Case Study on Determining Proper Imagery Collection for Digital Elevation Model Creation for the Purpose of Eco-Tourism Development of Condor Valley, Argentina

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Abstract

The value of studying the topography of an area from the comforts of an office is poignant. The digital elevation model (DEM) can provide the data needed for the analysis of a variety of applications, from ground water flow patterns to flight simulation. Bypassing the "boots on the ground" approach of old, DEMs allow the user to conduct initial research before committing resources to costly man-hours. A DEM can be derived from multiple sources each with advantages and disadvantages. This paper will look at the approach of selecting the most appropriate source data for the creation of a DEM for meeting the needs of Condor Valley LLC. Condor Valley LLC is a land developer based in the San Francisco area and it needed a solution for conducting preliminary studies on a 37 km^2 area about 60 km south of Salta, Argentina. The basis of developing this remote area lies in turning Condor Valley into a successful and sustainable eco-tourism destination.

Introduction

We all know water flows downhill and that water is essential to life. With the use of pumps and electricity, one can easily pump water uphill to hilltop reservoirs or water towers. Once at this unnatural elevated position, gravity, for the most part, does the rest. Without technology, one must use careful planning and surveying methods to determine the slope for water to flow to its intended destination. In years past, this was a painstaking process that took days, if not years to determine. The civilizations of the more arid regions of the world that practiced fundamental irrigation techniques had more time to develop gravity powered water transport projects. In the case of Condor Valley, one of the customer's first steps toward development is the establishment of a constant water source that could supply an irrigation network year-round.

Today, in a fast-paced society filled with due dates and crowded schedules, technological tools can aid in meeting deadlines. One of these technological tools is creation of a digital elevation model (DEM). The DEM is indispensable for many analyses such as topographic feature extraction, runoff analysis, slope stability analysis and so on (Takagi, Hiroshi and Kikuchi, 2003). Elevation data are becoming mainstream for a wide variety of applications such as

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water management, flood hazard mapping, network planning, biomass studies, topographic mapping, and land cover and land use mapping (Intermap Technologies, 2010). DEMs are commonly produced from satellite imagery, aerial imagery, radar data, LiDAR data and topographic maps. Knowing which source data to use is of utmost importance for making the most efficient use of resources. A DEM produced from high-resolution imagery allows the user to measure precise elevation points throughout a given area. With the source imagery draped over the area of interest (AOI), the user can get a good perspective and feel for the terrain.

Condor Valley LLC is a U.S. company that operates Condor Valley, an area of roughly 70,000 acres in northwest Argentina (Figure 1).

Figure 1. Small yellow “+” marks the location of Condor Valley in NW Argentina.

Condor Valley is generally made up of two historically separate ranches, La Bodega and El Tipal, that have been in operation on and off for over 150 years. The current vision for Condor Valley LLC is to create a self-sustaining entity through ecologically appropriate development of the area’s natural resources. This includes, but is not limited to, ranching, agriculture, eco tourism, hunting and fishing (Bannister, 2011). In April, 2009 Condor Valley LLC began its quest for a DEM of its property. Being in a remote area of northwest Argentina meant that there was minimal geospatial data and information regarding the Condor Valley area. As Condor Valley LLC progressed deeper into its main activities in the area it realized it would need more detailed information. The elevation data from the DEM, along with the imagery, could be used in a variety ways to improve and assist the ranch in its ranching, agricultural, and development activities, starting with the construction of an unpowered irrigation system for year-round crop growing (Wright, 2011).

Condor Valley (Figure 2) is more than 50 miles from the nearest electrical source making a connection to an electrical grid impractical.


Figure 2. Aerial photo of Condor Valley, Argentina.

Several solar panels currently provide temporary and minimal electricity for communication systems, but using them to power irrigation pumps would be too costly and technologically advanced for a local gaucho to maintain. Wind power falls into the same category. Traditional irrigation ditches provide a seasonal source of water, but the intakes for these systems are at the will of the river and can be destroyed at any time. Without a steady power supply, irrigation pumps cannot be used to elevate water into reservoirs. The solution is to use DEM derived data to guide the development of an irrigation network of appropriately elevated channels that will let gravity do the work.

At this point no extensive GIS-based analysis has been done using the DEM. To present, all that has been done has been the creation of a series of detailed maps of specific areas of the property (Wright, 2011). Future use of the DEM and imagery will be to aid in the ranch's agricultural, ranching and other general development activities. Because the DEM has yet to be used extensively in a GIS, the analysis of this paper will focus on the selection and acquisition of the appropriate satellite imagery for the creation of the DEM for the 37 km^2 area of Condor Valley, Argentina.

Methods

Software Used

The software used to perform the analysis consisted of the landscape visualization programs Terragen™ 2 Deep and Terragen™ 0.9x Classic, the GIS programs 3DEM, Global Mapper 12 and ArcView 9.3 and the image editing program Photoshop CS5.

Data Acquisition

Digital ground elevation data are predominantly collected photogrammetrically, from stereo satellite imagery, global positioning systems, stereo aerial photography, ground surveying, and from scanned contour data vectorized as x,y,z point data (De Sawal, 1997). The data necessary for this project was provided by East View Cartographic (EVC) as a part of a geospatial solution for a customer. The customer, Lohnes+Wright (LW), a GIS and mapping company based in Oakland, CA came to EVC with a request for a high-resolution DEM for its customer, Condor Valley LLC, the end-user. Several options were presented for the DEM and elevation data for the AOI. Three options were initially considered, a DEM derived from a) topographic maps, b) stereoscopic satellite imagery, c) radar data.

A 30 m resolution DEM can be created from 1:50,000 scale topographic maps. When 1:50,000 mapping is available and a 30 m resolution is sufficient, this option is the most cost-effective. However, in this case EVC's indexes showed that 1:50,000 mapping had yet to be published for the area. The best mapping currently available was at a 1:250,000 scale which would have allowed for the generation of a 90 m resolution DEM. This resolution is the same as the freely available Shuttle Radar Topography Mission (SRTM) data. The cost of this option was $34.00, the charge for the conversion to the file format and coordinate system of choice as well as the filling of any small void areas in the data through interpolation. This level of resolution was not acceptable for the primary application but was acceptable for a preliminary study of the area.

A step beyond the 90 m DEM derived from topographic maps is a 30 m resolution DEM derived from stereoscopic ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite imagery (Figure 3). The ASTER archive was checked and it was found that there was source imagery from 2005/2006. The cost for this option was $1,550.00 and included delivery of the imagery. This level of resolution was not acceptable for the primary application but was too expensive for preliminary studies.

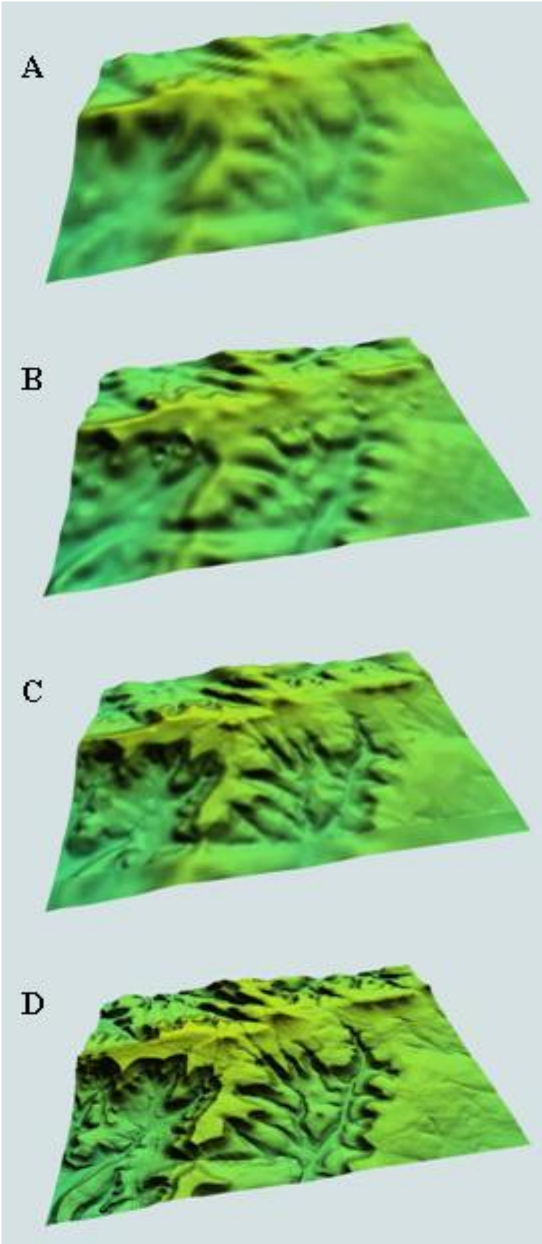

Figure 3. A. SRTM 90 m DEM. B. ASTER 30 m GDEM. C. Topographic 30 m DEM. D. GeoEye-1 3 m DTM.

After further discussion with LW, it was apparent that in order to meet the needs of the application, high-resolution (≤5 m) terrain data would be needed. This can be achieved by the production of a DEM sourced from high-resolution stereoscopic satellite imagery. One meter or less is generally accepted throughout the industry as high-resolution. Due to its extensive experience in imagery sourcing, EVC knew immediately the best sources for this imagery would be from the following satellites (prices reflect monoscopic imagery) (Table 1).

Table 1. Sub-meter color monoscopic satellite imagery prices.

Archive Imagery (1999-Present) - (50 km2 min order size)

Ikonos Satellite (GeoEye)	1m resolution color	$10.00 per km2
Quickbird Satellite (DigitalGlobe)	60cm resolution color	$14.00 per km2
GeoEye-1 Satellite (GeoEye)	50cm resolution color	$12.50 per km2

New Collect Imagery - (100 km2 min order size)

Ikonos Satellite (GeoEye)	1m resolution color	$20.00 per km2
QuickBird Satellite (DigitalGlobe)	60cm resolution color	$20.00 per km2
GeoEye-1 Satellite (GeoEye)	50cm resolution color	$25.00 per km2

Depending on the topography of an AOI, EVC can create a Digital Terrain Model (DTM) at either 2 m or 3 m post resolution with no difference in cost from ≤60 cm resolution imagery. The decision was up to the client, but EVC has found that certain geographic areas are better suited to one post spacing than another considering the accuracy parameters of the source imagery. In rugged and somewhat mountainous areas, 3 m resolution is recommended. In areas with relatively modest relief, the imagery is inherently more accurate and a 2 m DTM post spacing is more optimal (Cloutier, 2011). For Condor Valley, it was determined by a simple view in Google Earth that it seemed to be somewhere right in the middle. Both resolutions would support 2 m contour lines in proper accuracy.

It was determined that this area would require new satellite collection in stereo mode so there would be lead-time involved (commercial satellites usually only collect monoscopic imagery unless there is a request for stereo, which is needed for the DTM creation process). A feasibility request was submitted to the satellite operator to get an estimate on collection lead time. A feasibility request assesses collection competition in the area along with prevailing weather conditions to establish an expected lead-time. Once the imagery is in hand, it only takes about a week to produce the DTM and contour lines. This option was expensive at about \$115.00 per km^2, but it included a 2 m resolution DEM, 50 cm resolution satellite imagery and 2 m contours lines. The results of the feasibility study came back with an expected 90 day collection period assuming the order would be activated in the next 7-10 days. The collection time decreases significantly as the calendar moves toward Argentina’s winter months of June-Sept. If the order is activated in the May/June time frame, the collection time decreases to 40 days. These estimations were based on historical weather patterns, but basically the chances improve every day that passes until about August. GeoEye estimated they would have to shoot the area four different times in order to obtain an image with less than 15% clouds (the industry standard for a “successful” collection). At this time, a decision still was not made on whether to go through with the tasking of GeoEye-1 for this project.

Over four months passed before hearing back from LM who was waiting for their client to give the go-ahead on the DTM. This necessitated a new feasibility request from GeoEye. After receiving confirmed coordinates of the project area, a polygon file was created and a collection feasibility study was submitted. Two months later the feasibility request came back from GeoEye with two possible options. The first option was the previously discussed GeoEye-1 solution (Table 2). Advantages of this were a higher resolution DTM, higher resolution imagery and more accurate contour intervals. The only disadvantage was the longer lead-time needed due to current collection capacity (although a high-priority collection was available for a rather significant surcharge). The second option was suggested by the satellite operator in the event the client wished to sacrifice a bit of resolution/accuracy for faster collection, estimated at 15 days (Table 3).

For either option, EVC could further enhance accuracy of both the imagery and terrain model if GPS survey/measurements/control points were available in this area. These Ground Control Points (GCPs) would be introduced into the orthorectification phase of processing. This was not a requirement, but if LM had them available it would be beneficial to use them. LM did in fact have GPS waypoints, but they were acquired by consumer grade Garmin units. The standard Garmin hand-held GPS receivers are accurate to about 6 to 8 meters so in this case the inherent accuracy of the satellite imagery was already higher than that of the Garmin waypoints thus using them would not have improved the imagery. For applications such as this, it is recommended to use GCP measurements collected from a sub-meter accurate differential GPS unit (Cloutier, 2011).

Table 2. Option 1: 50 cm color orthoimagery, 3 m DTM and 2 m contour lines.

Type of Data	**Resolution**	**AOI Size (km^2)**	**Cost per km^2**	**Total**
Stereo satellite imagery	50 cm	100	$40.00	$4,000.00
Digital Terrain Model	3 m	37	$60.00	$2,220.00
Contour lines shapefile	2 m	37	$15.00	$555.00
TOTAL*				$6775.00

*based on standard collection.

Collection Vehicle	GeoEye-1 satellite	
Accuracy (without GCPs)	4 m Horizontal CE90%	6 m Vertical LE90%
Accuracy (with GCPs)	2 m Horizontal CE90%	3 m Vertical LE90%
Collection Feasibility**	102 days	Standard Collection
Collection Feasibility**	53 days	Priority Collection (+ $3,000)

**Estimated imagery collection lead-time based off of orbital collection parameters, prevailing weather patterns and area competition.

Table 3. Option 2: 1 m color orthoimagery, 5 m DTM and 5 m contour lines.

Type of Data	**Resolution**	**AOI Size (km^2)**	**Cost per km^2**	**Total**
Stereo satellite imagery	1 m	100	$35.00	$3,500.00
Digital Terrain Model	5 m	37	$55.00	$2,035.00
Contour lines shapefile	5 m	37	$15.00	$555.00
TOTAL*				$6,090.00

*based on standard collection.

Collection Vehicle	IKONOS-2 satellite	
Accuracy (without GCPs)	15 m Horizontal CE90%	22 m Vertical LE90%
Accuracy (with GCPs)	4 m Horizontal CE90%	6 m Vertical LE90%
Collection Feasibility**	15 days	Standard Collection

**Estimated imagery collection lead-time based off of orbital collection parameters, prevailing weather patterns and area competition.

A few months later, the imagery collection vehicle of Option 1 was chosen. This option had a standard turnaround time of 102 days. During this waiting period, EVC provided LW a 50 m contour shapefile for the creation of overview maps of the 30 k+ hectare property (Figure 4). Less than two months after the initial inquiry from LW, a group of tourism and agriculture developers visited the area to make assessments about potential development. The 50 m contour overview maps aided their efforts.

Due to administrative delays on the part of the customer, another feasibility study was necessary after two months passed since last contact was made. EVC felt it was almost a certainty that the situation has changed since the original study was performed back in February. The area was sent off to GeoEye for review. A different time frame was expected from the time frame that was originally anticipated due to both weather considerations in the area and a large government imaging contract that was awarded to the imagery provider back in August.

GeoEye’s collection feasibility estimate came back at 123 days which was only slightly longer than the initial estimate from February. The shapefile of the 37 km^2 production area was sent to LM for confirmation. The 50 cm imagery would cover the peripheral area outside this polygon to meet GeoEye's minimum collection size of 100 km² (Figure 5).

Two other options for high-resolution elevation data were available. These were traditional ground survey or to mobilize a plane outfitted with a LIDAR or RADAR sensor. The plane option usually is not cost feasible unless a huge area is involved and the assumption was the costs for ground survey would be more than doing it remotely via satellite.

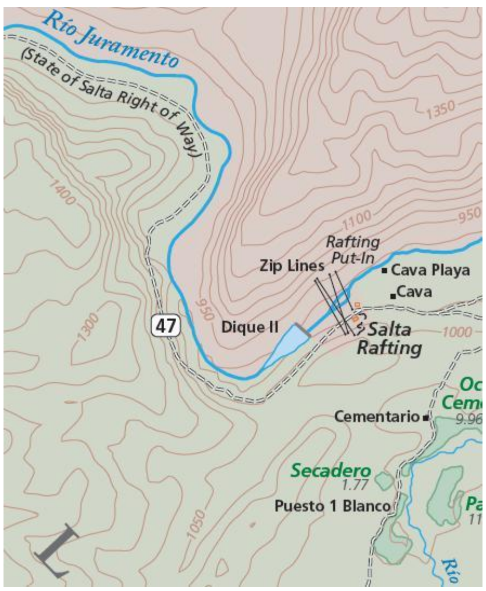

Figure 4. Topographic map derived from GeoEye-1 imagery created by Lohnes+Wright.

For the sake of due diligence, the option of a radar derived DEM needs to be addressed further so as not to leave a misguided view of radar DEMs. The most commonly known radar DEM data are from SRTM. These widely used data are free for public and commercial use and provides for a 90 m resolution DEM.

Notably, SRTM data are far from the top-notch elevation data compared to the DEMs produced from aerial radar acquisition. Aerial radar data approaches resolution levels on par with high-resolution stereoscopic satellite imagery. The method of Interferometric Synthetic Aperture Radar (IFSAR) is a radar-based remote sensing technique that provides wide-area DEMs with a radar beam at high accuracy. The result, after processing, is seamless, high-resolution elevation data (Intermap Technologies, 2010). This is a costly option given the limited number of companies that do it and the small swaths of coverage that low-flying airplanes acquire. Put another way, there is a lot more archived satellite imagery than archived radar imagery and if new tasking is required, its much easier to program an orbiting satellite to acquire a specific area than it is to fly a small plane great distances to acquire that same area.


Figure 5. Shapefile of 37 km2 DTM generated area overlaid on the GeoEye-1 satellite imagery source data bounded within the shapefile of the larger 100km2 study area in Global Mapper.

However, in recent years, the industry has seen an emergence of medium to high-resolution radar satellites.

These radar satellites commonly achieve elevation data resolutions of 2 m, making them “apples to apples” to “normal” high-resolution satellite imagery derived elevation data. One of these satellites, TerraSAR-X, is designed to be operational for 5.5 years, independent of weather conditions and illumination**,** and reliably provide radar imagery with a resolution of up to 1 m and a unique geometric accuracy (Infoterra, 2011). At this point, this method is more expensive due to it being more cutting-edge and, as a result, a much smaller archived collection. This makes tasking more commonplace, which is much more costly than archive.

LiDAR (light detection and ranging) is an active remote sensing technique that uses electromagenetic energy in the optical range to detect targets, determine the distance between the target the instrument (range) and deduce physical properties of the object based on interaction of the radiation with the target (Diaz, 2011).

Results and Discussion

After the decision was made to acquire high-resolution satellite imagery from GeoEye-1 and the tasking order was submitted, it was time to discuss data format requirements. See Table 4 for common formats of EVC produced data.

Just after the New Year, EVC got word that GeoEye took a great shot of the Argentina location. EVC received the imagery promptly and after study, it was deemed excellent. EVC henceforth began producing the elevation model and contours. In less than three weeks, it was complete (Figure 6 and Figure 7).

At this point, further discussion revolved around the data formats and the management of file sizes. The contour data were delivered in shapefile format.

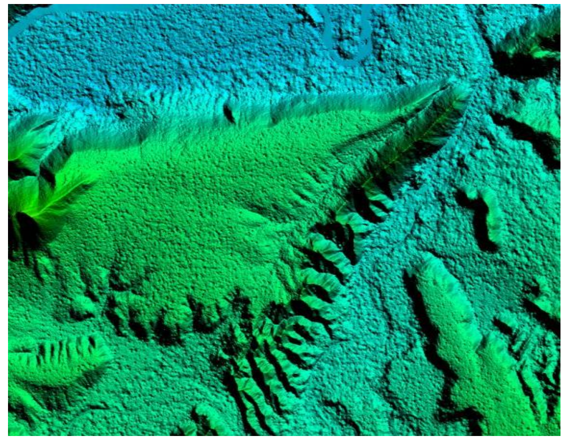

Figure 6. 2 m DTM derived from 50cm GeoEye-1 stereoscopic imagery viewed in Global Mapper

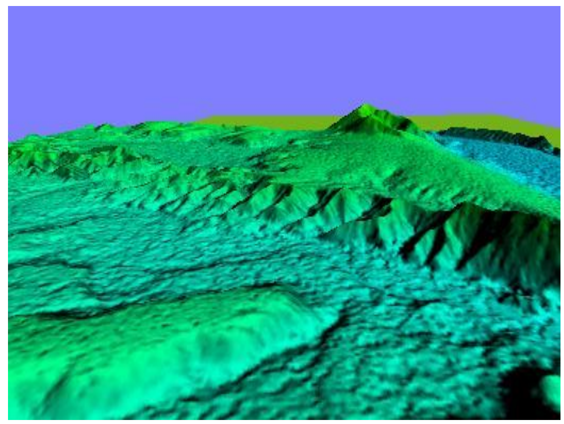

Figure 7. 2 m DTM derived from 50cm GeoEye-1 stereoscopic imagery. 3D view in Global Mapper

Contour elevation values were stored in the shapefile as attributes (2 m contour intervals). The DTM data was delivered as a gridded raster file at 2 m resolution (approximately 1/9th arc-second). The file format was left up to the customer’s preference. Typically it is delivered as a 32 bit GeoTIFF terrain file, USGS .dem, ASCII XYZ or ArcGRID file. It ended up being sent as ArcGRID file at the request of the customer. The imagery was also sent in GeoTIFF file format. The total imagery file size was anticipated to be around 1.5 to 2 GB. Because of this, EVC tiled this into pieces to make it easier to work with. The suggested file size was around 500 MB per tile which would make for three or four tiles.

Table 4. EVC geospatial data formats.

Product	Data format
50 cm color Orthoimagery	GeoTIFF, ECW, JPEG, MrSID, Jpeg2000
DTM	32 bit GeoTIFF, USGS .dem, ASCII XYZ, DXF Mesh, DXF Point File, XYZ Grid, BIL, DXF 3D Face, etc.
Contours	ESRI Shapefile, MapInfo TAB, AutoCAD DXF/DWG, ESRI Personal Geodatabase

Unexpectedly, GeoEye delivered EVC some extra imagery outside of the order polygon. In turn, EVC delivered the orthoimage in two iterations, one orthoimage clipped to the project AOI, and another orthoimage for all of the data that was delivered. After delivery of the data to the customer, it was requested that the tile sizes be resized smaller. This was an easy but time consuming task. EVC fulfilled LM's request of 20MB files and set everything up and let the batch-export process run over a weekend. LW stated that the need for 20MB files was mainly a file management issue. The consideration of a compressed raster format such as ECW or Jpeg2000 was proposed to LW in response. EVC usually can get a 10x to 20x compression ratio using these formats with virtually no loss in data quality and they are widely compatible with almost all GIS software today, including ArcGIS. The main reason this was proposed was because there would be around 400 to 600 tiles at ~20MB each, which could present organizational challenges of its own. Three samples of different files sizes of the same area in Argentina were sent to LW. The three formats and their respective file sizes were; TIF = 7.3MB, Jpeg2000 = 0.4MB, and ECW = 0.3MB. The customer still had the original GeoTIFF source data so there was nothing to be lost going with a compressed raster route. It was agreed that the Jpeg2000 format be used with an estimate of an end result of 30-40 tiles at about 20MB each.

Conclusions

Using EVC's network of partnerships with all of the major commercial satellite imagery providers and its decades long history of DEM production, it was possible to provide Lohnes+Wright with the best solution, who in turn was able to fulfill the request of their customer, Condor Valley LLC. Lohnes+Wright and Condor Valley LLC now have the geospatial data needed to conduct a number of different land use analyses. As an added service, the creation of a simulated "fly-through" using the landscape visualization program, Terragen 2, is in the works for Condor Valley (Figure 8).

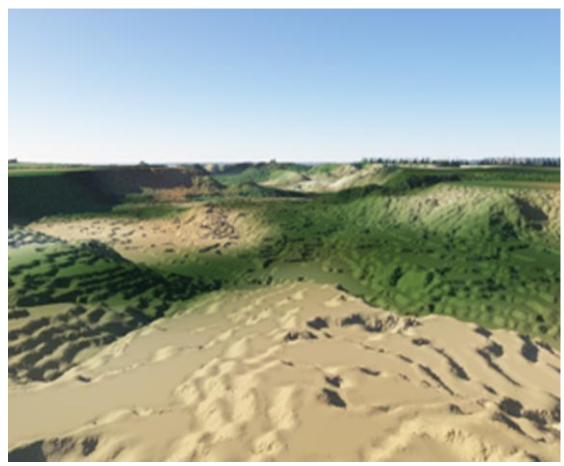

Figure 8. Rendered view of Condor Valley in Terragen 2 landscape visualization program.

The customers were very happy with the geospatial data that was provided to them by EVC. They were also pleased with the quick and informative responses to any of their questions and inquiries to the EVC staff. By using a company that specializes in the field of imagery sourcing and services, the customer was able to save time and money and continue to focus on matters at hand as part of the process of establishing Condor Valley as a tourist destination in Argentina.

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