



3D-SEISMIC SURVEY SOURCE ASSESSMENT

Val Verde County, TX

Abstract

An exercise in cost-mitigation through GIS analysis of a hypothetical project area

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I. Problem and Specifications

An energy company is interested in surveying a location for potential oil and natural gas deposits and have provided me with an appropriate source-receiver grid spacing (3D seismic survey design) (**Table 1**). What they have tasked me to do is to determine the seismic source suitability for the type of terrain, which I will then factor into an overall cost estimate.

The area of interest falls between the Pecos and Devil's Rivers, within Val Verde County which is located along the southern border of Texas. The county represents the western-most edge of the Edwards Plateau. The terrain is flat with dark, calcareous soil and clay loam underlain by massive limestone that is heavily dissected by canyons and arroyos. Numerous creeks stay dry for most of the year. The vegetation consists of desert shrub savannah (**Smith, 2019**).

The viability of seismic sources in question depends on the type of terrain. Vibroseis trucks are not viable on sloped surfaces because of poor coupling and their natural tendency to 'shake' themselves down-hill. Neither can they be used on agricultural lands because they destroy soil profiles. Conventional shot hole seismic cannot be used in riparian zones, near residential structures, near infrastructure such as pipes or cables, and otherwise environmentally sensitive areas. Heliportable drill rigs (HPD) are deployed when terrain is exceptionally rugged and inaccessible, or heavily vegetated.

The cost of a 3D seismic survey is significantly affected by the types of sources the project uses. Vibroseis is the most cost-effective method but is limited to relatively flat, accessible surfaces. Shot hole seismic is more expensive than vibroseis in terms of time, materials, and labor. By far the most expensive method is HPD because, on top of all the personnel and materials costs mentioned above, one has to factor in helicopter operating costs – which are significant on their own.



Figure 1: Vibroseis Trucks, West Texas. Credit: dB, LLC Petroleum Advisors

Client Specifications

Client Oil Co. 3D Survey	Parameters
Survey Area (km ²)	134.2
Receiver Station interval (m)	25
Receiver Line interval (m)	300
Source Station interval (m)	50
Source Line interval (m)	400
Active Receiver Stations per record	10560
Total Receiver Stations	17861
Total Source Stations	6641
Source Type: Primary	Vibroseis
Source Type: Secondary	Heliportable Dynamite
Total Cost Budget (\$)	\$1,800,000

Table 1: Client Specifications

II. Data Pre-Processing

The client sends three files: a shapefile of the Area of Interest (AOI), and two .CSV tables – one listing the locations of every seismic source point in the grid, and the other listing the locations of every geophone (receiver).

In a blank *ArcMap* document, I added a topographic base map, which was provided by the application. As a matter of personal preference, I set the Data Frame coordinate system to NAD 1983 UTM Zone 14N. This is convenient because the point data is already in these coordinates. I loaded the AOI shapefile which represents a 134,741.54 meter² square in the lower southwest corner of Val Verde County, Texas. The township of Comstock inhabits the southeast quadrant of the AOI.

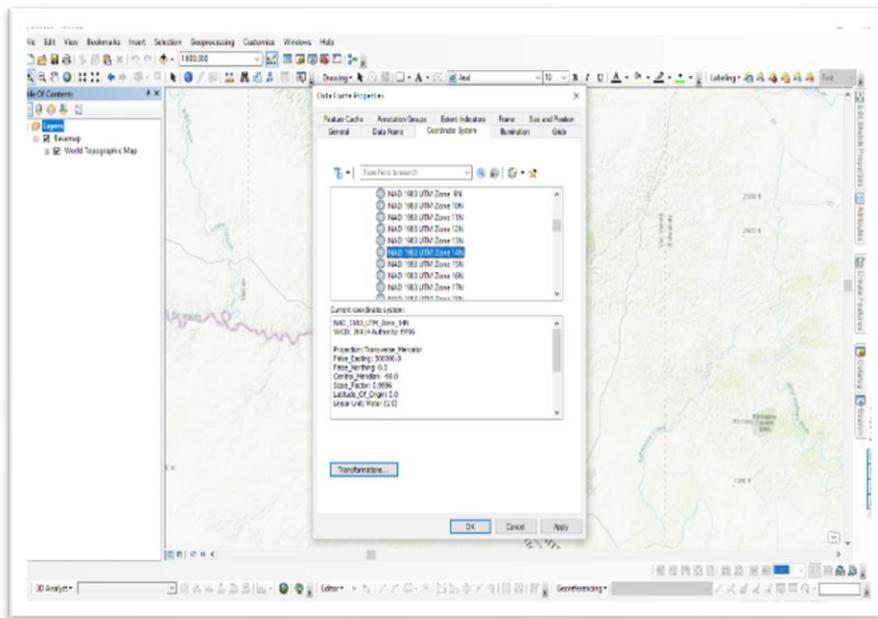


Figure 2: Setting Default Coordinates to NAD83 UTM 14N

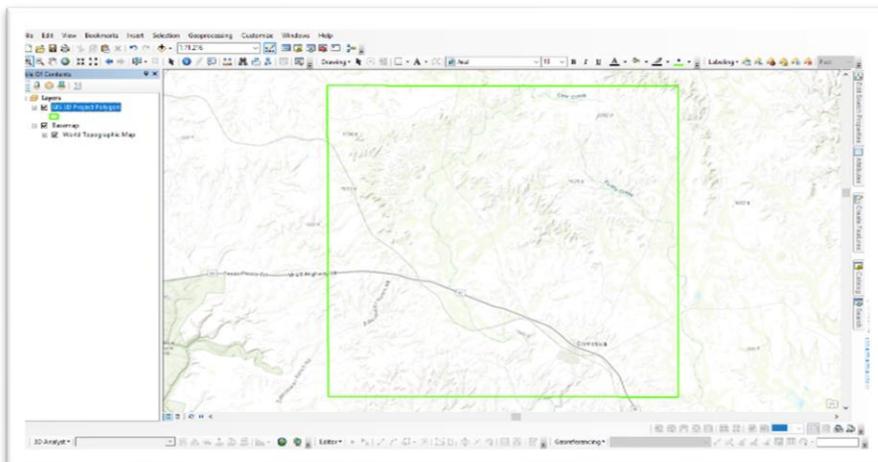


Figure 3: The AOI Loaded into the Map – AOI Width ~11.58km

In order to see the 3D Seismic Survey Grid, I first loaded the .CSV files into the map's table of contents, then right clicked each and selected *Display XY Data...*

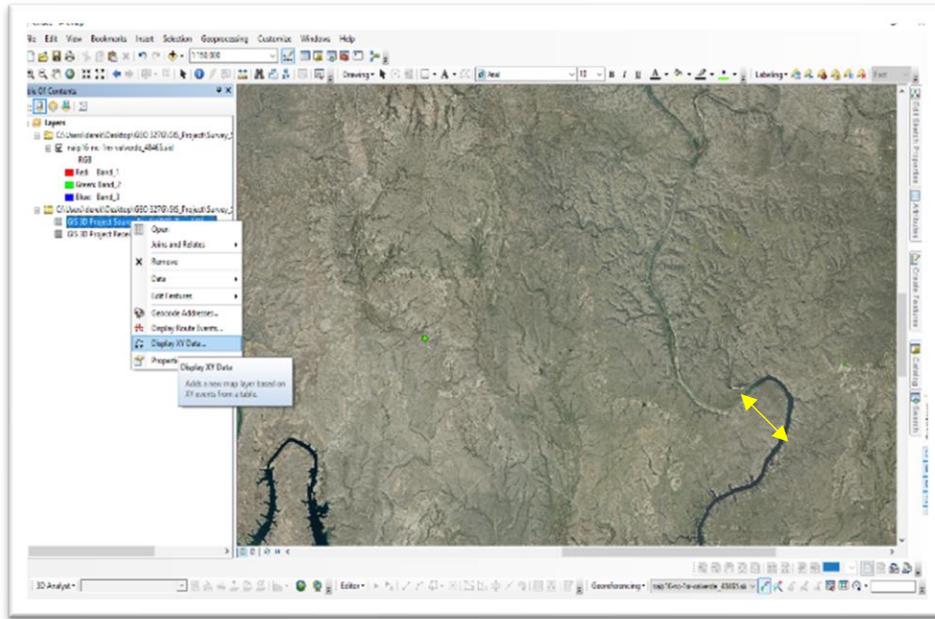


Figure 4: Loading in the .CSV tables – Yellow Bar ~2.65km

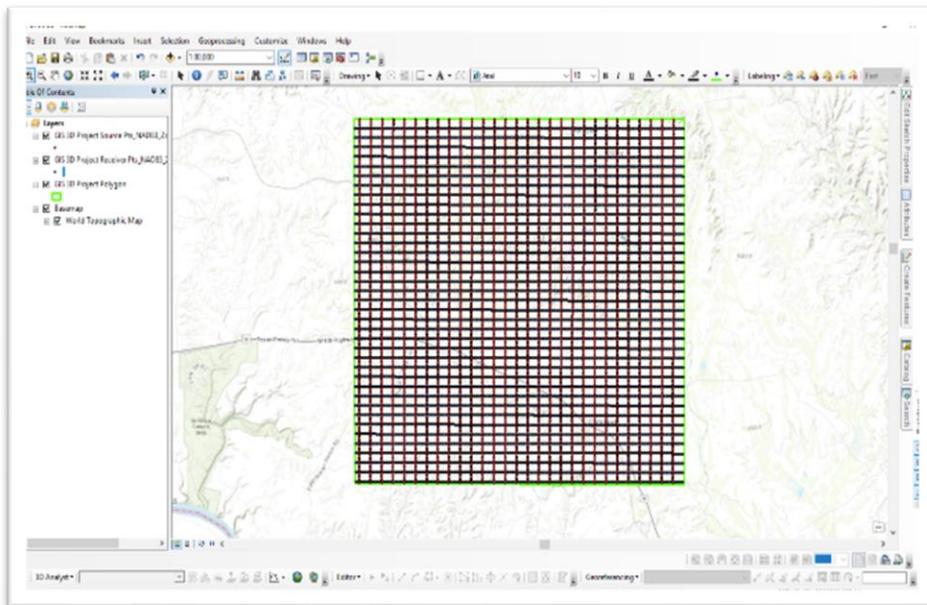


Figure 5: The 3D-Survey Grid- AOI Width ~11.58km

The survey grid lines were not needed at this time, so I switched them off. I obtained a digital elevation model, NED13-10m from the *Texas Natural Resources Information Systems (TNRIS)* data hub located at <https://data.tnris.org/>. I set the Symbology type to *Stretched* with standard deviation $n = 2.5$. Once established, I used the *3D Analyst > Raster Surface > Hillshade* tool to create a shaded relief map from the NED13-10m DEM.

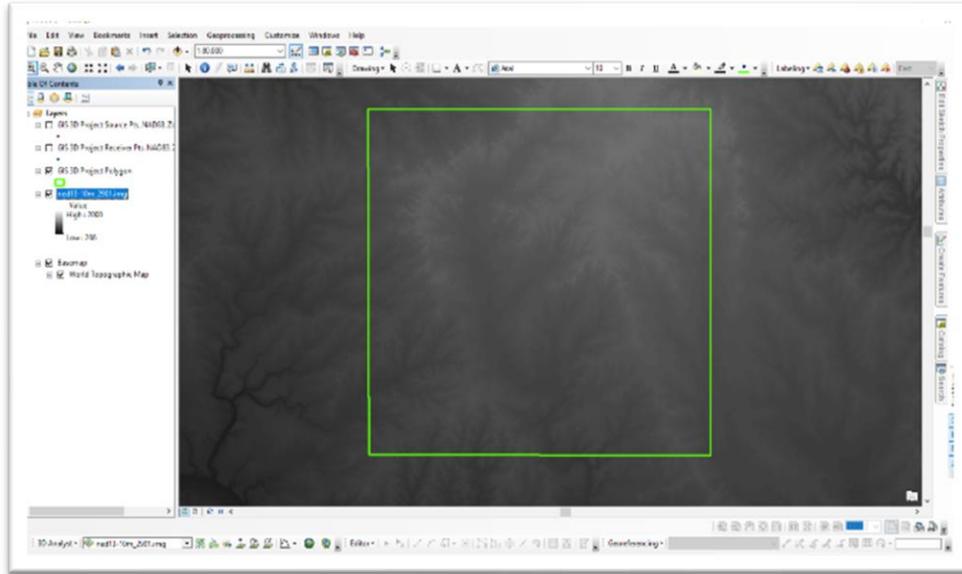


Figure 6: National Elevation Datum 13 - 10-meter resolution – AOI Width ~11.58km

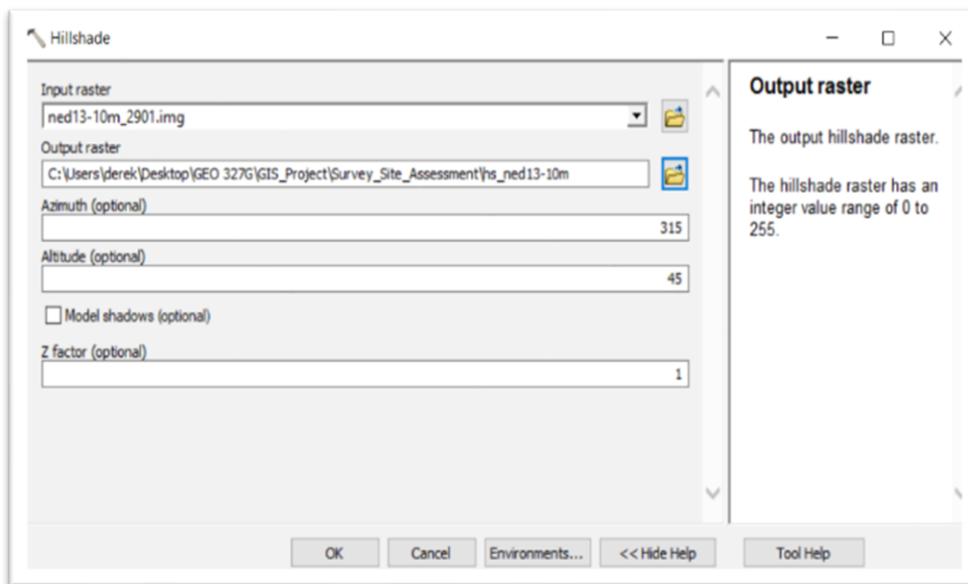


Figure 7: The Hillshade Tool

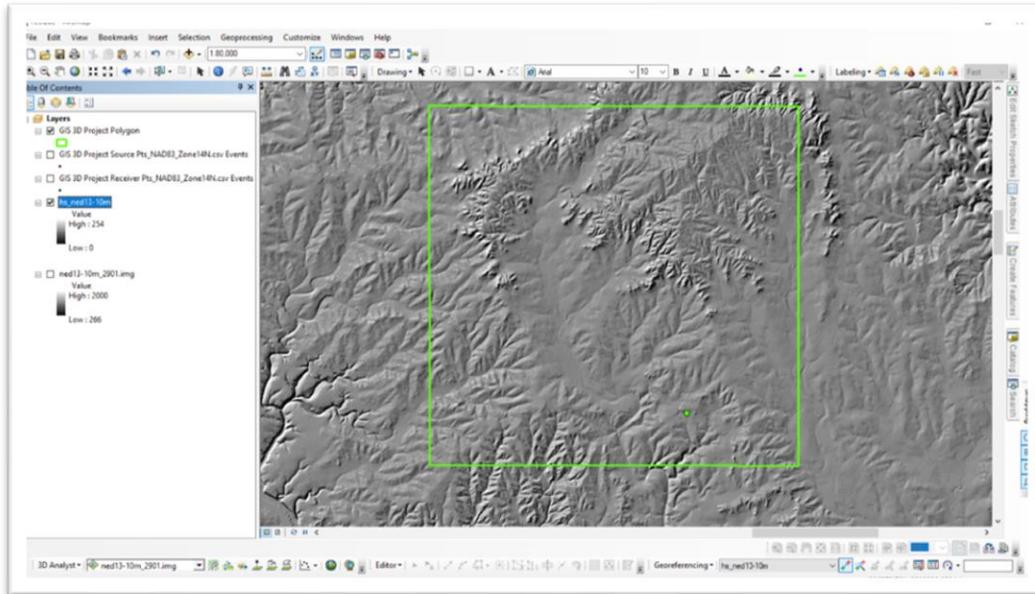


Figure 8: Shaded Relief Map aka Hillshade – AOI Width ~11.58km

With the same DEM and with the *Slope* tool in the 3D Analyst toolbox, I made a slope map (fig. 9).

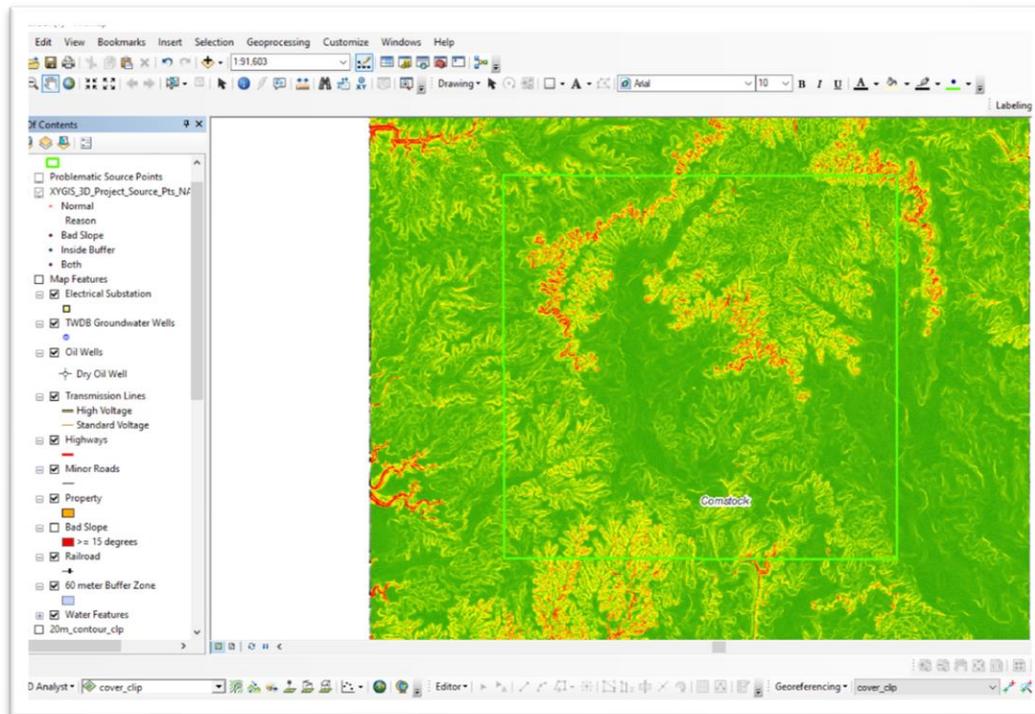


Figure 9: Initial Slope Map – AOI Width ~11.58km

However, as my Client states that only slopes of 15 degrees or above are problematic, I symbolized the raster as type *Classified* with only two Classes (fig. 11).

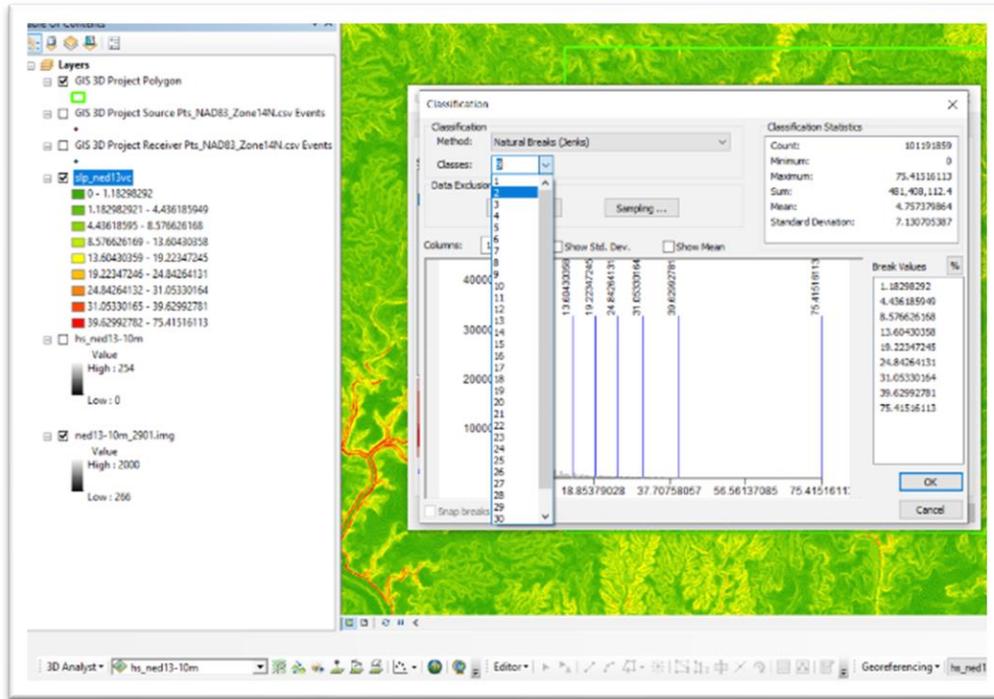


Figure 10: Re-Symbolizing the Slope Map – AOI Width ~11.58km

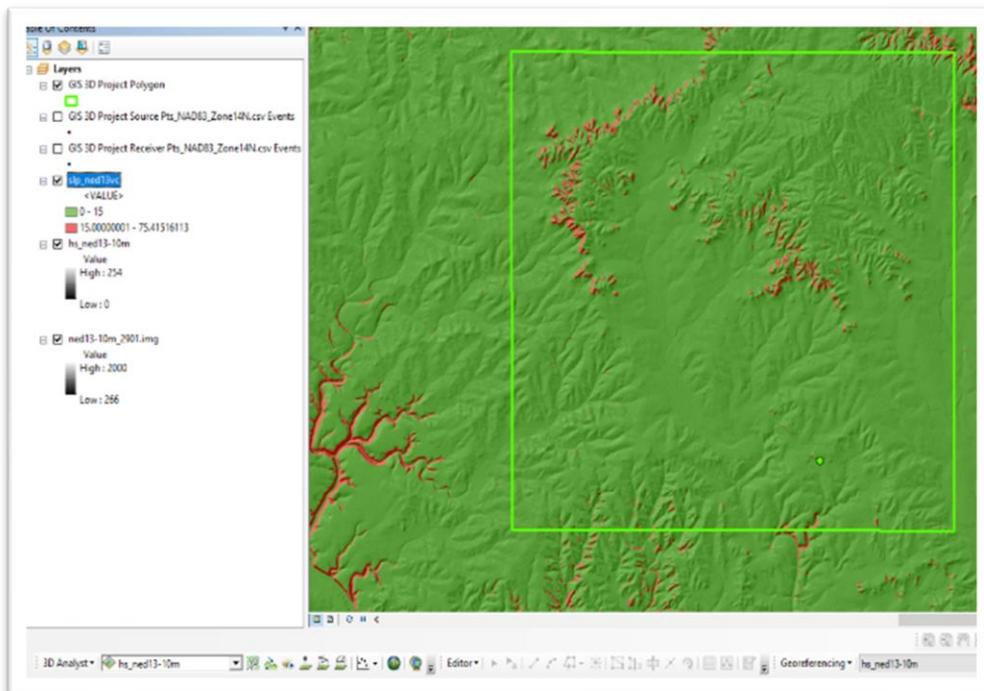


Figure 11: The Slope Map w/ two Classes of Degree – AOI Width ~11.58km

Next, I needed to pare down the size of the map, so I created an arbitrary 4km buffer around the AOI and clipped data layers to it. I set this buffer as a mask in *Environment Settings* to apply to subsequent layers automatically.

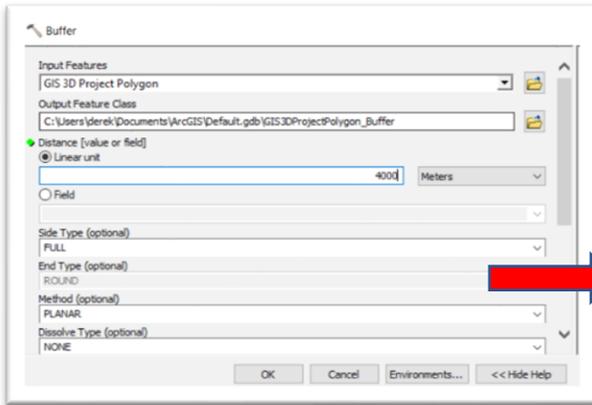


Figure 12: Decreasing the Map Area

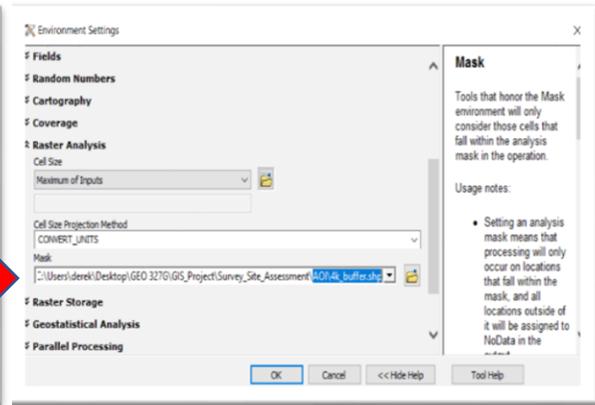


Figure 13: Setting Up Default Mask

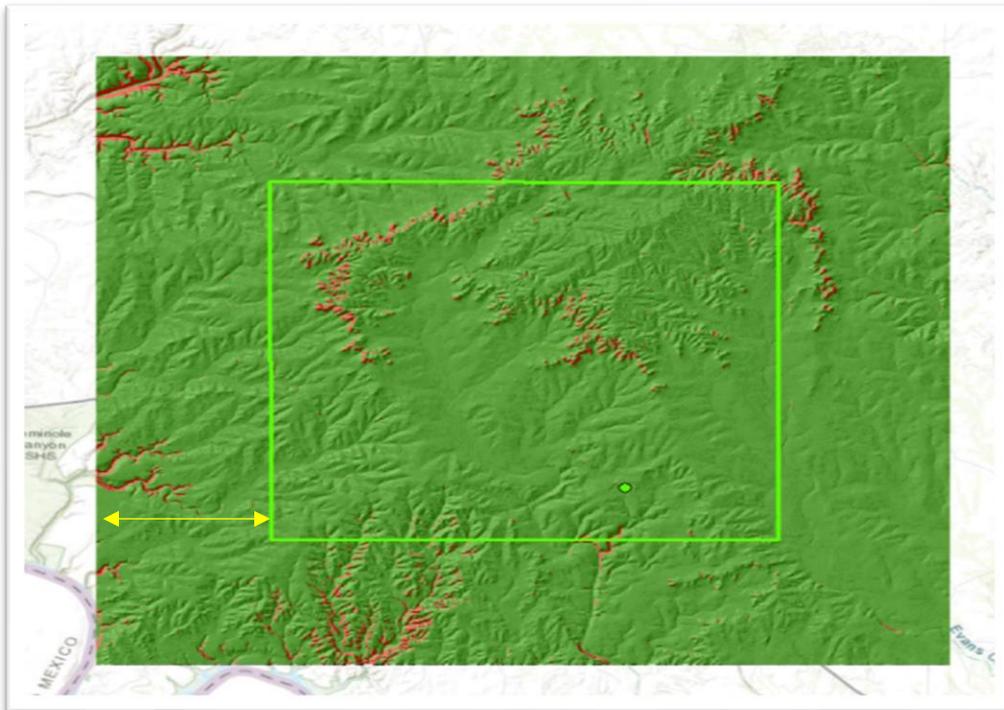


Figure 14: Masked Slope Map Showing Smaller Map Area – Yellow Bar = 4km

The next step involved sourcing and loading existing data sets:

Major road features-<https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html>

Railroad features - <https://www.rrc.texas.gov/about-us/resource-center/research/data-sets-available-for-download/>

Water Features - <https://www2.census.gov/geo/tiger/TIGER2019/LINEARWATER/>

All Line Features from US Census Data - <https://www2.census.gov/geo/tiger/TIGER2019/COUNTY/>

USGS Geology database - <https://data.tnris.org/collection/79a18636-3419-4e22-92a3-d40c92eced14>

Electrical Substations - <https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines>

Groundwater wells - <http://www.twdb.texas.gov/mapping/gisdata.asp>

Oil Wells - <https://www.rrc.texas.gov/about-us/resource-center/research/data-sets-available-for-download/>

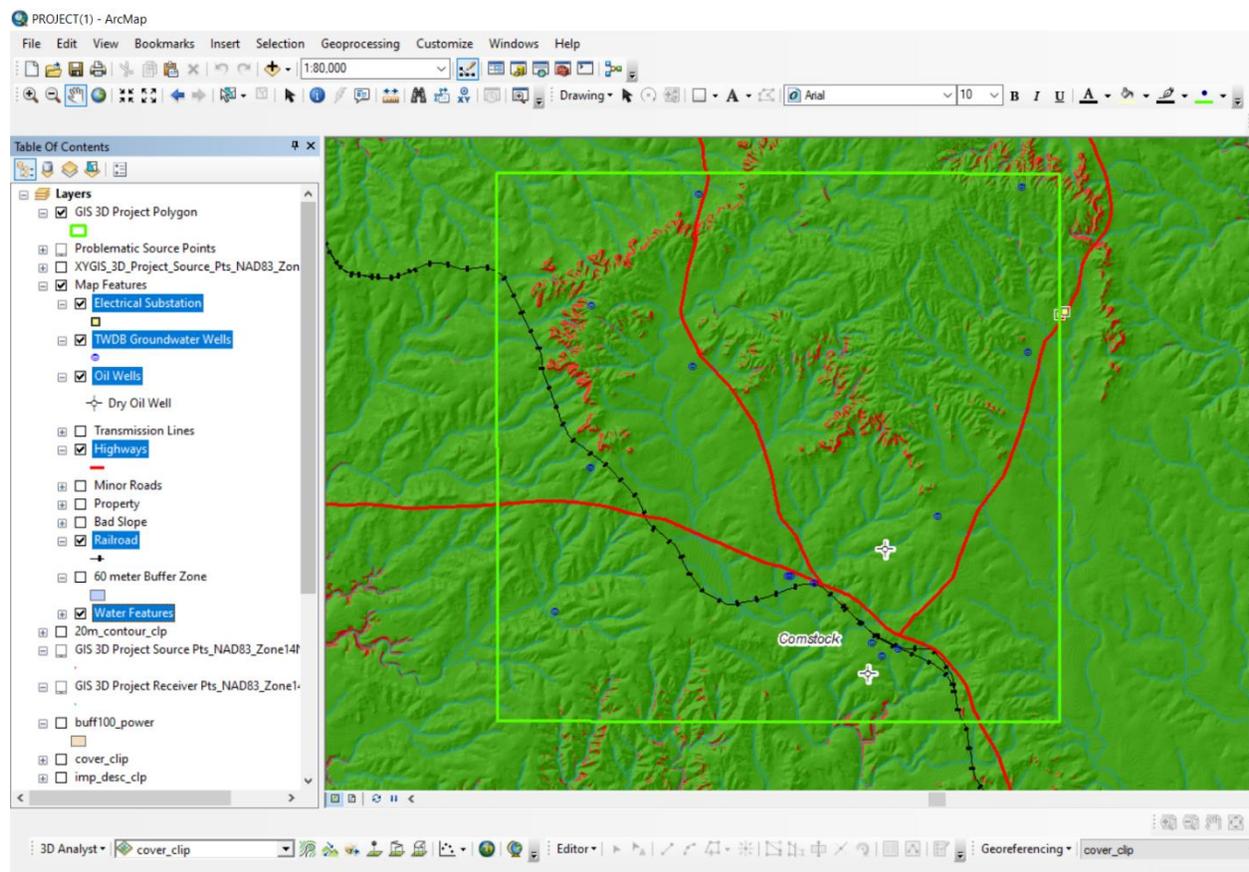


Figure 15: Sourced Feature Classes Added to the Map – AOI Linear Distance ~11.58km

III. Data Creation

The TIGER line shapefile for Val Verde County contains literally any and every linear feature. I already have major roads, rails, and rivers on my map. I just needed the minor roads. With the *Census_lines_Cip* attribute table open and the selection tool, I selected all minor road line features and saved them as a new layer (fig. 16,17). Then I removed the census line data from the map.

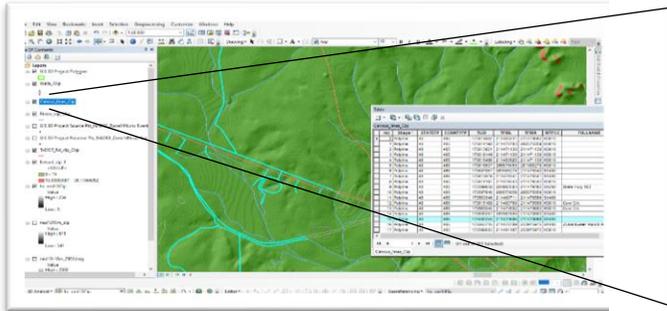


Figure 16: Selecting Minor Road Features

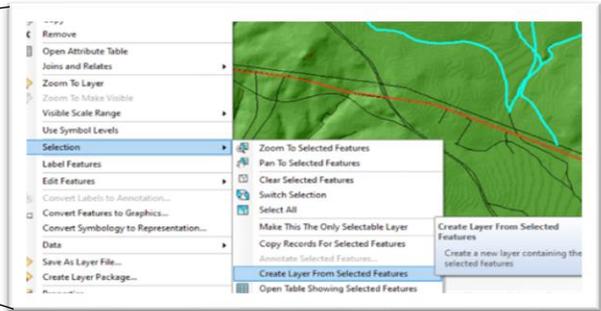


Figure 17: Making a Separate Layer from the Selection

I was unable to find any data for power lines or structure polygons. So, I created them in *Google Earth Pro*. Drawing polygons over property footprints was relatively easy but dropping points (that will eventually become power lines) took considerable time. Again, using *Google Earth* imagery, I manually dropped points on utility poles that I could discern from their distinctive shadow. I began the process at the substation in the northwest part of the AOI and traced utility poles all the way into town, moving radially outward towards structures outside the city limits. When available, I used *Street View* to assist point placement (fig. 18-21)

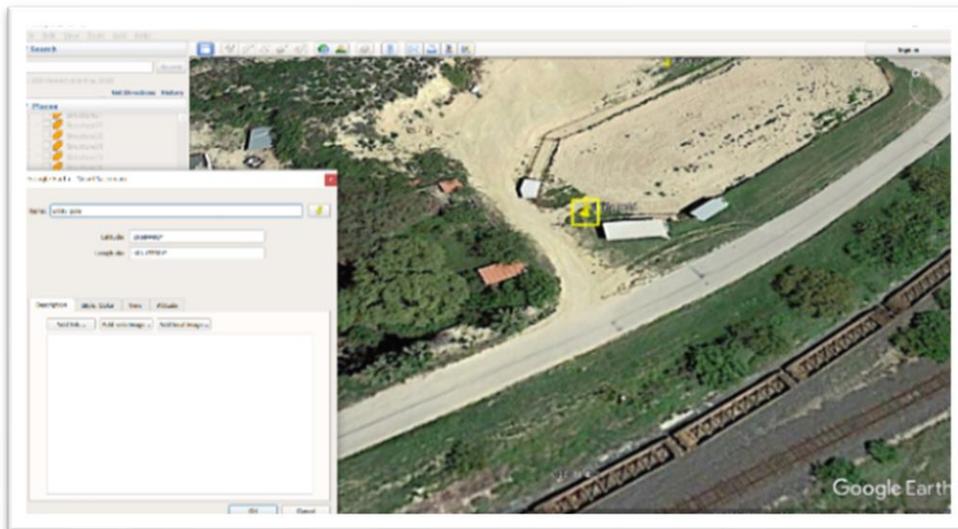


Figure 18: Manually Locating Point Features - Utility Poles

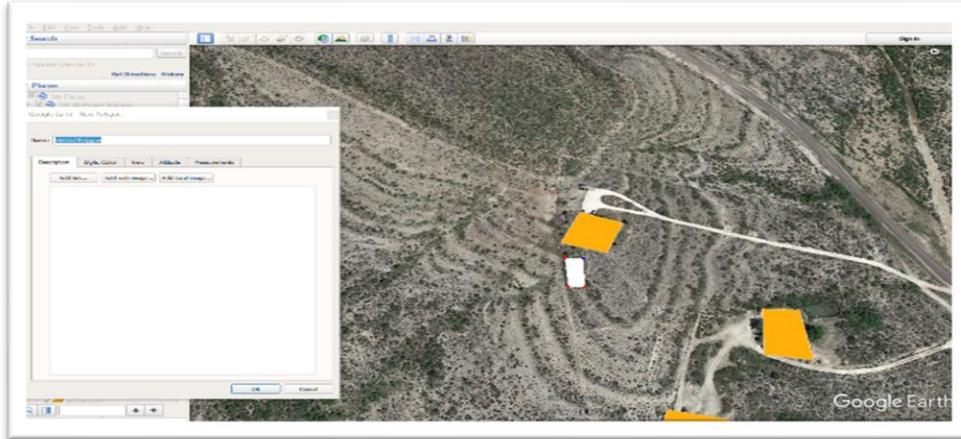


Figure 21: Drawing Polygons over Property Footprints

In all there are 462 standard voltage nodes and 23 High-Voltage nodes (but I already have the high-voltage data contained in *Electrical Substations* layer). I saved these points to the same workspace as the structure polygons before I exported the data in KML format. In *ArcMap*, I used the *KML to Layer* tool to import the data (fig. 22).

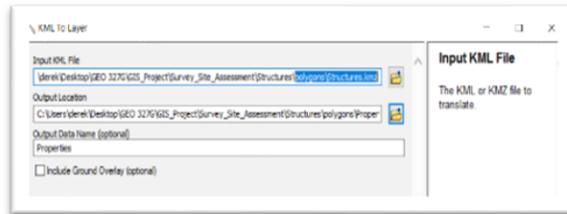


Figure 22: Importing KML Files into ArcMap

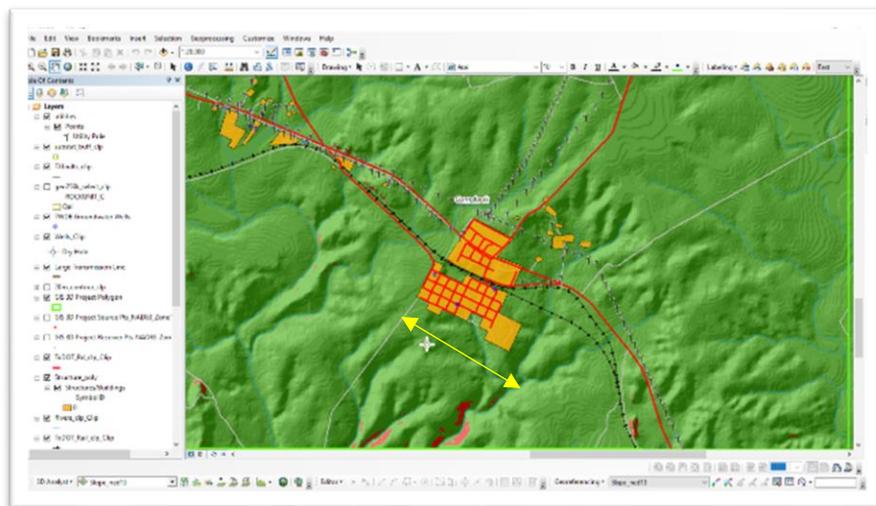


Figure 23: Google Earth Data Displayed on the Project Map – Length of Yellow Bar ~1.2km

I was satisfied with the results. Then I created and digitized the powerlines by connecting each node through use of the *Editor* tool bar. I did not want to have two separate files for electric utilities, so I performed the edits on the existing *Electrical Substation* data.

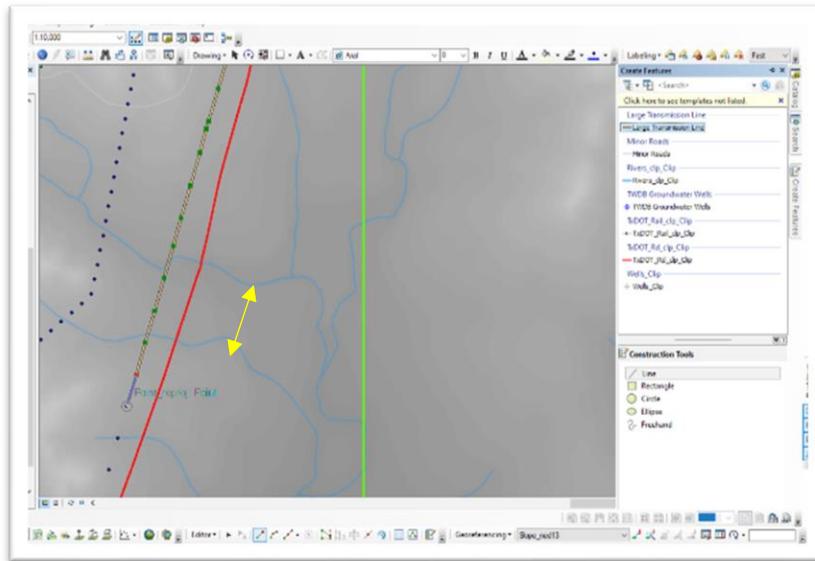


Figure 24: Digitizing Powerlines – Yellow Bar ~400m

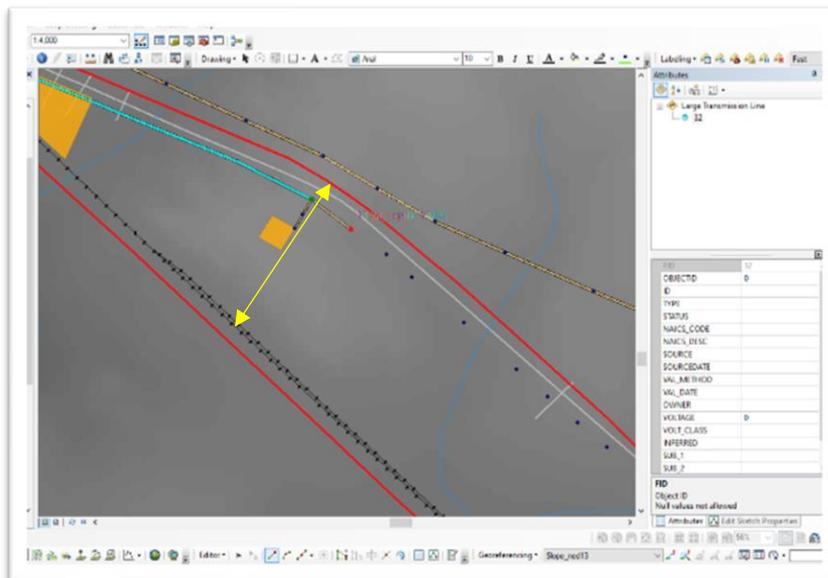


Figure 25: Continued – Yellow Bar ~268m

As stated at the outset, my goal was to determine which seismic source is to be used for every given source point, keeping in mind that vibroseis is the most cost-effective option and HPD the most cost prohibitive. Before a survey occurs, distance calculations from source points to man-made structural features are made¹. The industry refers to this as the Safe Distance (SD). The safe distance required of vibroseis surveying is a uniform 60-meters (by conservative estimate). That includes everything: roads, buildings, transmission lines, pipes, wells, etc. The safe distance for conventional explosives (5-lb TNT in this case) varies depending on the type of structure. Proximity to transmission lines and unpaved roads requires a 60-meter safe distance; Railroads require 100 meters, pipelines require 180 meters, and buildings/water wells require up to 240 meters. Again, these figures are very conservative!

After preliminary assessment of the map in this early stage, I determined that the use of TNT anywhere other than in inaccessible areas is unnecessary. Nonetheless, I made SD polygons of all types for comparison, as seen in **figure 28**.

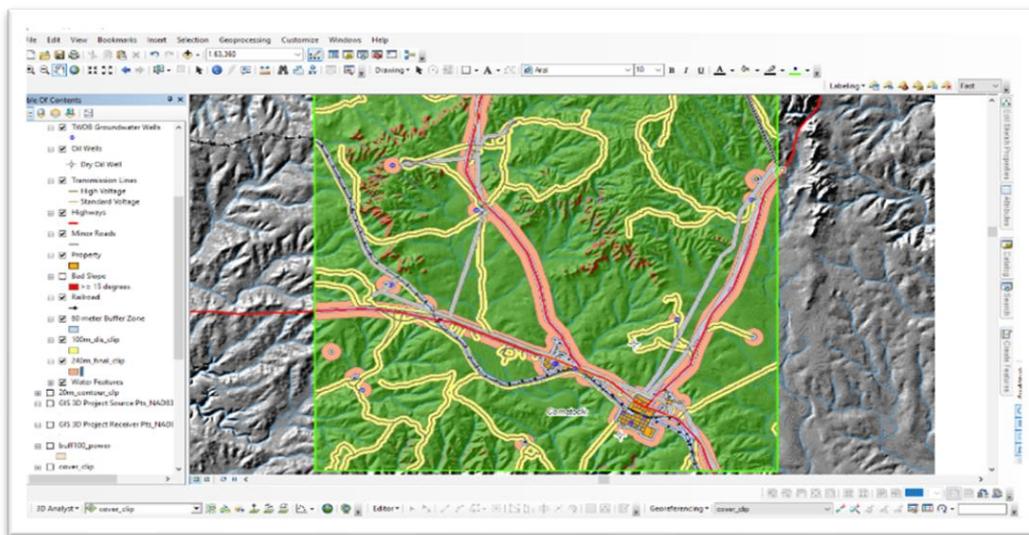


Figure 28: Safe Distance (SD) Buffer Zones – AOI width ~11.58km

These SD polygons were created from existing line and polygon features using the *Buffer* tool. I applied it to each man-made structure, setting a specified distance (in meters) appropriate for the structure type, and then *Merged* and *Dissolved* all buffers of the same distance to create single, uniform shapes with no internal boundaries (**figs. 29-31**).

¹ Other natural environmental features such as protected habitats, farmlands, and riparian zones are normally included, but these features are not present in my AOI, so they do not factor into my calculations.

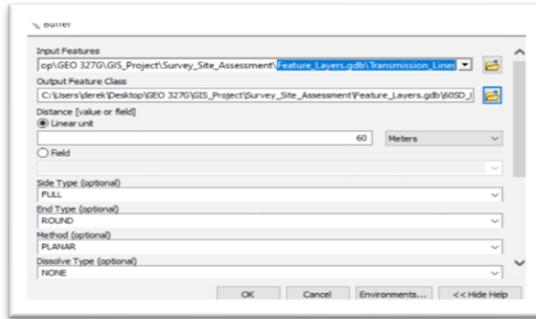


Figure 29: Creating a Buffer Around Transmission Lines

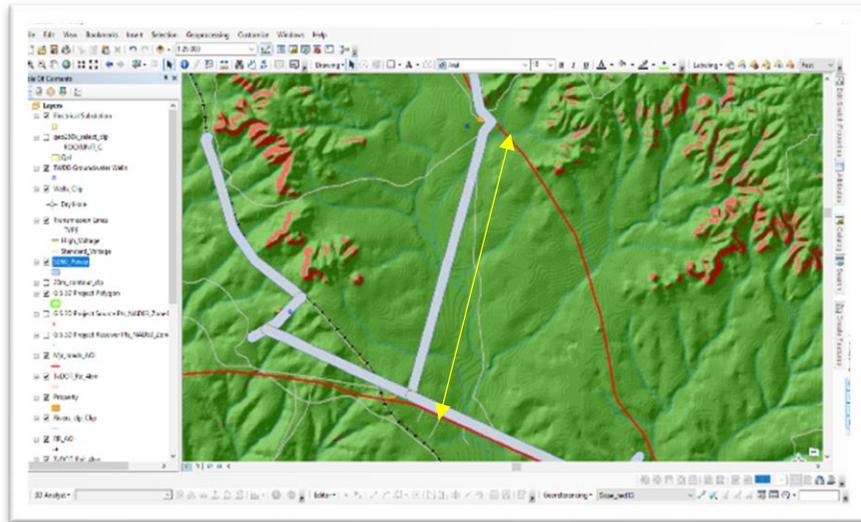


Figure 30: The Complete 60-meter Buffer Around Power Lines – Yellow Bar ~3.3km

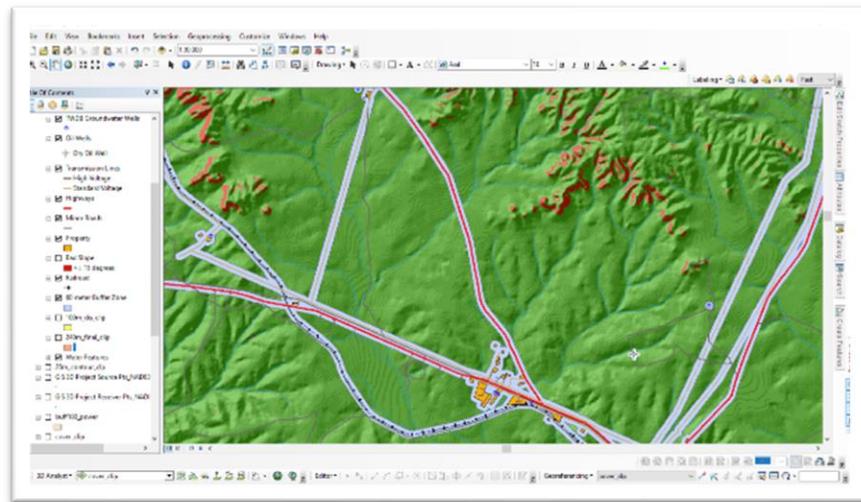


Figure 31: The Complete 60-meter Buffer Around All Required Features

After both Slope classes and SDs are established, I needed to quantify the number of source points that reside on 'Bad Slopes', that are within safe distance buffers, or in both. Prior to this step, I need to query both 'Bad Slope' areas and source point locations. There is an obstacle preventing me from carrying out this critical step however, because neither data are selectable. The slope raster has no value attribute table because it represents continuous rather than discrete or thematic data, thus I cannot query individual cells' locations. To remedy this, I used the *Raster > Reclassify* tool:

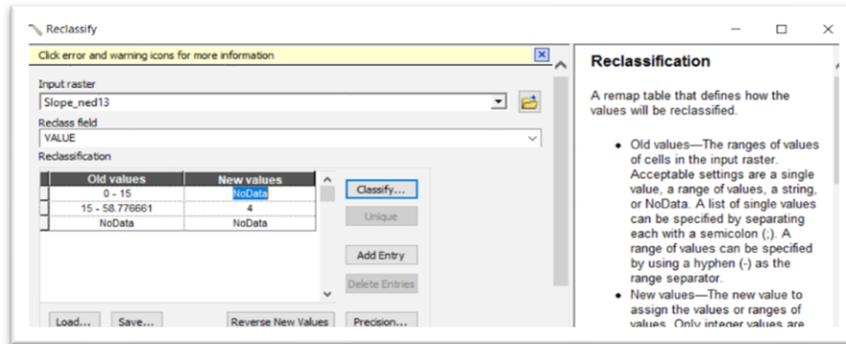


Figure 32: Reclassifying the Slope Raster

I arbitrarily reclassified slope values above 15 degrees to an *ordinal* value of 4. Values less than 15 degrees, I classified as *NoData* (toggled to *Not Show*), because I have already established that vibroseis will be used in any green part of the map. Therefore, I only concerned myself with the steep-sloped areas. I can select and display them separately after the process.

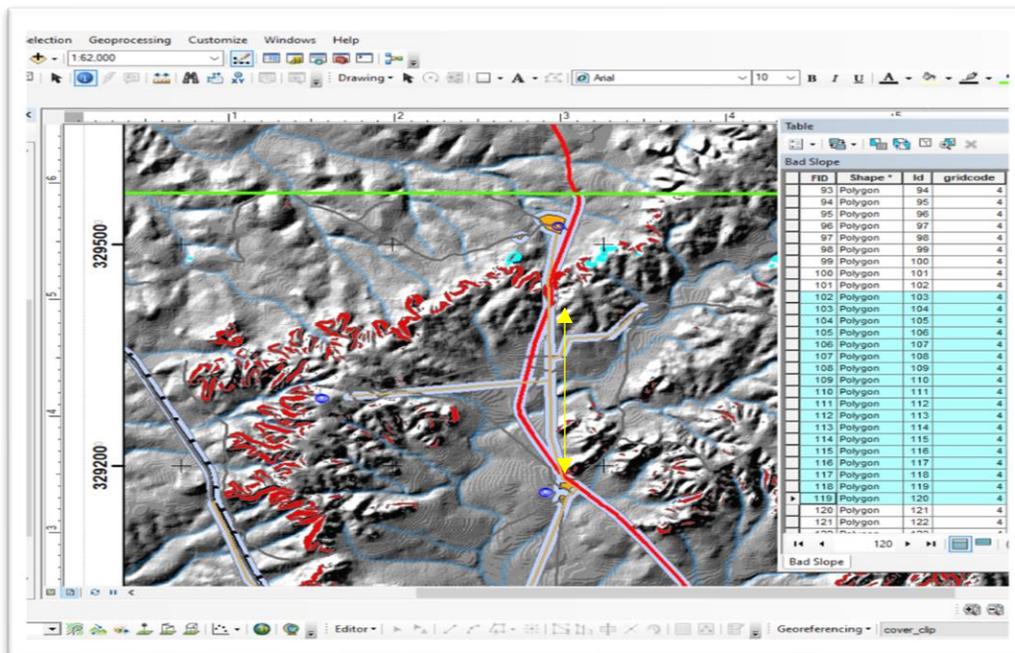


Figure 33: Selectable Problem Areas – Yellow Bar ~2.3km

To address the selection problem with the Source Point data, I made a feature class from the XY table, as seen in **figures 34,35** in *ArcCatalog* and *ArcMap* respectively.

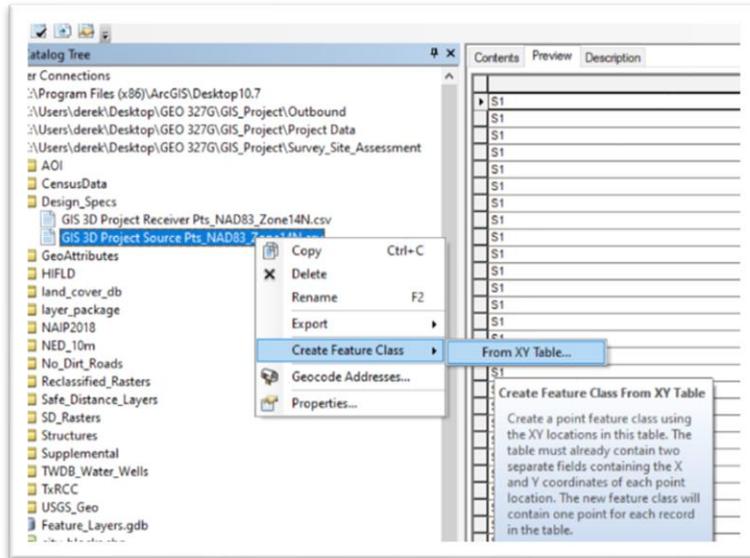


Figure 34: Creating a Feature Class from a Table

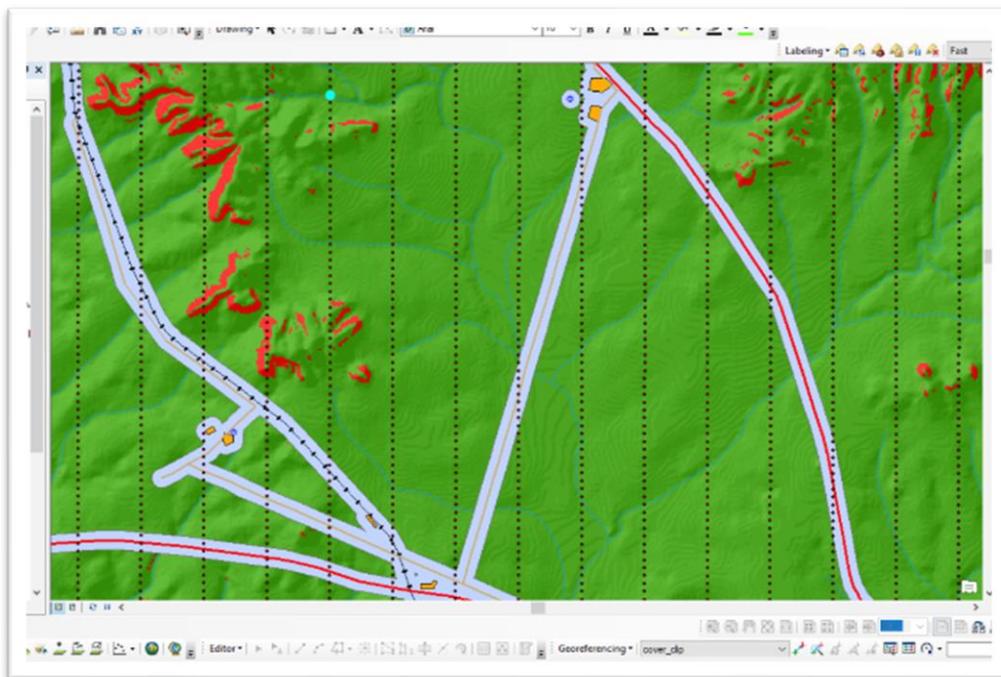


Figure 35: Source Points are Now Selectable – Point Spacing = 50m

I added three new fields to the attribute table – all are text-based fields set to a maximum string length of 25. The first field denotes whether a source point falls inside a buffer with a simple ‘Y’ or ‘N’. The same schema applies to the second field, which denotes if a source point falls on a bad slope polygon. I added a third field named *Reason* in which a point attribute can have one of four classifications: ‘Inside Buffer’, ‘Bad Slope’, ‘Both’, or ‘No Problem’.

FID	Shape *	source typ	PT	X NAD83	Y NAD83	Inside Buf	Bad Slope	Reason
1	Point	S1	10002	292736.3	3295601	N	Y	Bad Slope
575	Point	S3	30118	291926.6	3269602	N	Y	Bad Slope
916	Point	S5	50003	291156.2	3295553.1	N	Y	Bad Slope
1716	Point	S8	80114	289928.9	3290004.7	N	Y	Bad Slope
1721	Point	S8	80119	289928.6	3289754.7	N	Y	Bad Slope
1941	Point	S9	90110	289529.2	3290005.2	N	Y	Bad Slope
1945	Point	S9	90114	289528.9	3290005.2	N	Y	Bad Slope
1946	Point	S9	90115	289528.8	3289955.2	N	Y	Bad Slope
2052	Point	S9	90221	289521.8	3284655.2	N	Y	Bad Slope
2164	Point	S10	10010	289129.6	3290505.7	N	Y	Bad Slope
2165	Point	S10	10010	289129.5	3290455.7	N	Y	Bad Slope
2166	Point	S10	10010	289129.4	3290405.7	N	Y	Bad Slope
2356	Point	S11	11006	288732	3292356.2	N	Y	Bad Slope
2366	Point	S11	11007	288731.2	3291756.2	N	Y	Bad Slope
2371	Point	S11	11008	288731	3291606.2	N	Y	Bad Slope
2379	Point	S11	11009	288730.5	3291206.2	N	Y	Bad Slope
2382	Point	S11	11009	288730.3	3291056.2	N	Y	Bad Slope
2386	Point	S11	11009	288729.9	3290756.2	N	Y	Bad Slope
2394	Point	S11	11010	288729.5	3290456.2	N	Y	Bad Slope
2398	Point	S11	11010	288729.2	3290256.2	N	Y	Bad Slope
2516	Point	S11	11022	288721.4	3284356.3	N	Y	Bad Slope
2517	Point	S11	11022	288721.4	3284306.3	N	Y	Bad Slope
2569	Point	S12	12007	288331.7	3292156.8	N	Y	Bad Slope
2593	Point	S12	12007	288331.5	3291956.8	N	Y	Bad Slope
2595	Point	S12	12007	288331.3	3291856.8	N	Y	Bad Slope
2596	Point	S12	12008	288331.1	3291706.8	N	Y	Bad Slope
2622	Point	S12	12010	288329.6	3290506.8	N	Y	Bad Slope
2632	Point	S12	12011	288328.9	3290006.8	N	Y	Bad Slope
2634	Point	S12	12011	288328.8	3289906.8	N	Y	Bad Slope

Figure 36: Adding Fields to the Attribute Table

In order to fill the first two of the new fields, I used the *Select By Attribute* calculator to separately select points. Then, once inside an editing session, I used the *Field Calculator* to assign either a ‘Y’ or a ‘N’ to entire groups simultaneously. For the *Reason* field, I categorized ‘Bad Slope’ for all points with a ‘Y’ in the *Bad_Slope* field, and ‘Inside Buffer’ for points having ‘Y’ in the *Inside_Buf* field. Points with a ‘Y’ designation in both fields received ‘Both’ classification (fig. 37, pg. 20), and points with ‘N’ designation in both fields received ‘No Problem’ classification (fig. 38, pg.20).

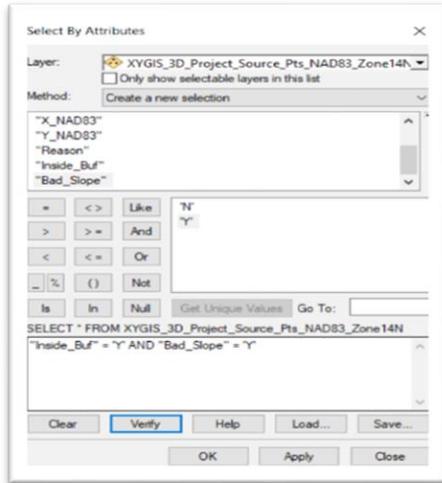


Figure 37: Selecting Attributes for the Field Calculator

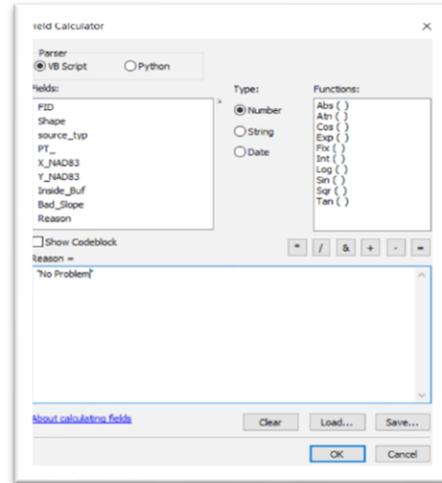


Figure 38: Using the Field Calculator to Categorize New Fields

Once the attribute table was completed and the edits saved, I symbolized the source points by *Reason* as seen below (fig. 39, 40).

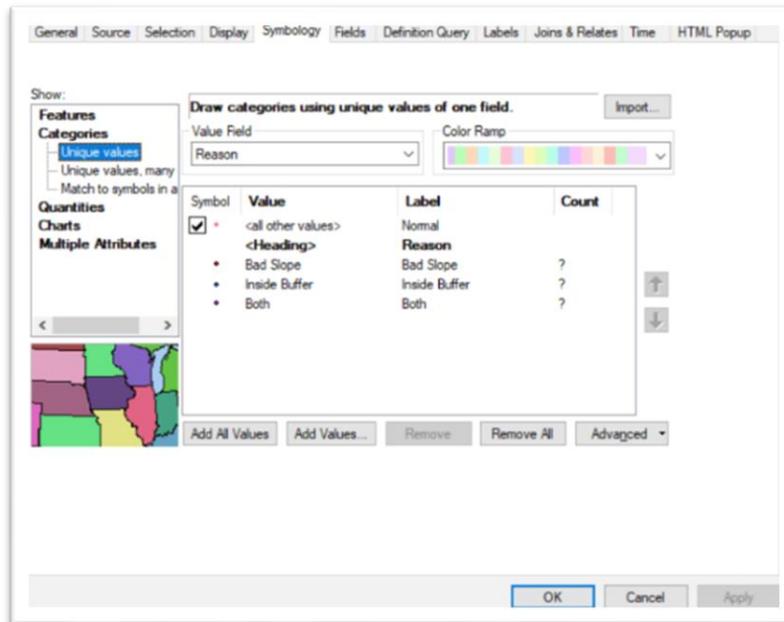


Figure 39: Symbolizing Source Points by 'Reason'

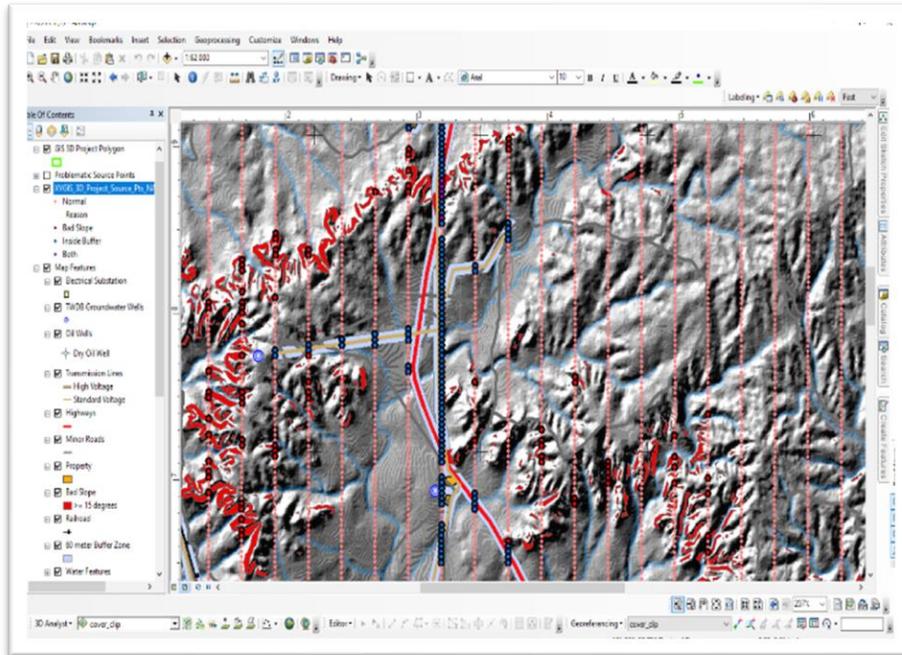


Figure 40: Prominent Problematic Source Points – Source Point Spacing = 50m

Now all problematic points are *easily* distinguishable (fig. 42, pg. 18).

IV. Source Point Distribution and Cost Estimate

A quick glance at the symbology table reveals:

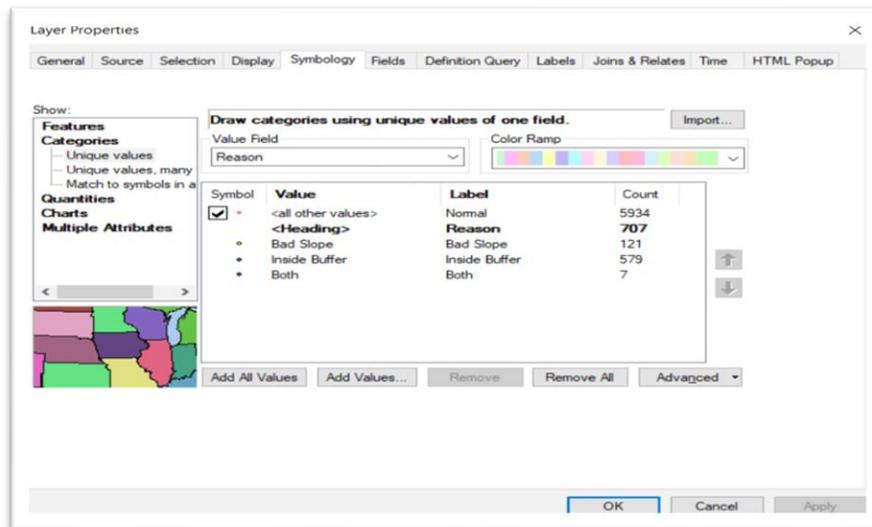


Figure 41: Source Point Layer Symbology

This means that approximately 12% of all source points are problematic and require relocation. It is more viable to simply eliminate the seven points that fall into the 'Both' category without suffering any noticeable decline in data quality.

Source Point Distribution*

Client Oil Co. 3D Survey	Parameters
Total Source Points	6,641
'Normal' Source Points	5,934
Net Problem Source Points	700
Points on 'Bad Slope'	121
Points 'Inside Buffer'	579

Table 2: Distribution

*The seven 'Both' point-types have been eliminated for simplicity (*above*, Net Problem Source Points).

Total Cost Estimate Before HPD Source Points Relocated

Total Vibroseis Points	6,513
Point cost for Vibroseis	\$270
Total Cost of Vibroseis	\$1,758,510
Total HPD Points	121
HPD Cost/Point	\$1,600
Total Cost of HPD	\$193,600
Cost with Unresolved Points	\$1,952,110
Amount Over Budget	+ \$152,110

Table 3: Cost Estimate with HPD

Total Cost Budget After all Source Points Relocated

Net Vibroseis Points	6,634
Point cost for Vibroseis	\$270
Total Cost of Vibroseis	\$1,791,180
Amount Under Budget	-\$8,820

Table 4: Estimated Cost Budget with All Points as Vibroseis

Relocating and reclassifying HPD sources will save **\$160,930** – See figure 43, pg. 19

V. Discussion

The use of GIS techniques to map, relocate, and reclassify cost-prohibitive seismic source points results in an estimated net savings to the company of \$160,930. While these methods are cost-saving measures, they also improve job safety because all source points are moved off steep slopes and the use of TNT – and therefore helicopters – is eliminated entirely. Other landscape qualities that can affect the deployment of 3D seismic survey grids are both the type and density of vegetative cover, water features, and property fencing – none of which factored into this exercise. The vegetation within the area of interest is primarily patchy, dry desert scrub that could potentially serve as a barrier to access among the steeper, narrower cuts and arroyos. However, there are numerous routes around them on adjacent, broader slopes. Creeks and other miscellaneous surface water features run dry for most of the year and might only be a factor during rainy seasons. Fencing does not yet factor in at this stage but will later when the surveyors begin to access landowners' property.

The accuracy of the slope calculations is limited by the 10-meter resolution NED13 raster upon which it is based. Accessibility and relocation calculations could be created with greater precision if LIDAR data had existed for the AOI at the time this exercise was conducted. Of course, nothing in an initial assessment is set in stone. This information is meant to serve as a guide for the ground crew. Ultimately, it falls to the engineers in the field to take their own measurements to verify or correct the data as needed.

3D Seismic Source Array Showing Conflicting Points, Val Verde Co., TX

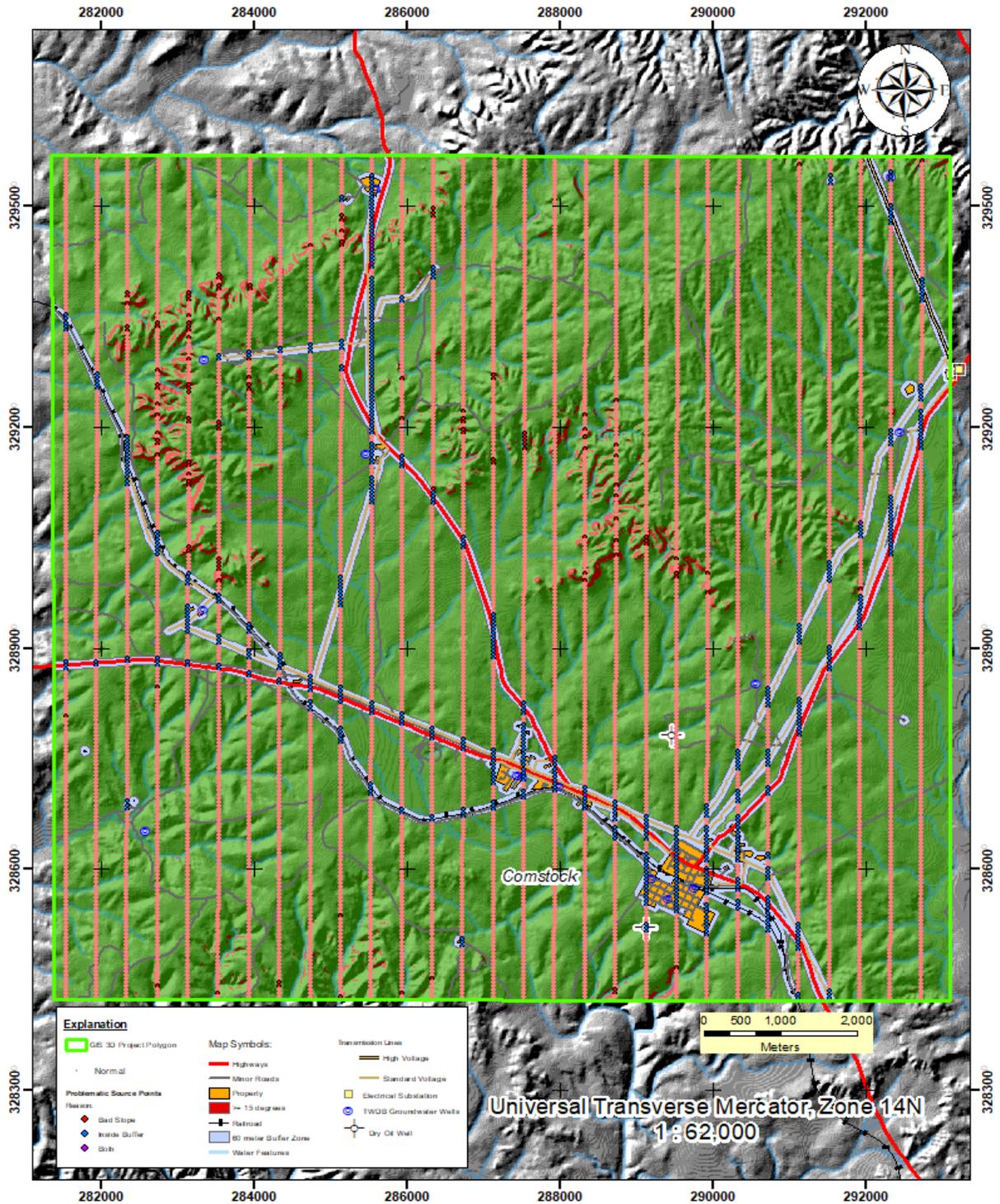


Figure 42: 3D Seismic Survey Grid w/ Problematic Source Points – Derek Behrman, 2019

NOTE - The UTM Zone 14N latitude labels in the map grid (above) are incorrectly displaying the first leading zeros of the coordinate values – they appear significantly smaller and less-shaded.

AOI Source Grid After Point Relocation

The red indicates $\geq 15^\circ$ slope, black indicates individual source points

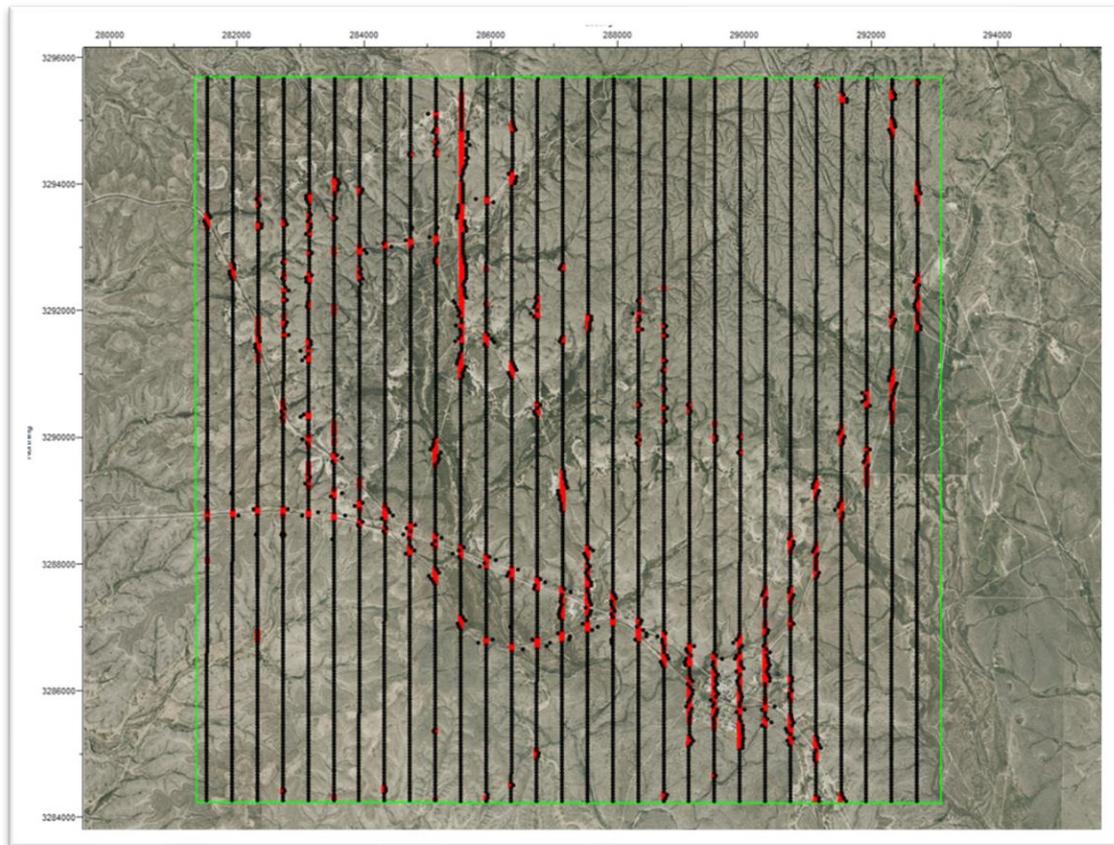


Figure 43: Source Grid feat. Relocated Points. Credit: David Behrman, 2019

The preceding (Figure 43) was created in *Mesa* - Green Mountain Software, Inc
By David Behrman

Works Cited

Smith, J. C. (2019, December 08). *Val Verde County*. Retrieved December 08, 2019, from tshaonline.org: <https://tshaonline.org/handbook/online/articles/hcv01>

Data Sources

Major road features - <https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html>

Railroad features - <https://www.rrc.texas.gov/about-us/resource-center/research/data-sets-available-for-download/>

Water Features - <https://www2.census.gov/geo/tiger/TIGER2019/LINEARWATER/>

All Line Features from US Census Data - <https://www2.census.gov/geo/tiger/TIGER2019/COUNTY/>

USGS Geology database - <https://data.tnris.org/collection/79a18636-3419-4e22-92a3-d40c92eced14>

Electrical Substations - <https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines>

Groundwater wells - <http://www.twdb.texas.gov/mapping/gisdata.asp>

Oil Wells - <https://www.rrc.texas.gov/about-us/resource-center/research/data-sets-available-for-download/>

NED13-10m DEM - <https://data.tnris.org/>

Client Files created by David Behrman, Amigos Energy Advisors LLC.

GIS 3D Project Polygon.SHP

GIS 3D Project Source Pts_NAD83_Zone14N.csv

GIS 3D Project Receiver Pts_NAD83_Zone14N.csv

Table 5: *Client Specifications*, Credit: David Behrman, 2019

Images

Figure 1: *Vibroseis Trucks, West Texas*, Credit: dB, LLC Petroleum Advisors. *Wikipedia.org*

Figure 43: *Source Grid feat. Relocated Points*, Credit: David Behrman, 2019