A Tale of Two Watersheds: Land Use, Topography, and the Potential for Urban Expansion

Land use patterns are often highly correlated with geographic variables such as slope and elevation gradients and sometimes with other variables such as land ownership, and proximity to markets, services, population centers, transportation systems and stream networks. In this project, we use census, land use, elevation and slope data to compare two watersheds and discover ways in which the watersheds are similar and ways in which they are different. Both watersheds are experiencing a high amount of urban and exurban (small communities outside of urban areas) development which is converting land use from non-urban (such as agricultural and forest cover) to urban. (Note: for the purposes of this project we will consider all non-agricultural, intensive human settlement to be "urban"). What we will do is see where people already live, investigate how they are using the land in each watershed, and then use slope and elevation to find the most likely areas in which further urban expansion could occur.

The study site watersheds are the Big Thompson watershed in north-central Colorado (832 square miles) and the Rio Espiritu Santo watershed in northeastern Puerto Rico (37 square miles). These watersheds are very different in size, location and climate, but still share many characteristics in common. We will use several different data sets to gather information about the two watersheds and then conduct a spatial analysis using GIS to determine areas where further urban and exurban expansion is most likely to occur.

Objectives of the Project

- To familiarize students with the use of a Geographic Information System for scientific inquiry
- To investigate the ways in which two watersheds are similar and different in how people distribute themselves and their use of land throughout these watersheds
- To illustrate how land use is correlated with two land use drivers: elevation and slope
- To compare the distribution of slope and elevation classes between the two watersheds
- To use elevation zones, slope zones and current land use polygons to identify suitable areas in the two watersheds where future urban expansion could occur

Lessons 1 and 2 show you where people live and how they use the land. Lesson 3 processes digital elevation data into elevation and slope classes to better visualize regions in which urban expansion could occur. Lesson 4 contains a spatial analysis that defines likely slope and elevation zones for human settlement and evaluates the areas where further urban expansion could occur based on these likely slope and elevation zones. Lesson 5 produces a final map product that communicates the results of the analysis.

The Watersheds

<u>The Big Thompson River, Colorado</u>

(location map: North American to Colorado to Big Thompson)

The Big Thompson watershed covers 832 square miles in north-central Colorado. Its highest elevations lie at the Continental Divide and its lowest elevations are on the western Great Plains. The Big Thompson River, for which the watershed is named, originates near Forest Canyon Pass on the Continental Divide in Rocky Mountain National Park and terminates on the Plains where it meets up with the South Platte River near Greeley, Colorado. This watershed contains numerous settlements including the cities of Loveland, Colorado and Estes Park, Colorado. Primary land uses and land covers in this watershed are Urban/Residential, Agriculture and Forest.

For more information on the Big Thompson, please visit these weblinks:
For more information on Colorado, please visit these weblinks:

<u>The Rio Espiritu Santo, Puerto Rico</u>

(location map: North America to Puerto Rico to RES)

The Rio Espiritu Santo watershed covers 37 square miles in northeastern Puerto Rico within the municipality of Rio Grande ("big river" referring to the Rio Espiritu Santo). Its highest elevations are in the mountains and its lowest elevations touch the Atlantic Ocean. The Rio Espiritu Santo is unique in that it is the only navigable river in Puerto Rico. Primary land uses and land covers in the watershed are Urban/Residential, Agriculture and Forest.

For more information on the Rio Espiritu Santo, please visit the GIS Information Sources web page. For more information on Puerto Rico, please visit the GIS Information Sources web page.

In this analysis project, we will be using elevation and slope zones to better visualize areas in which human settlement is mostly likely to occur. The definitions for each of the zones were developed from published scientific literature on ecological life zones for elevation and from scientific literature regarding cartographic principles for slope. Ecological life zones have long been used to categorize plant and animal species according to climatic (average precipitation, mean temperature, etc.) and topographic (elevation, etc.) considerations. We have selected one particular set of zones for this project, but in theory any pertinent classifications of elevation and slope could be used. The definitions are as follows:

Description of Slope Zones

Both watersheds will use the same slope zone classifications. We use the four slope elements recommended by Miller and Summerson (1960) as follows:

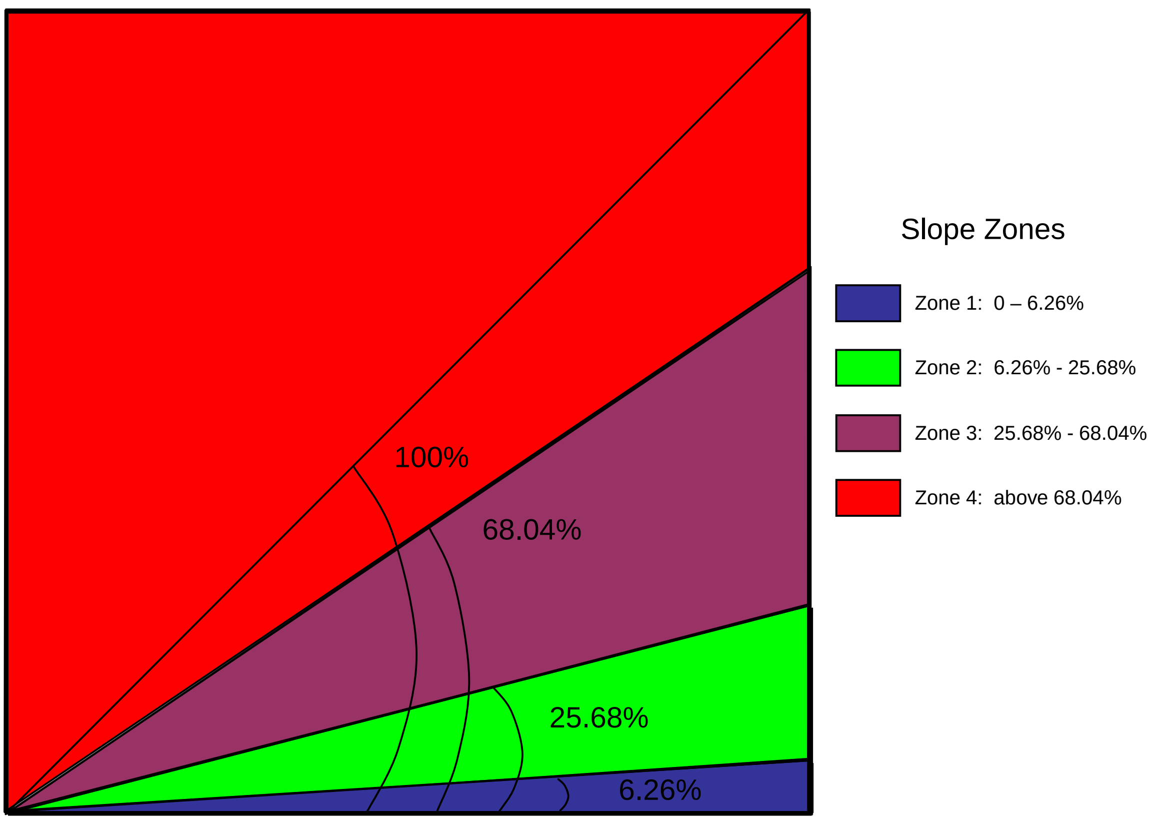
> Flat to Gentle (Zone 1): 0% to 6.26 %   (0° - 3° 35´)   Flat to gentle surfaces such as valleys, coastal plains and outwash areas

Shallow (Zone 2): 6.26% to 25.68 % (3° 35´ - 14° 26´) The shallow portion of slopes including features such as pediments, fans and depositional features of ice and wind.

Moderate (Zone 3): 25.68% to 68.04 % (14° 26´ - 34° 14´) The steeper portion of slopes with loose material such as talus or debris.

Steep to Free Face (Zone 4): 68.04% and up (34° 14´ and up) The "free face" area including all steep surfaces.

Below is a graphic that illustrates each of the slope zones:



***Thought Question*: Which slope zone(s) do you think is (are) the most likely areas for people to have urban settlements?**

Description of Elevation Zones for the Big Thompson Watershed

These elevation bands are approximate, average boundaries for the ecological life zones of Colorado identified in three different publications from the early 1900s: Plant Zones in the Rocky Mountains of Colorado by Ramaley (1907), Entomostraca and Life Zones, A Study of Distribution in the Colorado Rockies by Dodds (1920), and An Ecological Study of Nesting Birds in the Vicinity of Boulder, Colorado by Johnston (1943).

Plains (Zone 1): less than 1,700 meters (<5,577 feet). This is also known as the Upper Sonoran Zone.

Foothills (Zone 2): between 1,700 meters and 2,500 meters (5,577 – 8,202 feet). This is also known as the Transition Zone.

Montane (Zone 3): between 2,500 meters and 3,100 meters (8,202 – 10,171 feet). This is also known as the Canadian Zone.

Subalpine (Zone 4): between 3,100 meters and 3,400 meters (10,171 – 11,155 feet). This is also known as the Hudsonian Zone.

Alpine (Zone 4): above 3,400 meters (11,155 + feet). This is also known as the Arctic-Alpine Zone.

***Thought Question*: Which elevation zone(s) in Colorado do you think is (are) the most likely areas for people to have urban settlements?**

Description of Elevation Zones for the Espiritu Santo Watershed

These elevation bands are approximate, average boundaries for the ecological life zones of Puerto Rico identified in the publication: Ecological Subregions of the United States: Chapter 51, Puerto Rico (1994). This publication identified the Coastal Lowlands as a single zone, but we have split this zone into 3 sub-zones of low (0 – 25 m), middle (25 – 75 m) and high (75 – 150 m) to better visualize differences in elevation near the ocean.

Coastal Lowlands (low) Zone (Zone 1): 0 meters (sea level) to 25 meters (0 feet to 82.02 feet)

Coastal Lowlands (middle) Zone (Zone 2): 25 meters to 75 meters (82.02 feet to 246.06 feet)

Coastal Lowlands (high) Zone (Zone 3): 75 meters to 150 meters (246.06 feel to 492.13 feet)

Foothills Zone (Zone 4): 150 meters to 300 meters (492.13 feet to 984.25)

Montane Zone (Zone 5): 300 meters and above (above 984.25 feet)

***Thought Question*: Which elevation zone(s) in Puerto Rico do you think is (are) the most likely areas for people to have urban settlements?**

<u>GIS Concepts Used In This Project</u>

Data Formats: vector vs. raster

Two of the primary data formats used in a GIS are vector and raster. Vector data files use a "feature" data structure which represents geographic phenomena as discrete entities (Theobald, 2005, pg. 38). Usually we think of vector data as points, lines and polygons, but they can also include networks and surfaces, too. We use the term "feature" with vector data because points, lines, polygons, etc. represent features on the Earth's surface. Raster data files use a "field" data model with a raster data structure. Raster data is a matrix of cells (a mesh or grid) in which each cell contains a value, such as elevation. These values vary in a continuous manner through space, hence the term "field" data model. Both vector and raster data have their strengths and weaknesses for analysis so we will use both in this project.

Exploratory data analysis: collecting and interpreting feature attributes

Although a GIS can be used to visualize the shape and spatial relationships of data, it is important to keep in mind that there is an "aspatial" characteristic of the data as well – each dataset has a collection of attributes that tells us something about the data besides just its shape or location in space. Many attributes are in tables attached to the spatial data when it comes from the source, but a GIS can also calculate new attribute information using a variety of tools. In this project, you will see many attribute tables and be asked to explore some existing data about the two watersheds by collecting and interpreting feature attributes. This kind of data exploration is a simple example of one of the important functions of a GIS – to change data (a collection of observations or measurements) into information that explains or describes a phenomenon.

Spatial Analysis

Local raster cell functions – reclassifying continuous raster data (elevation and slope) into zones

Local functions only operate on the current cell without using information from any other cells in the grid. Reclassification consists of grouping values into a few categories or classes (such as the elevation and slope zones we have already mentioned). Each cell in processed individually from all other cells and is assigned to a class or category (a new attribute) based on the value of its cell. A new grid is generated with the new attribute tied to each cell in place of the old value.

Global raster functions – surface analysis: converting elevation surface to a slope surface

Global functions operate on the entire raster all at once – they change the entire field at one time. The global surface analysis we will perform in this project involves calculating a new surface (slope) from an existing one (elevation).

Map Algebra

Single-Layer Analysis

Map algebra treats a raster dataset as a field of variables on which mathematical operations can be performed. New data layers can be created from individual layers by performing mathematical or logical operations on all cell values in a raster dataset.

Overlay Analysis – a new dataset is created by performing map algebra calculations on multiple input layers

One of the most powerful spatial analysis characteristics of a GIS is the ability to overlay and compare multiple data layers. We will use the Raster Calculator in ArcGIS to build mathematical expressions which compare the values of two data sets and create a new dataset based on the results of the expression.

Communicating Analysis Results with a Map

Maps are not just pretty pictures – they are created in order to communicate information about spatial phenomena to the user of the map. In addition to a graphic representation of the results, all maps should contain seven essential map elements: a descriptive title, a north arrow, a legend, some indication of the scale of the map, who created the map, when it was created, and the source of the data used in the map. The map maker also has some responsibilities to consider. The map maker must be fair to the data, must create clear maps for the map readers, and must anticipate ways in which a third person may be affected by any foreseeable misinterpretation. In lesson 5, we will use a map to communicate the results of the spatial analysis completed in lesson 4.

Modeling: Developing your Analysis Process

Modeling is a key component to spatial analysis and developing your analysis process. One method of modeling is flowcharting, which allows you to describe the various steps in your analysis. In addition to rationalizing your process through flowcharting, it also allows anyone to follow your analysis process.