GIS3: Evaluating a land use issue with visibility analysis

The problem

Landfills hold waste and the average person in the US sends 1,870 lbs. of waste to landfills. In 2005, Cumberland County, PA proposed to expand the capacity of its landfill in Hopewell Township, which would increase the total height of the landfill terrain by 114 feet (34.7 m). Concerned about the visual impact that so much vertical growth might have on nearby residents, county officials lofted a tethered 15-foot tall, 15-foot wide helium balloon above the site and up to the proposed expansion height. Some residents thought the balloon test was helpful, but others became angry. Leigh Cavanaugh was quoted as saying, "if you can see a landfill or a junkyard from your home, its value goes down" (Heberlig, May 24, 2006).

A small group of vocal citizens organized and challenged the fairness of the balloon test at public meetings. They sent opinion letters. They claimed the balloon test was unfair because a 15-foot tall balloon is too small to be seen from the same distances that a mountain of trash can be seen.

In July 2006, Cumberland County officials decided to "reduce the height of the proposed expansion by 30 feet – from 805 feet down to 775 feet above sea level" (Heberling, July 19, 2006). They cited "comments triggered by the balloon test" (Heberling, July 19, 2006) as reasons behind their decision. The reduction notwithstanding, some valley residents still believe the revised landfill expansion will still hurt their property values.

The research question

Was the balloon test a fair indicator of the visual impact of the proposed landfill expansion on the Cumberland Valley?

The purpose of this lab is to answer the research question. As you know, a GIS can be used to do many things, but there is no Fairness toolbox, no Goodness toolbar, and no Justice button. So, like most research questions, this one needs to be broken down into manageable pieces - a set of incremental objectives.

Incremental objectives

We need to break down the problem and identify the pieces of information that we need:

1. What was the surface height of the landfill back in 2005 (before any expansion)?
2. Where is the landfill expansion site located (or, where was the balloon tethered)?
3. What is the maximum distance that a person with normal visual acuity can stand away from a person, a 15 foot-tall helium balloon, a +114 foot-tall pile of trash, or an +84 foot trash pile and still see each of those things?
4. From which locations in the Cumberland Valley can a person stand with a clear view of the helium balloon test, the proposed landfill expansion, or the revised landfill expansion?

Methods and Data

Task 0: Prepare a workspace (via ArcCatalog).

Visit the course website to obtain the DEM that was extracted from the U.S. Geological Survey's National Elevation Dataset.

The balloon was tethered to the ground at 77° 30' 10.3" W, 40° 8' 12.0" N (NAD83). Convert these coordinate data from DMS format to DD format, then use either Microsoft Excel ® or a simple text editor to create a file to store these geographic coordinates as a point feature.

Task 1: Choose a suitable spatial reference system. **Bolstad (2016) p124-128**.

We want to focus on the landfill site, so it makes sense to use a planar coordinate system that will not introduce nefarious distortions into our analysis. Given the county-level scale of this project, it makes perfect sense to use the metric (NAD83) SP PA-South spatial reference system.

Task 2: Create geospatial data (via ArcCatalog). **Bolstad (2016) p35, p81**.

In your workspace, create a **new** file geodatabase. Create a **new** toolbox.

Next, in ArcCatalog, right-click your text file (or your Excel worksheet) and **Create Feature Class > From XY Table**. Map your **Input Fields**, set the **Coordinate System of Input Coordinates** properly, specify the **Output Feature Class**, and, using the **Advanced Geometry Options…** button, choose the metric (NAD83) SP PA-South spatial reference system for your output. You've used this workflow before.

Task 3: Get started by using some simplifying assumptions

We'll ease into our analysis by making some simplifying assumptions. First, we'll assume the earth's surface is flat and featureless (Figure 1) and that the average person has normal visual acuity (i.e., 20/20 vision). Normal visual acuity means the ability to resolve an object that spans 1 arc minute (see Figure 2 and Equation 1).

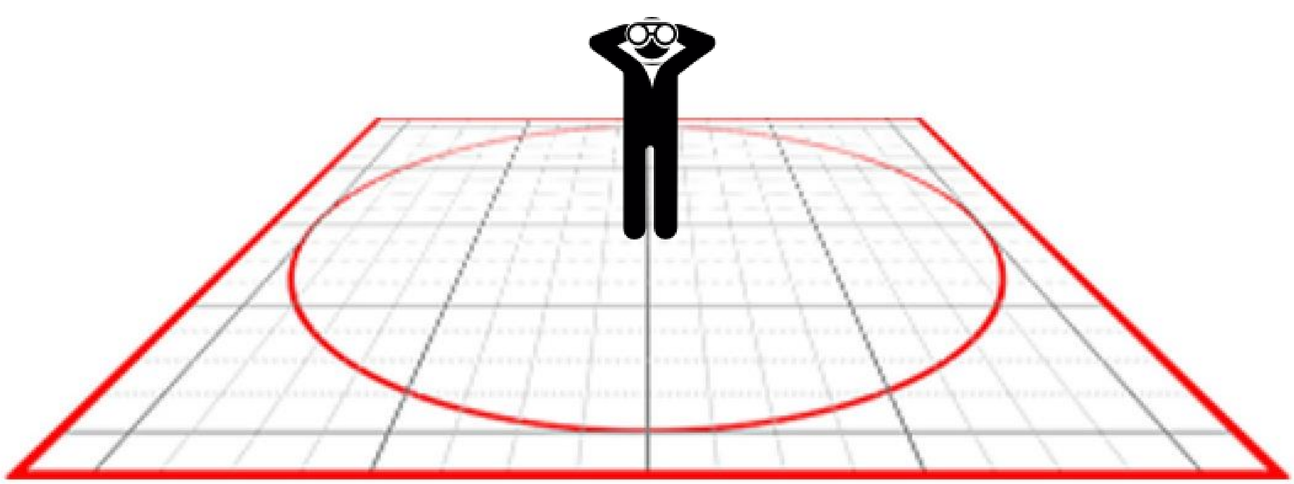
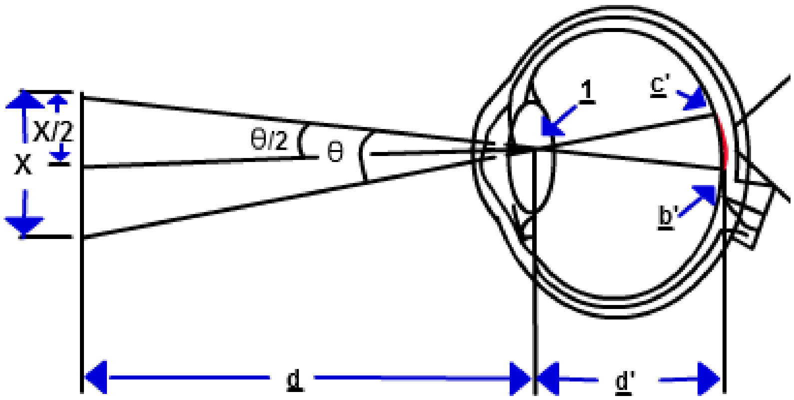


Figure 1: A flat and featureless plane.



$$\frac{x}{2} = d \cdot \tan\left(\frac{\theta}{2}\right) \qquad \text{Eq. 1.}$$

Where:

x = size of the distant object

d = distance between eye and object

θ = degrees of arc *

Figure 2: The visual geometry of the human eye. Sketch not drawn to scale.

Task 4: Find the anatomical limits of normal visual acuity for different size objects.
With our simplifying assumption and the method shown in Eq.1, find the longest distance an average person with normal visual acuity can see an object of a particular size. * Whether you use Excel or a calculator, make sure you know if it assumes your angles are measured in degrees or in radians. Equation 1 assumes you are working with degrees of arc.

1. What is the maximum distance a person with normal visual acuity can stand away from:
    a. a 5’ 7” person (1.7 m)
    b. a 15’ (4.57 m) tall balloon
    c. a 114’ (34.75 m) tall object
    d. an 84’ (25.60 m) tall object

    and still see it?

With the method shown in Figure 2 and the four examples above, we can easily see how the anatomical limits of human vision are constrained by both object size and distance from the object. This relationship is the basis for landowner complaints about the balloon test.

Task 5: Relax one of our assumptions
The surface of the earth is not flat, but curved. Maybe you watched the Space X Falcon Heavy rocket launch and the views from “Starman” in space (**https://youtu.be/aBr2kKAHN6M**). Or perhaps you’ve noticed, while at the shore, that distant ships appear to fall over the horizon as they sail away. The curvature of the earth limits human vision in a way that’s unrelated to visual acuity. We need to find the longest distance that a person can see something before his or her line of sight is interrupted by the surface of the earth.

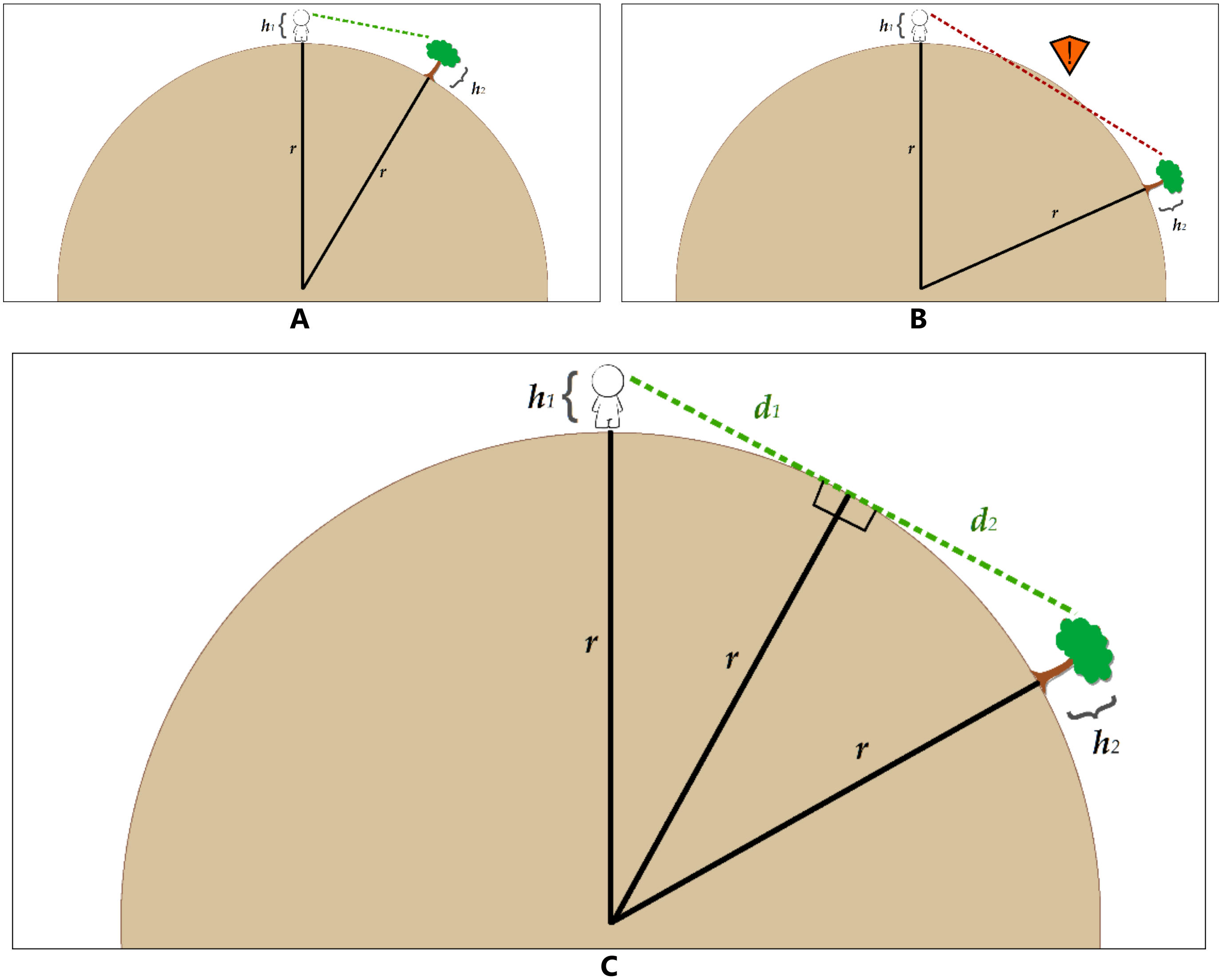


Figure 3: Sight lines over a curved earth surface: **A**) a straight and uninterrupted line of sight between a person (h_1) and a nearby tree (h_2) allows (most of) the tree to be in view. **B**) A straight line of sight to a distant tree is interrupted by the person's local horizon, so the tree is not visible to him or her. **C**) The longest sight line possible ($d_1 + d_2$) between a person of height h_1 and a tree of height h_2. In this last case, the viewer can technically still "see" the tree, albeit the leaves and not the ground from which it grows.

Take another good look at Figure 3**C**. If we assume that earth surface curvature over relatively short distances can be reasonably approximated by a sphere, then we can leverage the Pythagorean Theorem (Equation 2) to find the longest sight line distance possible that is not interrupted by the earth's curved surface. Do you see the two right triangles?

$$c^2 = a^2 + b^2 \qquad \text{Eq. 2.}$$

Task 6: Find the limits of human sight lines as a function of earth curvature.

At 40° N latitude, the radius of the earth, ***r***, is 6,374,380 m. According to the U.S. Centers for Disease Control, the ***h***eight of the average person is 5' 7" (1.7 m) tall. With these metric lengths, you have all the data you need to substitute the terms in Equation 2, rearrange, and solve for d_1, d_2, and $d_1 + d_2$

substitute: $(r + h)^2$ for c^2; r^2 for b^2; and d^2 for a^2

2. Ignoring visual acuity for a minute, what is the maximum total sight line distance from a standing person to …
    a. his or her local horizon (i.e., d_1)
    b. a 15' (4.57 m) balloon (i.e., $d_1 + d_2$)
    c. a 114' (34.75 m) tall object (i.e., $d_1 + d_2$)
    d. an 84' (25.6 m) tall object (i.e., $d_1 + d_2$)

    … over the curved surface the earth?

Task 7: Which constrains human vision the most: visual acuity or earth surface curvature?
Build a table like Table X below and populate it with your answers to questions 1 and 2. Then, find the most limiting distance between the two constraints on human vision.

3. Table X. The constraining limits on object visibility.

Object	Maximum sight line distance as constrained by normal visual acuity	Maximum sight line distance as constrained by earth surface curvature	Most limiting distance of the two
4.57 m balloon			
34.75 m trash cell			
25.60 m trash cell			

Copy the **ArcToolbox > Analysis Tools > Proximity > Buffer** tool into your toolbox. Next, use the most limiting distances and *fixed distance buffering* (**Bolstad (2016) p398-402**) to construct annular polygons.

4. What is the area [mi^2 (km^2)] of the simple buffer defined by radius =
    a. the most limiting sight line distance to a 15' (4.57 m) balloon?
    b. the most limiting sight line distance to a 114' (34.75 m) tall object?
    c. the most limiting sight line distance to an 84' (25.60 m) tall object?

Visibility Analysis

The surface of the earth is not featureless, but covered by a vast array of landforms. The Cumberland Valley in southcentral Pennsylvania – a small portion of the geologic Great Valley – is bounded to the north by Blue Mountain and to the south by South Mountain (Figure 4). Surely these imposing landforms also constrain human vision.

Figure 4. A view of South Mountain while traveling south on Interstate 81.

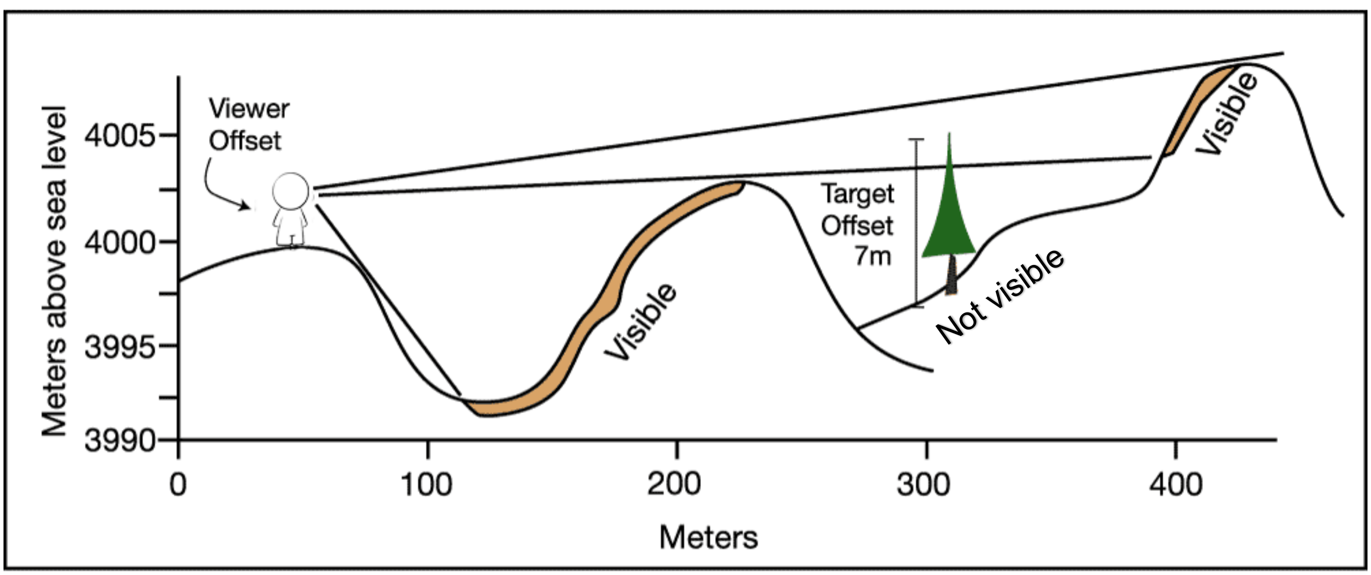


Figure 5: A topographic profile and various lines of sight; some locations are in view while others are obstructed by intervening terrain. Notice: a) the viewer is standing, so the viewer's eyes are above the ground; and b) the tree is visible but the ground from which it grows is not.

Task 8: Perform visibility analysis **Bolstad, Table 11-1 on p484, p504; Kimmerling et al. Ch 16.**

Figure 5 illustrates a person standing on terrain; some distant locations are visible while others are obstructed by intervening terrain. Visibility analysis extends the simple ideas presented in this sketch to all 360 directions. Visibility analysis is a GIS workflow that ingests a DEM and allows the user to find locations (cells) that are visible by a point (or set of points).

To achieve computational efficiency, Esri's visibility and viewshed tools will work by casting sight lines from the inputted points (the landfill/balloon spot) to each cell (kinda like the landfill or balloon is looking down at the DEM; not from the cells up to the points as you might expect). Cells reachable by unobstructed lines of sight will be coded as visible, all others as not visible.

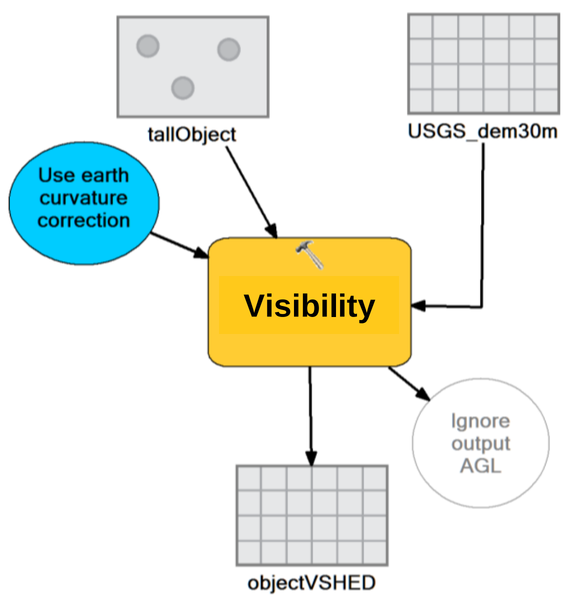
I strongly recommend that you consult your textbooks and the ArcGIS Help menu to learn about ***Using Viewshed and Observer Points for visibility analysis***. The 'visibility', 'viewshed', and 'observer points' tools can all be used to perform this type of analysis, but the viewshed and observer points tools have special data preparation requirements that the visibility tool does not. You might also find Shea O'Neill's **YouTube** video about viewsheds, observer points, and visibility to be useful.

There are two ways to access the **Visibility** tools in ArcGIS Desktop: via the Spatial Analyst toolbox and the 3D Analyst toolbox. Copy the **ArcToolbox > Spatial Analyst > Surface > Visibility** tool into your toolbox.

The cartographic model below (Figure 6) illustrates a simple workflow that involves one tool. In short, I'm leading you to the one tool, but you're on your own to figure out how to make it work to run three (3) visibility analyses.

Figure 6: Cartographic model for conducting visibility analysis for:

1. the balloon test;
2. the original landfill expansion plan; and
3. the revised landfill expansion plan.



Task 9: Report your visibility analysis parameters and calculate visible areas
Build a table like Table Y below and populate it with the values that you used to setup and run your three visibility analyses.

5. Table Y: Selected attributes and values used to control each visibility analysis.

Attribute	**Balloon** Test	**Proposed** Landfill Expansion	**Revised** Landfill Expansion
SPOT	?	?	?
OFFSETA	?	?	?
OFFSETB	?	?	?
RADIUS2	?	?	?

If you setup and run each of your visibility analyses correctly, then each should produce a raster showing a circular area. Cells beyond your buffer radius will be coded as not visible. Cells inside the buffer radius that are shielded from view by intervening hills or ridges will also be coded as not visible. The balance – the cells that are coded as visible – is your viewshed.

6. Calculate the actual visible area [km^2 (mi^2)] under each scenario. Esri's surface/visibility tool generates integer rasters with value attribute tables. You can use the cell counts and raster cell size to inform your calculations. Or, you can convert each raster to polygons to generate Shape_Area values and use those to inform your calculations.

Task 10: Interpreting your results
Reporting facts, tables, and maps is not enough to answer your research question. You need to interpret your results to draw meaning from them.

7. Compare and contrast the results of your three viewshed analyses (**balloon** test vs. the **proposed** expansion plan vs. the **revised** expansion plan). Don't describe each circular buffer – describe the locations covered by the buffer. And don't describe each viewshed – describe the locations covered by the viewshed. For example, if your description of visible areas makes references to places in the valley, distances, directions, landforms, etc., then you're doing it right. If all you're doing is making vague statements or describing blobs of color, then you're doing it wrong.

Deliverables

Complete a well-written report of the lab exercise. Your report should be organized using five sections and section headings: Purpose, Objectives, Methods and Data, Results and Answers, and Summary. Provide concise purpose and objectives using your own words.

Move Tables X and Y from your Results and Answers section to your Methods and Data section. Discuss the values in those tables in your Methods and Data section.

In the Results and Answers section, include the answers to the questions posed above and any maps/figures that you prepared to support those answers. For Questions 4 and 5, use a complete sentence to refer the reader to the tables in your Methods and Data section. There's no need to insert two copies of each. Just refer the reader back.

In the Summary section, address each of the objectives and make a direct statement that answers the research question. For example:

From these results, I conclude that Cumberland County's balloon test < was | was not > a fair indicator of the visual impact of the proposed landfill expansion plan. It < was | was not > a fair indicator because … < evidence > .

All lab reports should be typed and printed on 8.5" by 11" stock. Before drafting your report, set all page margins to be 0.7", but set your left margin to 1.2". Put your lab title, your name and the date at the top of the first page. Set the normal font face to be readable (e.g., Candara, Bookman Antiqua, Bookman Old Style, or Georgia); never use Times New Roman or any kind of decorative font. Also, set the normal font size to be 11 points. Major section headings should be in **bold** face. Use 1.5 line spacing. Include page numbers on every page. All tables and figures must be inserted into the body of your report and conform to the formatting and margin requirements.

References

"Chapter 36: Human Eye" in Gross, Herbet (Ed.) 2008. *Handbook of Optical Systems: Vol. 4 Survey of Optical Instruments*. Wiley. Last accessed on February 12, 2018 at https://application.wiley-vch.de/books/sample/3527403809_c01.pdf

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Heberlig, Dale. 2006. "Mountain of trash will be a bit lower." *The Sentinel*, July 19, 2006.

US Geological Survey. 2017. National Elevation Dataset - NAVD88 Meters - 1/3rd-Arc-Second (Approx. 10m). *The National Map*. Last accessed on February 12, 2018 at https://viewer.nationalmap.gov/basic/

US Geological Survey. 2017. National Elevation Dataset - NAVD88 Meters - 1-Arc-Second (Approx. 30m). *The National Map*. Last accessed on February 12, 2018 at https://viewer.nationalmap.gov/basic/