Harlan County Landslide Risk Analysis
A Geoprocessing Task Using ArcGIS Model Builder

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ABSTRACT

This document will describe how ArcGIS 9.3 Model Builder was utilized to build a geoprocessing model to predict landslide potential in Harlan County, Kentucky. The customized scripting enables the end user to make simple modifications to the geoprocessing model to incorporate different variables and/or parameters into a subsequent model of a different geographic area where conditions may vary from the Appalachian region of eastern Kentucky.

Harlan County is located in the extreme southeastern corner of the state of Kentucky. It is in the heart of the Appalachian Mountains and shares a contiguous boundary with the western panhandle of the state of Virginia. The topography and surface land use of Harlan County is representative of much of the Appalachian Region – rugged, heavily mined for coal – and extremely prone to landslides, be they natural or anthropogenic in origin. The focus of this project was to build a geoprocessing model using Model Builder in ArcEditor 9.3 to determine which site-specific locations of Harlan County were most prone to future landslides.

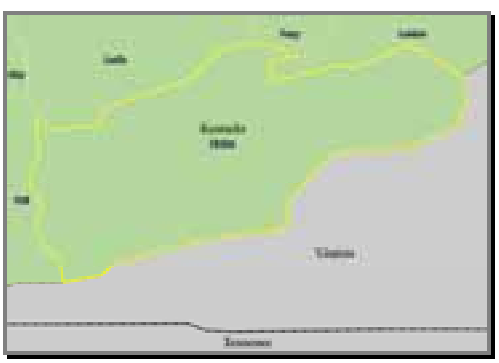


Figure #1 and #2 – Inset Map – Location of Harlan County, Kentucky, Satellite Image of Harlan County, courtesy of Google Earth

Model Builder is a powerful tool within the software that enables the user to drop and drag data (be it vector or raster) into the geoprocessing window and establish connections with specific tools and/or scripts within ArcToolbox. The interface is remarkably similar to Microsoft Visio and enables the user to build complex geoprocessing models without needing to learn and manipulate a scripting language. The newly released version of ArcGIS 9.3 comes equipped with an icon on the Standard ArcMap toolbar, making access to Model Builder far more straightforward than with previous versions of the software.

<u>Data Acquisition</u>

The initial step in building a geoprocessing model is to determine exactly what the model is intended to execute. Variables form the foundation of the model, and hence data acquisition is a prerequisite before one starts to construct the framework of the model.

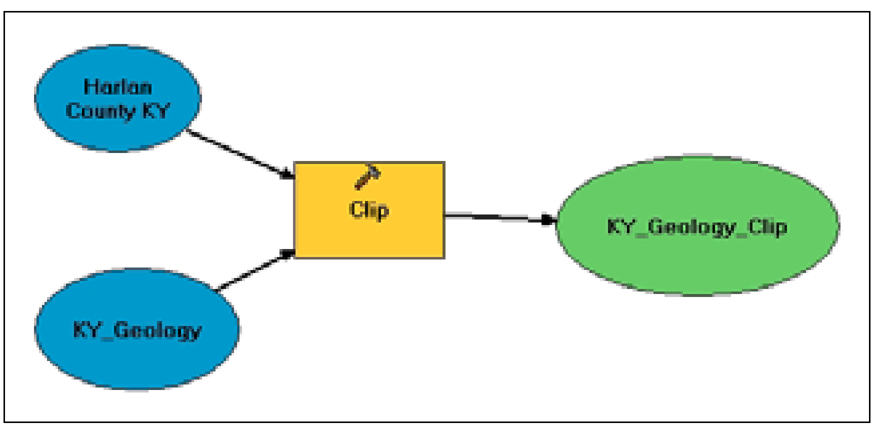
It was decided in advance that all variables would be incorporated into a **personal geodatabase** (GDB) as raster datasets or as feature classes within a personal GDB. The use of a GDB is not mandatory but it enables all data for the model to be stored within a single entity and also allows for the user to develop topological rules within the GDB to eliminate any potential conflicts.

The most important variables that influence the probability of landslides are *slope, geology, soil type* and *surface land use*. These four variables would acquire specific weights of importance later in the development of the model. Secondary variables that were used in the model included the hydrological profile, proximity to the road network and, in an example of how local factors play into landslide risk assessment, proximity to surface coal mines. The following table displays all variables incorporated into the analysis and their respective data source.

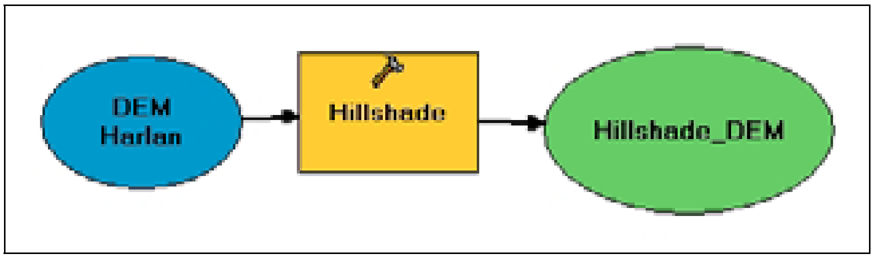
Variables	**Source**	**Web URL**
Soils	Kentucky Geography Network	http://kygeonet.ky.gov/
Surface Coal Mines	Kentucky Geography Network	http://kygeonet.ky.gov/
Geology	Kentucky Geography Network	http://kygeonet.ky.gov/
Streams	USGS National Hydrographic Dataset	http://nhd.usgs.gov/
KY State Roads	Kentucky Geography Network	http://kygeonet.ky.gov/
Local Roads	Kentucky Geography Network	http://kygeonet.ky.gov/
National Land Use Cover	National Land Cover Dataset 2001	http://www.epa.gov/mrlc/nlcd-2001.html
Elevation Data	National Elevation Dataset (DEM)	http://seamless.usgs.gov/index.php)

Developing the Geoprocessing Model

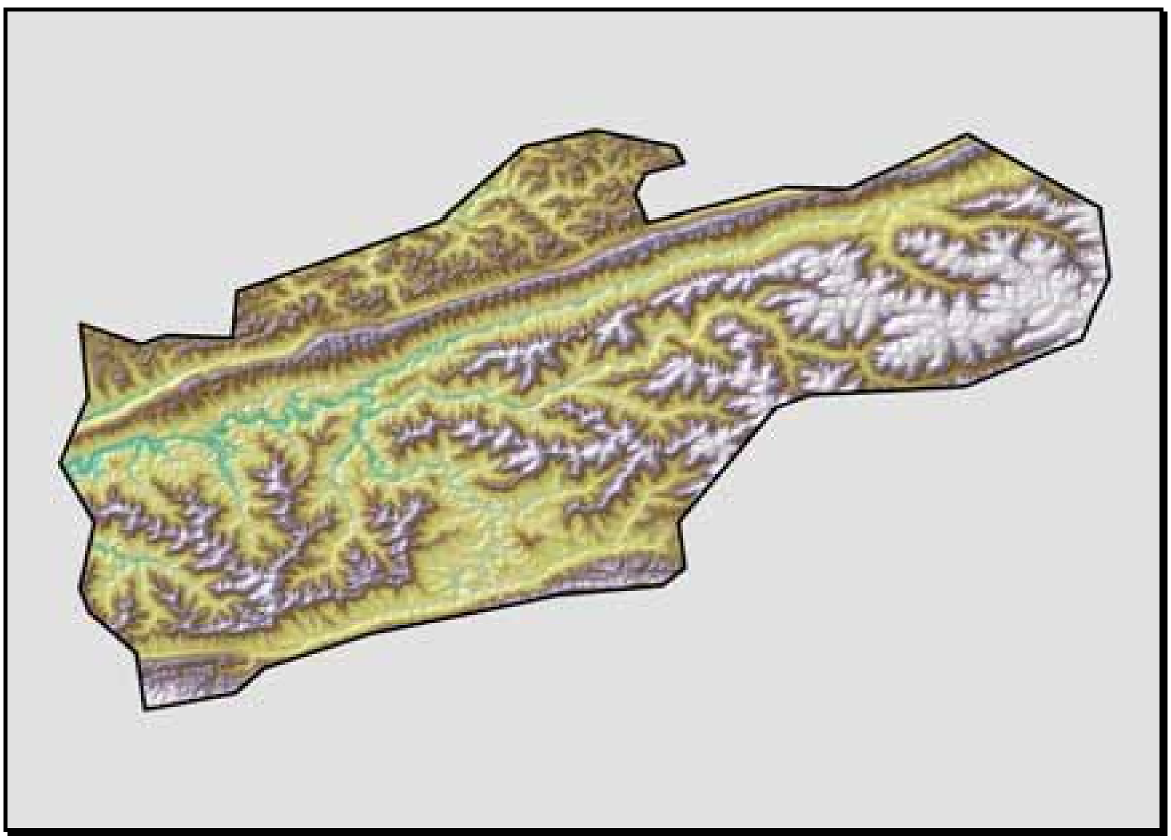
The first step in developing a geoprocessing model was to clip all of the feature classes, both vector and raster, to the bounding coordinates for the Harlan County feature class. The clip function is located within ArcToolbox and is one of the most common operations utilized in data processing. An example of what the clip function looks like in Model Builder is featured below.



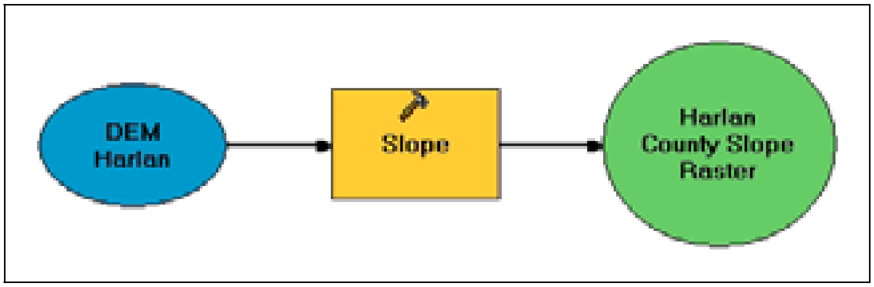
The Digital Elevation Model (DEM) was further enhanced by generating a hillshade effect. This operation is primarily cosmetic but greatly enhances the visual quality of a DEM for the end viewer. A hillshade *(azimuth 315°, 45° sun angle)* enhancement was added along with an exaggerated Z-factor of 2. The operation appears in Model Builder as follows:



The end result of the DEM with the applied hillshade effect was as follows:



Slope was perhaps the most important variable to incorporate into the model. This variable was generated for all surfaces in Harlan County by using the slope tool within the Spatial Analyst toolbox. This tool was summarily dragged into the model and applied to the clipped DEM for Harlan County.



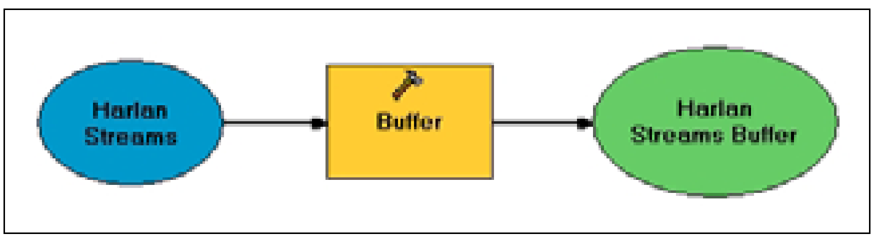
Buffer Creation

The literature that addresses landslide probability makes a strong correlation between anthropogenic disturbances on the landscape and increased landslide potential. Nowhere is this more apparent than the creation of roads throughout the mountainous terrain that dominates Harlan County. The cumulative destabilizing effects of road creation coupled with the subsequent intrusion of vehicular traffic into environmentally sensitive terrain that possesses considerable natural relief will inevitably lead to both landslides and rockfall, especially if not properly maintained and assessed by civil engineering corps.

Harlan County is one of the most heavily mined counties in the United States of America and has topography littered with surface coal mines. The presence of surface coal mines greatly amplifies the risk of landslides, especially if the mines have been summarily abandoned and improperly managed to mitigate future landslide risk.

The natural watershed of the Middle Fork of the Kentucky River in itself also lends itself to exacerbating the risk of landslides. Natural erosion of the landscape caused by the effects of drainage will carve steep ravines into the landscape over millennia.

These three feature classes were clipped to the Harlan County boundary file and subsequently incorporated into the next phase of the model, where they both underwent the process of buffering. A buffer is a common geoprocessing task found in ArcToolbox where the user commands the software to generate a buffer around an existing feature class. The user has the option of creating a new feature class with the buffer or expanding the geometry of the existing feature class through the buffer. A buffer of 100 feet was assessed to all state roads, 50 feet to all county and local roads within Harlan County. A 50 foot buffer was also applied to all existing streams within Harlan County, as listed by the National Hydrography Dataset (NHD). A 1000 foot buffer was also placed around all surface coal mines, regardless whether they were active or abandoned mine sites. An example of the buffer tool within Model Builder follows:



Data Reclassification

The most extensive stage of the geoprocessing model was to engage in data reclassification. Spatial Analyst was used extensively to reclassify data within the model. Reclassification allows specific variables to be combined within one class, thus making it easier to run specific analyses. Reclassification may also allow the user to assess specific weighted values to certain variables within datasets in order to amplify their importance within the analysis. The feature classes that underwent reclassification were *land use cover, slope, geology, coal mines* and *soils*.

1. Coal Mines – The data listed three types of surface mines – active, abandoned and undetermined. Each surface mine was assigned a weighted value. Undetermined mines were given a value of “1” due to the lack of qualified data about them. Active mines were assigned a value of “5”, while abandoned mines, posing the greatest potential threat to contributing to landslides, were assigned a value of “20”

2. Soils – Soils play an integral role in the science of landslide risk assessment. Three soil types found within Harlan County[1] were strongly associated with areas with steep slopes and rocky terrain:

   1. Helechawa-Varilla-Jefferson (HeF), *very rocky, 35 to 75 percent slope*
   2. Highsplint-Cloverlick-Guyandotte (HsF), *35 to 75 percent slope, very stony*
   3. Alticrest-Totz-Helechawa (AtF), *rocky, 20 to 55 percent slope*

   These three soil types were reclassified with a value of “25”. All other soil types were assigned a value of “1”.

3. Geology – The geological profile of Harlan County, like most of the counties that comprise the Appalachian Belt of Eastern Kentucky, fall into one of five distinctive categories. Shale is extremely susceptible to landslides. Rock formations found throughout the region in which the primary layer was composed of shale were assigned high reclassification values, underlying their strong potential to contribute to landslides. The following table displays the geological formations found in Harlan County and their assigned reclassification values for the geoprocessing model[2].

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[1] A full listing of soil types found within Harlan County may be found at http://soildatamart.nrcs.usda.gov/Report.aspx?Survey=KY638&UseState=KY

[2] A detailed description of these formations can be found in Appendix A.

KY Geological Classification	Reclassification Value
Breathitt Formation, lower part	10
Breathitt Formation, middle part	5
Breathitt Formation, upper part	1
Chattanooga and Ohio Shales	25
Lee Formation	1
Pennington Formation	2

4. Land Use Cover – The National Land Cover Dataset lists more than three dozen primary land cover designations. A majority of these were not present in Harlan County and were excluded from the reclassification. Barren land is by far the most susceptible to landslide risk, and thus was assigned a value of “25”. Developed areas, depending upon the degree of land development, constitute a secondary risk and were assigned values 0f “7”, “10” and “15”, respectively. A full view of the NLCD Table and the values assigned to each in the reclassification is listed in the following table.

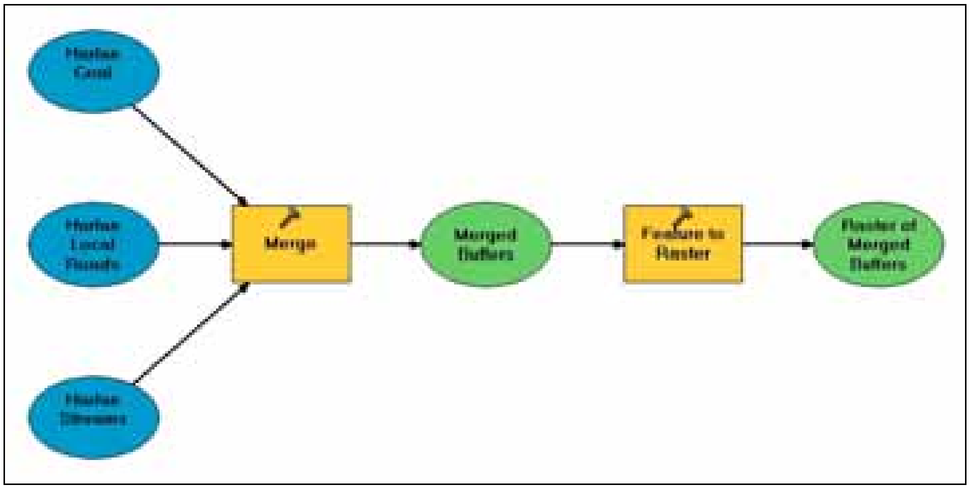
2001 Scheme	Reclassification Value
11 - Open water 12 - Perennial Ice/Snow	0 N/A
21 - Developed, Open Space 22 - Developed, Low Intensity 23 - Developed, Medium Intensity 24 - Developed, High Intensity	15 7 10 15
31 - Barren Land 32 - Unconsolidated Shore	25 N/A
41 - Deciduous Forest 42 - Evergreen Forest 43 - Mixed Forest	2 2 2
51 - Dwarf Scrub 52 - Scrub/Shrub	N/A 5
71 - Grassland/Herbaceous 72 - Sedge Herbaceous 73 - Lichens 74 - Moss	7 N/A N/A N/A
81 - Pasture/Hay	7

82 - Cultivated Crops	N/A
90 - Woody Wetlands	1
91 - Palustrine Forested Wetland	N/A
92 - Palustrine Scrub/Shrub	N/A
93 - Estuarine Forested Wetlands	N/A
94 - Estuarine Scrub/Shrub	N/A
95 - Emergent Herbaceous Wetland	N/A
96 - Palustrine Emergent Wetland (pers.)	N/A
97 - Palustrine Emergent Wetland	N/A
98 - Palustrine Aquatic Bed	N/A
99 - Estuarine Aquatic Bed	N/A

5. Slope – No variable played as important a role in determining the potential for a landslide than did slope. The slope raster was simply reclassified into nine categories and assigned a risk value that increased geometrically in value with an increase in slope.

Slope (by percent)	**Reclassification Value**
<1%	1Bret
1%-2%	4
2%-4%	8
4%-7%	16
7%-10%	32
10%-15%	64
15%-25%	128
25%-45%	256
>45%	512

It was also necessary at this stage of the analysis to convert the buffers for coal mines, roads and streams from vector data into raster datasets so that they could be merged into the final landslide risk raster. An example of the conversion tool in Model Builder is as follows:



<u>Creating the Final Weighted Raster</u>

The final stage of the geoprocessing was to generate a *weighted sum raster*. The process entailed combing the following reclassified raster datasets: geology, slope, land use cover, soils, and the merged raster of buffers for coal mines, streams and roads. Each of these raster files has the same cell size and each contains a common field called VALUE which contains the assigned reclassified value that was assigned to it. The weighted raster also stipulates that each raster file itself be assigned a percentage weight, with all included raster files required to equal 100%. The following weighted percentages were assigned to the raster files:

Reclassified Raster File	**Weighted Percentage**
Slope	40%
Land Use Cover	20%
Geology	15%
Soils	15%
Coal Mine, Stream & Road Buffers	10%

A hypothetical raster cell with a slope of 4.5%, a land use cover of mixed forest, found in the Pennington Formation, comprised of Shelocta-Gilpin (SgE) silt loam soil, located neither within an assigned coal mine, stream or road buffer, would have the following value in the final weighted raster:

Slope = 18.5%, Reclassified Value = “64” * (0.40) = **25.6**

Land Use Cover = Mixed Forest, Reclassified Value = “2” * (0.20) = **0.4**

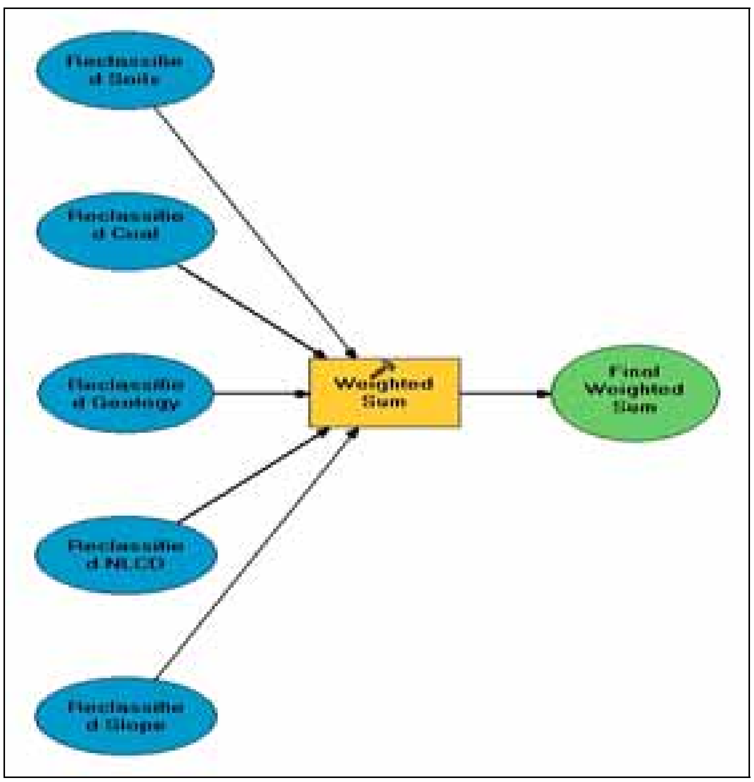
Geology = Pennington Formation, Reclassified Value = “2” * (0.15) = **0.3**

Soil = Shelocta-Gilpin (SgE) silt loam, Reclassified Value = “1” * (0.15) = **0.15**

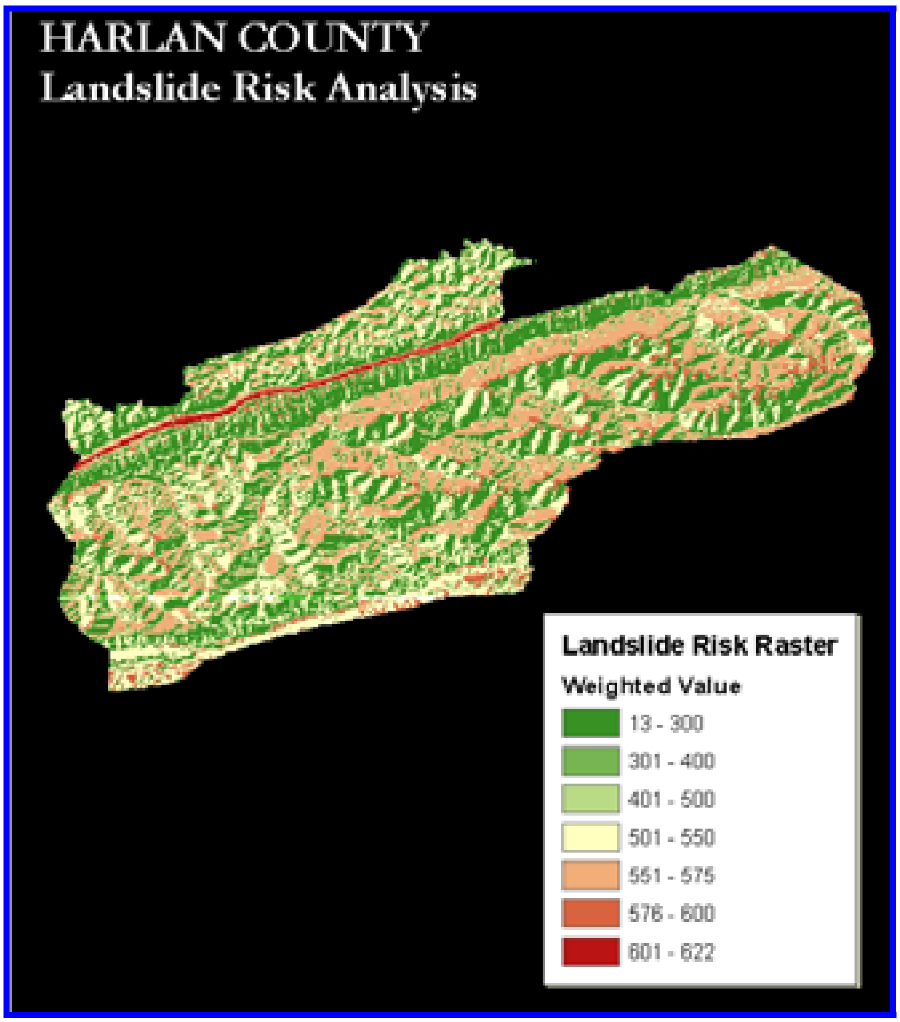
Buffer = None, Reclassified Value = “0” * (0.10) = **0**

Total Cell Value = 26.45

The weighted raster tool in Model Builder appears as follows:



The final weighted sum raster was then separated into seven distinct risk classifications using manual breaks. Raster cell values ranged from a low of 13 to high value of 622. Green values indicate low risk for landslide; dark red indicates extremely high risk for landslide. The end product for Harlan County reveals that landslide potential is greatest along the Pine Mountain Ridge, with secondary risk potential in the east/southeastern portion of the county nearing the Virginia border.



Conclusion

Model Builder is one of the most powerful features to be incorporated into ArcGIS. It enables the software user to build fast and efficient geoprocessing models which can quickly be edited for content and applied to a new area of coverage. Model Builder also enables the user to tinker with parameters of the geoprocessing framework in the event a new set of site-specific conditions arise which necessitate the model be altered to meet a new set of requirements. Model Builder also allows the user to export the geoprocessing framework as a scripting language (ex. Python), thereby circumventing the necessity for the user to learn a complex scripting language. The entirety of the model used in this document is listed in Appendix B as a Python script.

Appendix A – USGS Geological Classifications

Breathitt Formation, middle part

State	Kentucky
Original map label	PAbm
Name	Breathitt Formation, middle part
Age	Pennsylvanian
Description	Breathitt Formation, middle part
Comment	along and south of Pine Mountain; thickness is at least 350+ m; in east-central Kentucky, thickness is 0-195 m; in northeastern Kentucky, thickness is 35-135 m; in south-central Kentucky, thickness ranges from at least 80-85+ m
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock type	sandstone
Secondary rock type	shale
Tertiary rock type	siltstone; coal; limestone
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Bell - Boyd - Breathitt - Carter - Clay - Elliott - Floyd - Garrard - Greenup - Harlan - Johnson - Knott - Knox - Lawrence - Leslie - Letcher - Lincoln - McCreary - Magoffin - Martin - Morgan - Owsley - Perry - Pike - Rockcastle - Whitley - Wolfe

Breathitt Formation, lower part

State	Kentucky
Original map label	PAbl
Name	Breathitt Formation, lower part
Age	Pennsylvanian

Description	Breathitt Formation, lower part; lower part which includes Livingston Conglomerate Member of Lee Formation in eastern Rockcastle County
Comment	along and south of Pine Mountain; thickness is 625-800 m; in south-central Kentucky, thickness is at least 500+ m; in northeastern Kentucky, thickness is 50-300+ m; in east-central Kentucky, thickness is 225-415 m
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock type	shale
Secondary rock type	siltstone
Tertiary rock type	sandstone; coal; conglomerate
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Bell - Breathitt - Carter - Clay - Clinton - Elliott - Estill - Floyd - Greenup - Harlan - Jackson - Johnson - Knott - Knox - Laurel - Lawrence - Lee - Leslie - Letcher - Lewis - McCreary - Madison - Magoffin - Martin - Menifee - Montgomery - Morgan - Owsley - Perry - Pike - Powell - Pulaski - Rockcastle - Rowan - Wayne - Whitley - Wolfe

Breathitt Formation, upper part

State	Kentucky
Original map label	PAbu
Name	Breathitt Formation, upper part
Age	Pennsylvanian
Description	Breathitt Formation, upper part
Comment	in east-central Kentucky, thickness is at least 45+ m
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock	sandstone

type	
Secondary rock type	siltstone
Tertiary rock type	coal; limestone
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Boyd - Breathitt - Carter - Elliott - Floyd - Greenup - Harlan - Johnson - Knott - Lawrence - Leslie - Letcher - Magoffin - Martin - Morgan - Perry - Pike

Lee Formation

State	Kentucky
Original map label	PAMl
Name	Lee Formation
Age	Mississippian to Pennsylvanian
Description	Lee Formation
Comment	along and south of Pine Mountain; thickness is 260-610 m
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock type	conglomerate
Secondary rock type	sandstone
Tertiary rock type	siltstone; shale; coal
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Bell - Harlan - Letcher - Pike - Whitley

Pennington Formation, Newman Limestone, Fort Payne Chert, Grainger Formation, Sunbury Shale, Berea Sandstone, and Bedford Shale, undivided; Pennington Formation locally includes sandstone tongue of Lee Formation

State	Kentucky
Original map label	PADpg
Name	Pennington Formation, Newman Limestone, Fort Payne Chert, Grainger Formation, Sunbury Shale, Berea Sandstone, and Bedford Shale, undivided; Pennington Formation locally includes sandstone tongue of Lee Formation
Age	Devonian to Pennsylvanian
Description	Pennington Formation, Newman Limestone, Fort Payne Chert, Grainger Formation, Sunbury Shale, Berea Sandstone, and Bedford Shale, undivided; Pennington Formation locally includes sandstone tongue of Lee Formation
Comment	along and south of Pine Mountain; collectively the thickness ranges from about 270- 830 m
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock type	limestone
Secondary rock type	sandstone
Tertiary rock type	siltstone; shale; conglomerate; chert; dolostone (dolomite); black shale
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Bell - Harlan - Letcher - Pike - Whitley

Chattanooga and Ohio Shales, undivided

State	Kentucky
Original map label	MDc

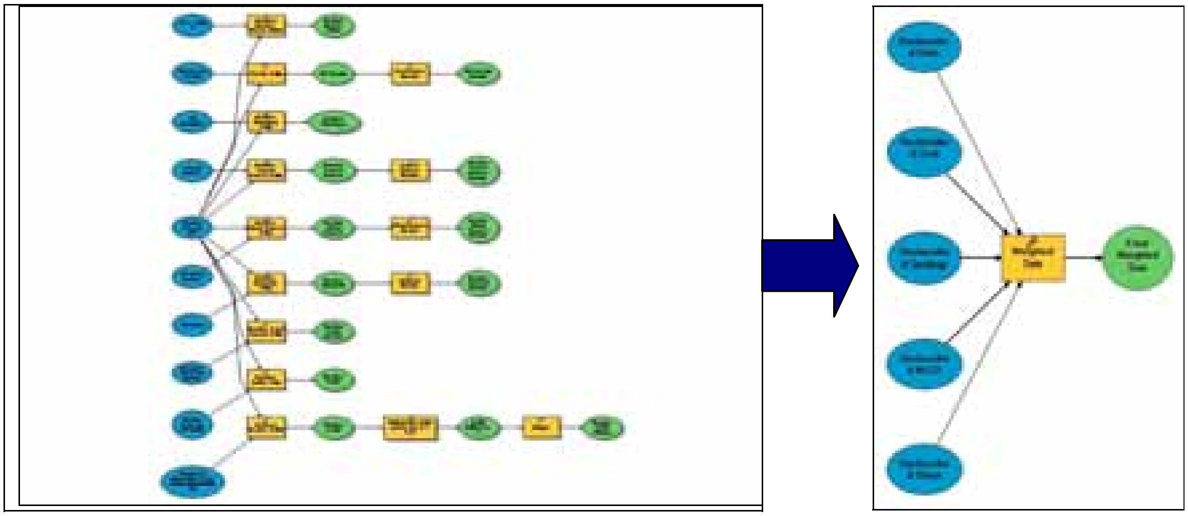
Name	Chattanooga and Ohio Shales, undivided
Age	Devonian to Mississippian
Description	Chattanooga and Ohio Shales, undivided; along and south of the Pine Fault
Comment	along and south of Pine Mountain; at least 300+ m thick
Map references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Primary rock type	black shale
Unit references	Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
Geographic occurrence	Bell - Harlan - Letcher - Pike - Whitley

Appendix B – Harlan County Landslide Model Exported as Python Script

```
# ---------------------------------------------------------------------------
# Harlan_Landslide_Analysis.py
# Created on: Thursday, August 13, 2009
# Created by Ryan Kelly
# Description:
# This model examines landslide risk.  The process involves the importation of a raster, from which slope, aspect and landcover are calculated, weighted, and then reclassified into a new raster that shows landslide risk.  The new reclassfied raster is then exported into a TIN so that it can be viewed in 3D Analyst.
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")


# Local variables...
Harlan_DEM = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_DEM"
Harlan_County = "Harlan Group Layer\\Harlan"
Harlan_DEM_Hillshade = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_DEM_Hsd"
Harlan_Slope = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_Slope"
NLCD_2001 = "NLC_2001"
NLCD_Harlan = "E:\\GIS 750 Project\\Harlan.mdb\\NLCD_Harlan"
Harlan = "Harlan Group Layer\\Harlan"
NED_93429768 = "E:\\GIS 750 Project\\Harlan.mdb\\ned_93429768"
Harlan_Geology = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_Geology"
Harlan_GLY_Raster = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_GLY"
Harlan_NLCD_Reclass = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_NLCD_Reclass"
Harlan_GLY_Reclass = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_GLY_Reclass"
kygeol_tect_shp = "E:\\GIS 750 Project\\kygeol_tect.shp"
Harlan_Landslide_Risk = "E:\\GIS 750 Project\\Harlan.mdb\\Harlan_Landslide_Risk"

# Process: Extract by Mask...
gp.ExtractByMask_sa(NED_93429768, Harlan_County, Harlan_DEM)
```

```
# Process: Hillshade…
gp.HillShade_sa(Harlan_DEM, Harlan_DEM_Hillshade, "315", "45", "NO_SHADOWS",
"2")

# Process: Slope...
gp.Slope_sa(Harlan_DEM_Hillshade, Harlan_Slope, "DEGREE", "1")

# Process: Extract by Mask (2)...
gp.ExtractByMask_sa(NLCD_2001, Harlan, NLCD_Harlan)

# Process: Reclassify (2)...
gp.Reclassify_sa(NLCD_Harlan, "VALUE", "11 0;21 15;22 7;23 10;24 15;31 25;41 2;42
2;43 2;52 5;71 7;81 7;90 1", Harlan_NLCD_Reclass, "DATA")

# Process: Clip...
gp.Clip_analysis(kygeol_tect_shp, Harlan, Harlan_Geology, "")

# Process: Polygon to Raster...
gp.PolygonToRaster_conversion(Harlan_Geology, "LABEL", Harlan_GLY_Raster,
"CELL_CENTER", "NONE", "0.011")

# Process: Reclassify...
gp.Reclassify_sa(Harlan_GLY_Raster, "VALUE", "0 1;1 2;2 25;3 2;4 2;5 15",
Harlan_GLY_Reclass, "DATA")

# Process: Weighted Sum...
gp.WeightedSum_sa("'E:\\GIS 750 Project\\Harlan.mdb\\Harlan_Slope' VALUE
10;'E:\\GIS 750 Project\\Harlan.mdb\\Harlan_NLCD_Reclass' VALUE 5;'E:\\GIS 750
Project\\Harlan.mdb\\Harlan_GLY_Reclass' VALUE 10", Harlan_Landslide_Risk)
```

Appendix C – The Geoprocessing Model



The size of the geoprocessing model prevents its display with visible text on a single page.

Selected Bibliography

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