ( landunit == 90 )  gwdepth3 = 5
else if ( landunit == 91 ) gwdepth3 = 7
else if ( landunit == 92 ) gwdepth3 = 3
else if ( landunit le 94 ) gwdepth3 = 5
else if ( landunit == 95 ) gwdepth3 = 3
else if ( landunit == 96 )  gwdepth3 = 9
else if ( landunit le 99 )  gwdepth3 = 3
else if ( landunit == 100 ) gwdepth3 = 5
else if ( landunit le 102 )  gwdepth3 = 3
else if ( landunit le 109 ) gwdepth3 = 5
else if ( landunit == 110 ) gwdepth3 = 7
else if ( landunit le 112 ) gwdepth3 = 5
else if ( landunit == 113 ) gwdepth3 = 3
else if ( landunit == 114 )  gwdepth3 = 5
else if ( landunit == 115 ) gwdepth3 = 7
else if ( landunit le 118 ) gwdepth3 = 5
else if ( landunit == 119 ) gwdepth3 = 7
else if ( landunit le 121 ) gwdepth3 = 5
else if ( landunit le 123 )  gwdepth3 = 3
else if ( landunit le 126 )  gwdepth3 = 5
else if ( landunit == 127 ) gwdepth3 = 7
else if ( landunit == 128 ) gwdepth3 = 2
else if ( landunit == 129 )  gwdepth3 = 3
else if ( landunit == 130 ) gwdepth3 = 2
else if ( landunit == 131 ) gwdepth3 = 5
else if ( landunit == 132 )  gwdepth3 = 3
else if ( landunit == 133 ) gwdepth3 = 2
else if ( landunit == 134 ) gwdepth3 = 3
else if ( landunit == 135 )  gwdepth3 = 5
else if ( landunit == 136 ) gwdepth3 = 2
else if ( landunit == 137 ) gwdepth3 = 5
else if ( landunit == 138 )  gwdepth3 = 2
else if ( landunit == 139 ) gwdepth3 = 7
else if ( landunit le 141 )  gwdepth3 = 5
else if ( landunit == 142 ) gwdepth3 = 3
else if ( landunit == 143 ) gwdepth3 = 5
else if ( landunit == 144 )  gwdepth3 = 3
else if ( landunit le 148 )  gwdepth3 = 5
else if ( landunit == 149 ) gwdepth3 = 3
else if ( landunit == 150 ) gwdepth3 = 5
else if ( landunit le 153 ) gwdepth3 = 3
else if ( landunit le 155 ) gwdepth3 = 7
else if ( landunit == 156 ) gwdepth3 = 5
else if ( landunit le 158 ) gwdepth3 = 7
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else if ( landunit le 161 ) gwdepth3 = 5
else if ( landunit le 164 ) gwdepth3 = 7
else if ( landunit le 167 ) gwdepth3 = 5
else if ( landunit == 168 ) gwdepth3 = 7
else if ( landunit == 169 )  gwdepth3 = 5
else if ( landunit == 170 ) gwdepth3 = 7
else if ( landunit le 173 ) gwdepth3 = 5
else if ( landunit == 174 ) gwdepth3 = 9
else if ( landunit == 175 )  gwdepth3 = 3
else if ( landunit le 179 ) gwdepth3 = 5
else if ( landunit == 180 ) gwdepth3 = 3
else if ( landunit == 181 )  gwdepth3 = 7
else if ( landunit le 188 ) gwdepth3 = 3
else if ( landunit == 189 ) gwdepth3 = 5
else if ( landunit le 191 ) gwdepth3 = 3
else if ( landunit == 192 )  gwdepth3 = 9
else if ( landunit le 199 )  gwdepth3 = 5
endif
/*
/* Explanations/Definitions
/*
/* GWDEPTH3 VALUES
/*     10:  0-5 ft.
/*      9:  5-15 ft.
/*      7:  15-30 ft.
/*      5:  30-50 ft.
/*      3:  50-75 ft.
/*      2:  75-100 ft.
/*      1:  >100 ft.
/*
```