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Applications of LiDAR-Derived Data in the Operations of the Southern Negros Geothermal Field, Philippines

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ABSTRACT

Light Detection and Ranging (LiDAR) is now one of the remote sensing methods commonly used for geothermal resource exploration. LiDAR outputs such as high-resolution digital elevation models (DEMs) are used to delineate faults and identify lineaments to better understand the geologic environment. DEMs are also used to produce high resolution topographic maps and orthorectify images.

In the Southern Negros Geothermal Field, airborne LiDAR surveys were conducted in 2014 and 2016 that produced DEMs, 1-meter contour maps and orthophotos. While the primary objective of the surveys was to produce comprehensive topographic maps for engineering applications, the DEMs were also used to further characterize the structural geology of Palinpinon-1 and Palinpinon-2 and ultimately improve drilling targets. In addition, the contour maps and slope maps were used to verify the location and elevation of wellheads and identify possible areas for pad development. The orthophotos also played many practical roles in spatial analyses. Since the Southern Negros Geothermal Field coexists with communities, identifying the affected residents during vertical discharge activities of wells was more accurately made through the creation of distance buffers. Geohazard prone areas were more visible to the geohazard team that often needed quick visual assessment before field inspection. Determining areas that are covered by and still to be applied for tenurial/environmental permits was also made easier through image overlays and visualization. Overall, the present applications of LiDAR data are commendable for spatial analyses, but LiDAR data may be exploited further through integration with GIS applications, additional survey campaigns as well as personnel training and development.

1. INTRODUCTION

“LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.”–NOAA (2018, para. 1)

In 2014, Energy Development Corporation (EDC) proposed to conduct a LiDAR aerial survey campaign as a more affordable and faster method for topographic mapping. The outputs of the survey would provide comprehensive and high accuracy digital terrain models (1-meter contour accuracy) and digital orthophotos covering EDC’s geothermal production fields that could be used for various civil works such as pad preparation and road and site development plans. The first aerial survey campaign was conducted in May 2014 in Bacman Geothermal Field (BGF) and Southern Negros Geothermal Field (SNGF), two of EDC’s four geothermal sites.

Table 1: Acquisition parameters

	General	**Pipeline**
Flying Height	900 m above ground	500 m above ground
Capture Speed	100 knots	100 knots
Laser Pulse Frequency	100 KHz	100 KHz
Scan Half Angle	20º	20º
Point Density	2.7 points per m^2 before classification	15 cm between points on the LiDAR cross track
Vertical Accuracy	10 -12 cm	15 cm
Horizontal Accuracy	Approximately 20 cm	Approximately 15 cm
Image Pixel Resolution	5 cm ground pixel size	5 cm ground pixel size

Source: Surtech (2014)

The total area covered by the aerial survey campaign in SNGF was 6,420 hectares, encompassing the entire development block which includes the Palinpinon-1 and Palinpinon-2 geothermal fields in the Municipality of Valencia as well as the exploration field in the Municipality of Dauin (See Fig. 1). The survey reference system used for the survey campaign was the Philippine Transverse

Mercator Zone IV-PRS 92, with elevations referred to mean sea level (MSL). The ground survey data also utilized available geodetic stations established by the National Mapping and Resource Information Authority (NAMRIA) of the Philippines. In addition, orthometric heights were derived using the 2008 Earth Gravitational Model (EGM) (Surtech, 2014). The flight details and LiDAR acquisition parameters are summarized in Table 1.

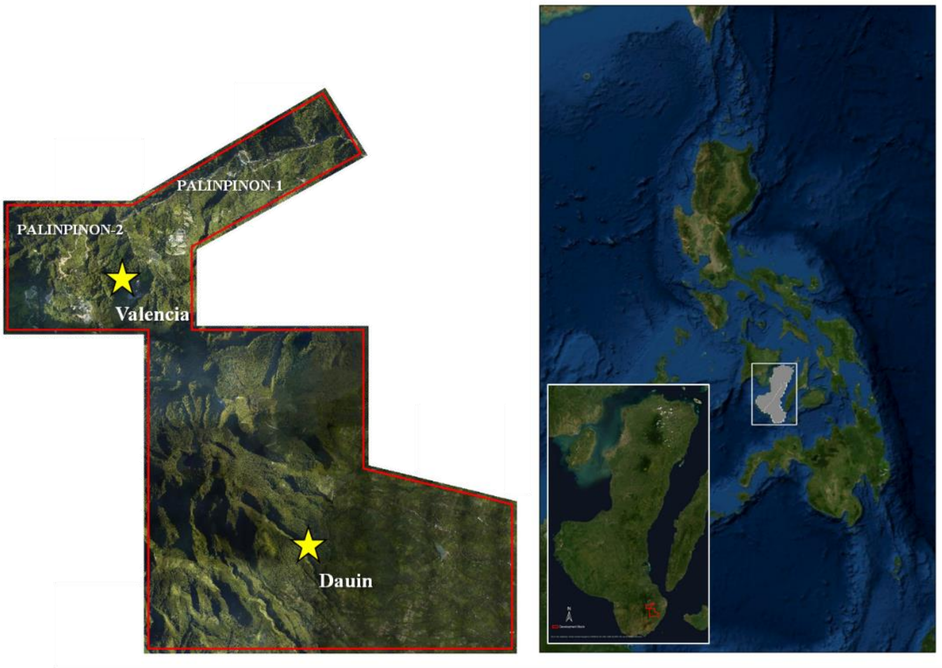


Figure 1: Coverage of the 2014 SNGF LiDAR aerial survey campaign.

From the raw data, the following outputs were produced: (1) 1-meter elevation contour files in .dgn, .dxf, and .shp formats, (2) 33 tiles of orthophotos in .tif and .ecw formats, and (3) ground data in .xyz format.

2. BASIC USES OF THE LIDAR OUTPUTS

From the LiDAR acquired data, high accuracy topographic maps of SNGF were produced. The 1-meter resolution maps were an upgrade to the 10-meter resolution maps derived from the TerraSAR-X digital elevation model (DEM) (See Fig. 2). Moreover, the former is anchored on the local projected coordinate system (PRS 1992 Zone IV) with meters as primary unit of measurement while the latter is based on the geographic coordinate system (GCS_WGS 1984) that makes use of degrees as primary unit of measurement.

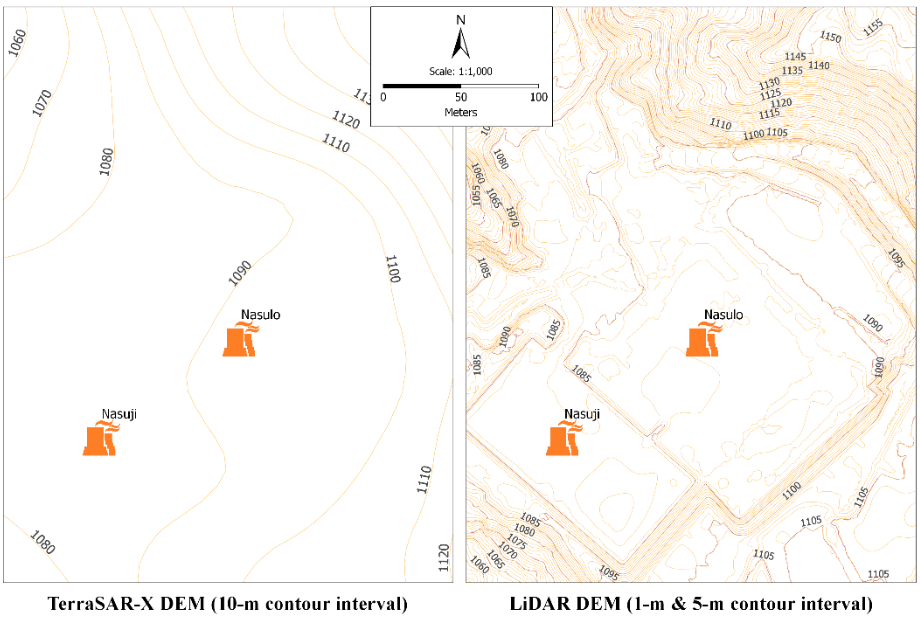


Figure 2: Improvement in resolution of topographic maps.

2.1 Topographic Maps

The high resolution maps were used to aid in many civil works applications such as in pad preparation. With more accurate information on the elevation of a certain pad, key decisions regarding sloping mitigations, pad leveling, and cellar preparation are made with more confidence (See Fig. 3).

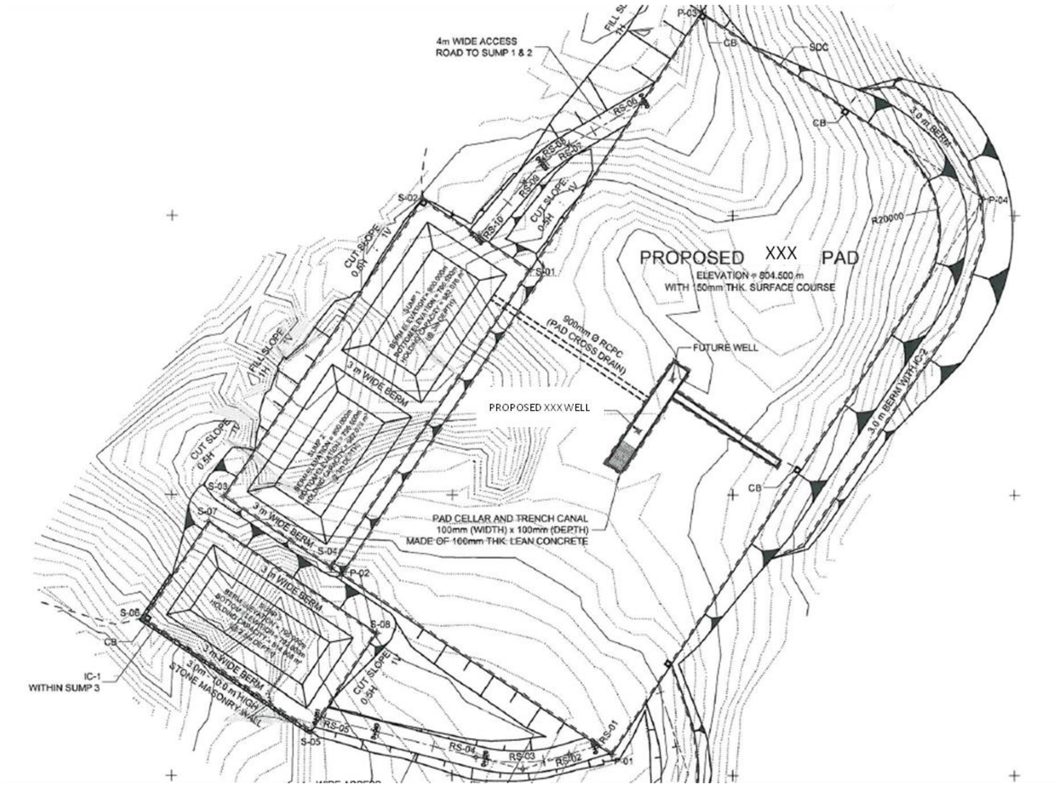


Figure 3: Layout for proposed new pad overlaid on high resolution contour map.

In addition, the DEM produced from the LiDAR-derived ground data was also essential in geohazard monitoring. Every year, bi-annual geohazard assessments are conducted to update as well as mitigate the possible dangers imposed by known geohazard areas within the Palinpinon-1 and Palinpinon-2 geothermal fields. Through the DEM, better mitigating measures were adopted while new geohazard prone areas were also identified.

2.1.1 Updating of Well Elevation Data

The DEM was also used as a reliable source for updating the elevation of well heads (at casing head flange or CHF). Previously, the elevation of wells were based on the values reported in the well's geologic report. The elevation was mostly likely measured through actual surveys done on the pad where the well was drilled, but could have been performed in various ways, depending on the surveyor's tools and methods. To standardize, the elevation values of the DEM were adopted for all wells drilled in May 2014 or earlier.

2.2 Digitization of Geothermal Facilities

The orthophotos or aerial photos taken of the site did not only provide high resolution imagery—these also became the means for digitizing (tracing geographic data found in images and converting them into vector data) the various geothermal facilities captured in the orthophotos. The digitized facilities included buildings, cooling towers, sumps, wells, pipelines, and ground characteristics such as lot boundaries and roads (see Fig. 4). Features like transmission towers and lines and houses (residential areas) were also digitized. The digitized data became the first comprehensive source of GIS data of surface facilities for SNGF. These are now available as shapefiles (.shp) and feature layers in EDC's geodatabase. Previously, GIS data were limited to well location, well track, and geological features (e.g., faults, craters, peaks) or those that could be derived from the TerraSAR-X DEM and commissioned geodetic surveys. With the additional GIS data, a more detailed base map has been produced and is accessible to EDC employees through online web maps.

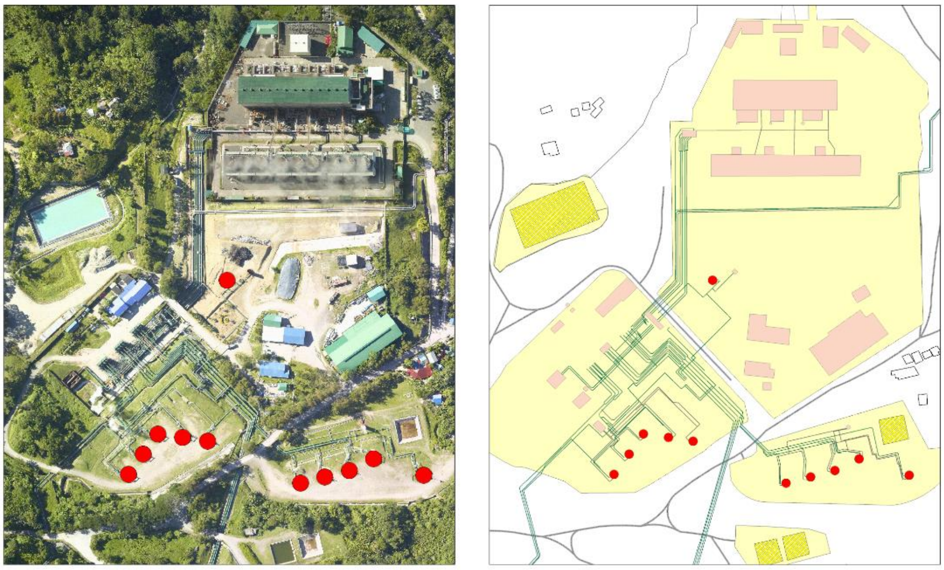


Figure 4: Digitized facilities based on aerial photos.

2.2.1 Discrepancies Found in the Orthophotos

There were notable discrepancies in the orthophotos, particularly in the offset of wellhead locations (Easting and Northing coordinates) when compared with the locations previously surveyed using Global Navigational Satellite System (GNSS) in 2013 (see Fig. 5). Since the aerial photos were assumed to be properly orthorectified, there was a need to reconcile it with the results of the 2013 GNSS survey done on the ground. These discrepancies were later confirmed through another GNSS and as-built survey conducted in 2016. The 2013 and 2016 survey data matched, only varying in the centimeter level. The issues concerning the offsets were communicated to the LiDAR survey contractor who, after reviewing their data, were able to confirm the errors and consequently correct them. The corrected orthophotos now provide accurate locational information, which could have otherwise been misleading to end users.

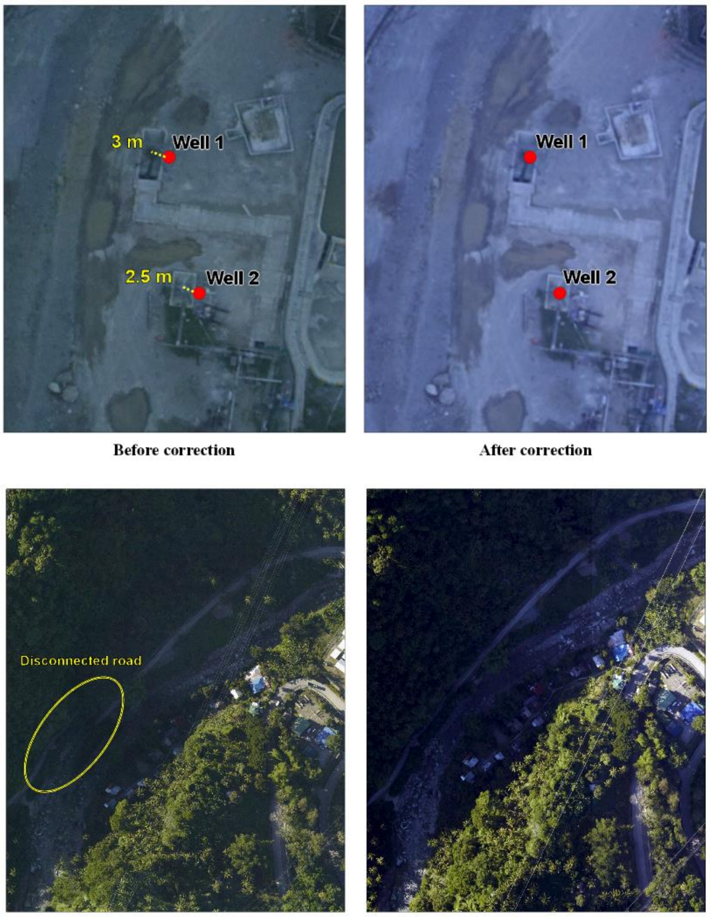


Figure 5: Discrepancies found in the orthophotos were addressed.

3. 2016 LIDAR SURVEY

In July 2016, another LiDAR aerial survey campaign was conducted in order to capture West Sogongon and South Lagunao area (outlined in red), the new proposed development area southwest of the existing development block, covering 3,272 hectares (see Fig. 6). Similar flight and acquisition parameters were used for the survey. The outputs derived from the aerial survey campaign were 1-meter elevation contour files, orthophotos, ground data as well as a digital surface model (DSM) which was not included in the 2014 survey campaign.

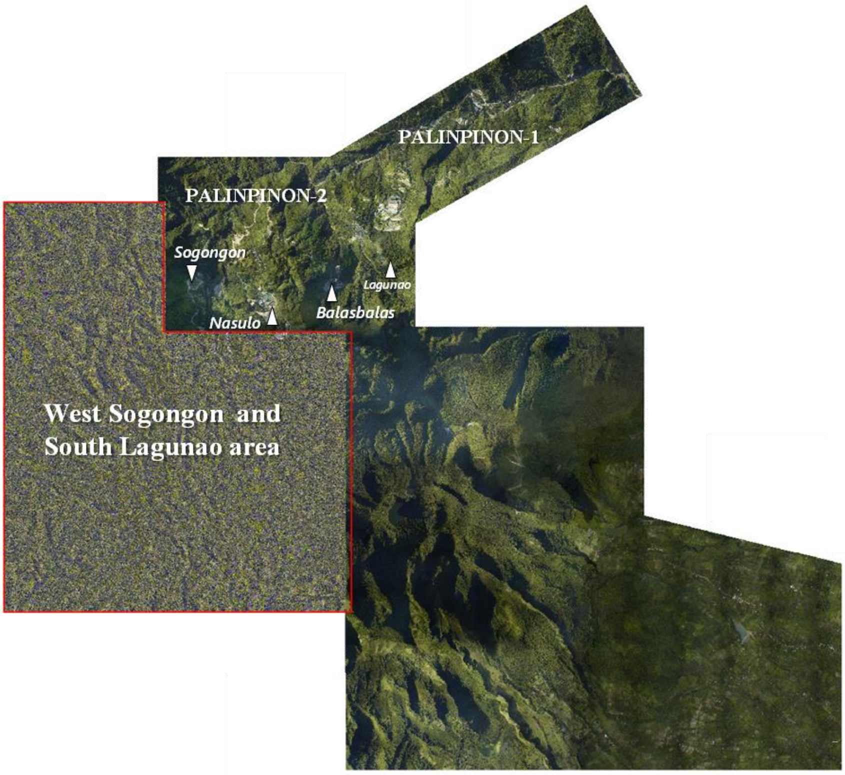
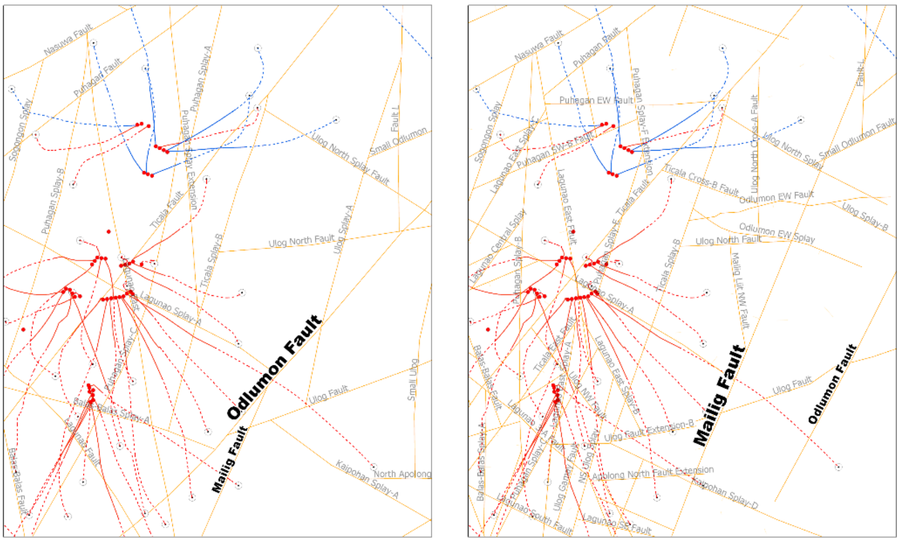


Figure 6: Coverage of the 2016 SNGF LiDAR aerial survey campaign.

3.1 Structural Interpretation using LiDAR-derived DEM

Using the high resolution DEMs of 2014 and 2016 and targeted field verification activities, regional structural data of Palinpinon-1 and Palinpinon-2 were further refined. Additional faults were identified and verified in the field while the strike and dip of some faults were corrected. For instance, Odlumon Fault, widely accepted as the main conduit of reinjection (RI) fluids in Palinpinon-1, was more accurately delineated to be much farther an influence to the sector, and was replaced by Mailig Fault as the main RI conduit (see Fig. 7). This development became the updated reference when presenting decrease in steam flow due to RI returns in Palinpinon-1.



Old structural map (based on TerraSAR-X DEM) New structural map (based on LiDAR DEM)

Figure 7: Refinement of structural map.

Drilling targets in West Sogongon and South Lagunao area were refined using the 2016 DEM. The DEM was also used to delineate lineaments in the said area. Through field verification, these lineaments were further classified as confirmed faults, inferred faults, or otherwise remained as lineaments. This resulted into an updated structural map that was essential in preparing the well design and geological prognosis of new wells to be drilled in the area.

4. OTHER USES OF THE LIDAR OUTPUTS

The outputs of the 2014 and 2016 LiDAR aerial survey campaign were also beneficial for EDC's community, social and regulatory compliances and obligations. Some of the practical uses are discussed in the following sections.

4.1 Regulatory Compliance

The SNGF is situated in the foothills of the largest remaining forest patch in the province of Negros Oriental. It covers both public lands and alienable and disposable lands. Consequently, it is also one of the geothermal sites which is operating in close proximity with communities. Hence, it is critical that the operation is not just legally compliant particularly to applicable forestry laws and regulations but also socially and environmentally acceptable.

4.1.1 Base Map for Forest Land Use Agreement (FLAg)

Facilities within public lands (i.e., forestlands) are utilized through tenurial instruments from the Philippines' Department of Environment and Natural Resources (DENR). In 2013, EDC secured a Forest Land Use Agreement (FLAg 01-2013), a 25-year tenurial instrument allowing the company to use and sustainably manage the forestland within SNGF.

The LiDAR-derived orthophotos proved valuable in the company's compliance to proposed development plans within the approved FLAg area. EDC was able to use the imagery to visually appreciate the boundaries of the FLAg without having to go on site for field inspection. Using GIS mapping software such as ArcMap and ArcGIS Pro, spatial analysis were performed to determine which proposed development areas, for example, are within or outside the approved FLAg area. This, in turn, helped in making key decisions regarding which areas to prioritize for forestry permitting (i.e., Special Land Use Permit, Forest Land Use Agreement, Tree Cutting Permit).

4.1.2 Special Land Use Permitting for the Two-Phase Line Interconnection Project

In the event that there is an immediate need to construct facilities (e.g., pipelines, well pads, access road) outside the existing FLAg area, EDC applies for a Special Land Use Permit (SLUP), such as in the case of the Lagunao to Balasbalas Two-Phase Line Interconnection (LG-BL TPLI) Project (EDC, 2018).

The LG-BL TPLI required the installation of ~2-km length of pipeline to transfer available steam from production wells in Lagunao Pad (Palinpinon-1 sector) to the Okoy-5 Modular Power Plant in Balasbalas (Palinpinon-2 sector) to address the latter's steam shortfall. The 2014 orthophotos were used during the project design stage to (a) determine the route with the least disturbance to the environment (e.g., no trees affected) and (b) ascertain the minimum area for permit application. Majority of the pipeline and its pipe supports fell within the boundaries of the FLAg. Those that extended beyond the FLAg were further minimized into four small lots (each less than 3,500 m2 in area) that were then identified for SLUP application (see Fig. 8).

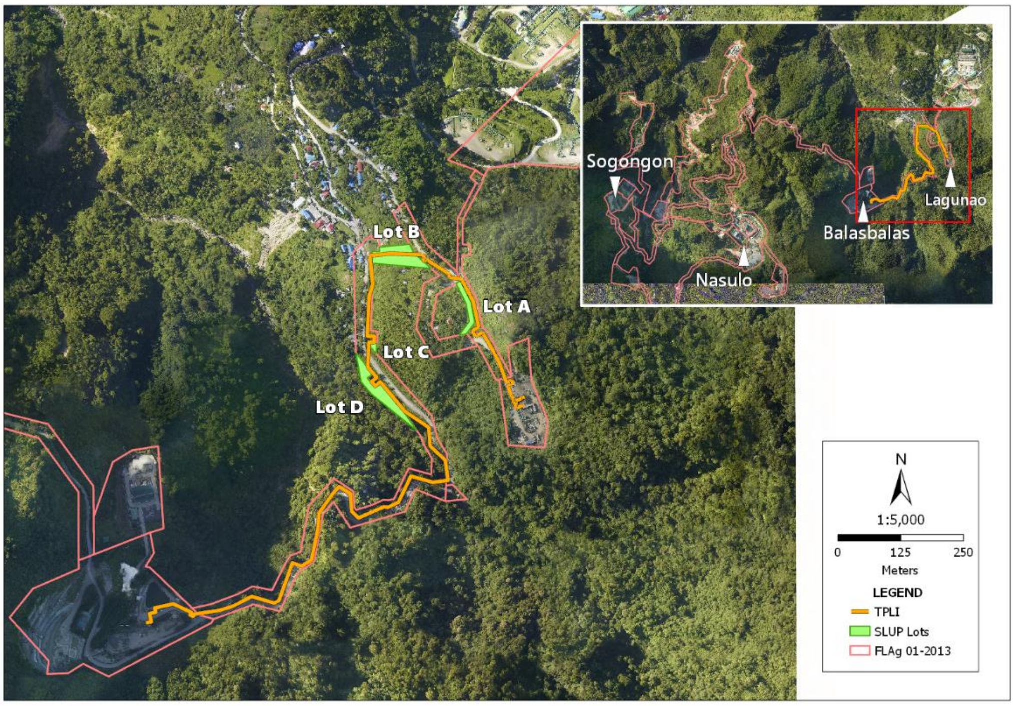


Figure 8: SLUP application aided by orthophotos.

4.1.3 Distance Buffers during Vertical Discharge Activities

During critical field activities such as vertical discharge of production wells, it is necessary for nearby residents to be temporarily evacuated to avoid exposure to potential harmful geothermal gases such as hydrogen sulfide (H_2S). This is in compliance with the Clean Air Act (Republic Act 8749), where EDC is not only concerned with the right of residents to air quality, but more importantly with their safety. Before the availability of orthophotos, the extent of evacuation was only estimated based on known locations of nearby residents. With the orthophotos and the digitized residential areas, the process was done with more certainty and speed. The imagery allowed visual inspection of possible evacuees based on the radial distance of the well to be discharged (see Fig. 9). Through spatial analysis techniques such as creation of distance buffers, the coverage of the community that they needed to inform and evacuate was determined more efficiently.

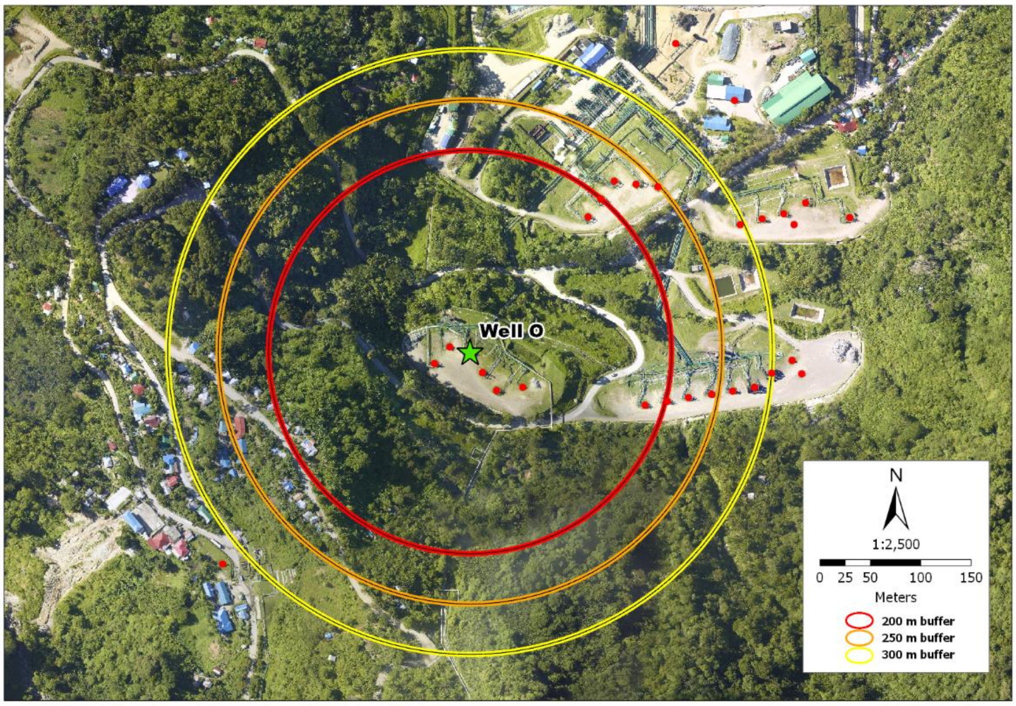


Figure 9: Distance buffer map created in preparation for vertical discharge of Well O.

4.2 Location Maps using Aerial Photos

EDC often conducts information, education, and communication (IEC) campaigns for its external stakeholders. Maps are one of the visual tools being used to help the general public appreciate the geographic context of the geothermal projects EDC operate.

4.2.1 Plotting of GPS Track during Field Work

EDC conducts field work for various purposes such as general habitat assessments and site visits requested by external groups. An example of the latter is seen in Figure 10. In 2016, a special hike was arranged by EDC for an environmental group who requested to take part in a field inspection of a potential area for pad development. The trail covered by the team was recorded using a Global Positioning Systems (GPS) device, which was then imported into a mapping software. The aerial photos acquired in 2016 were used as overlay on the track traversed by the team, enabling them to appreciate the location of points of interest.

4.2.2 Relocated Housing

Part of EDC's corporate social responsibility is to extend assistance to the communities where it operates. In 2016, EDC partnered with the local government units to secure alternative residential lots for residents whose houses/properties then had close proximity to power plants and production wells. Using mapping software, the new locations were overlaid on the 2014 LiDAR-derived orthophotos to come up with a map showing their distance relative to Palinpinon-1 Power Plant and certain production wells (See Fig. 11).

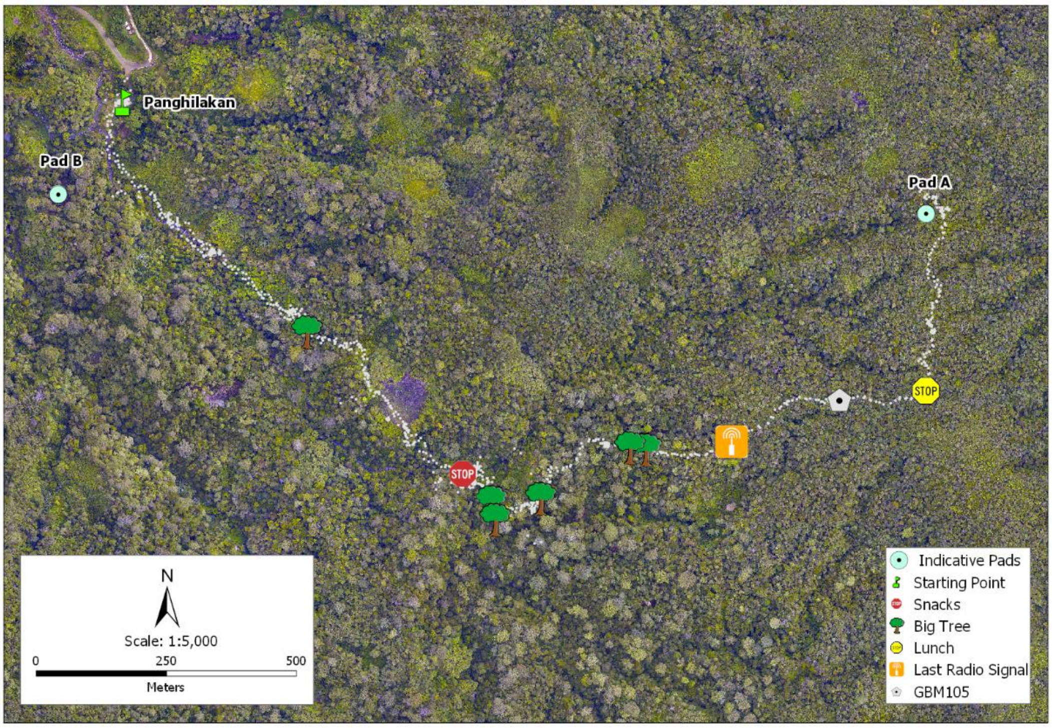


Figure 10: Plotted GPS track on 2016 LiDAR orthophoto.

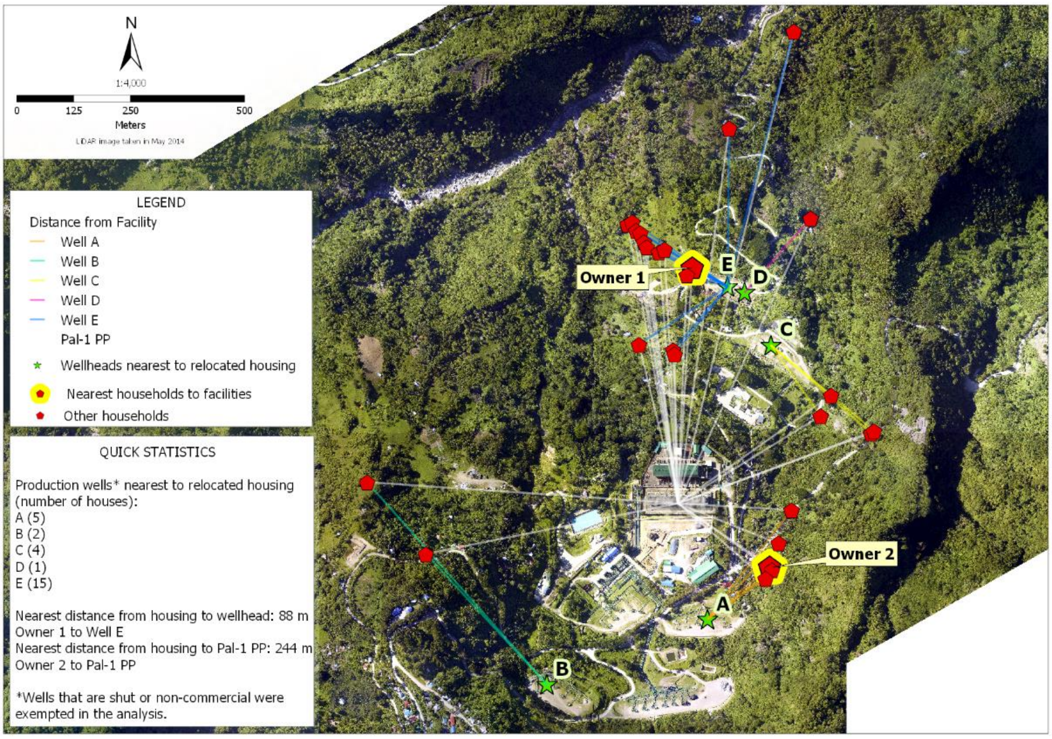


Figure 11: Map of relocated housing.

5. LIMITATIONS TO THE PRESENT USES

The current applications of LiDAR data have been mostly on spatial analysis and visual representation. However, utilization of the available LiDAR data is yet to be fully exhausted. There are also limitations when it comes to the LiDAR-derived data itself.

5.1 Utilization of LiDAR Data

Recall that the output of the LiDAR data included ground data. These are actually 3-dimensional point cloud data collected by the sensor during the survey campaign. There was also a DSM from the 2016 aerial survey campaign which contains elevation from terrain and vegetation features. Initial data exploration showed that the data could potentially be used further for other applications such as feature extraction and biomass estimation. There are many methods to exploit these data, such as those detailed by

Buenaobra et al. (2015) and Hamdan et al. (2015). For these applications, GIS practitioners in EDC can be further equipped through advanced training in LiDAR data processing. This would also entail additional specialized software that can manage pre-processing, configuration, and integration of LiDAR datasets.

5.2 Limitations in the 2014 and 2016 LiDAR-derived Data

It must be apparent by now that the greatest limitation of the 2014 and 2016 LiDAR-derived data is its staticity—the data, particularly, the aerial photos, are only a capture of a specific moment in time. Any changes after the specific day(s) in which the aerial photos were taken may not be well-represented. This is true especially for geohazard monitoring and even for monitoring growth or significant changes in the residential areas. Even changes in pad development, such as the presence of new cellars for newly drilled wells after 2014 are not captured. The frequency of survey campaigns conducted were also by demand. After 2016, no further LiDAR survey campaigns in SNGF were proposed and this is partially because of the high cost of investment. Taguines (2015) noted that SNGF has the highest data acquisition and processing cost per hectare due to its relatively smaller area (~6,000 Ha) compared to other EDC geothermal sites (~18,000 Ha to ~31,000 Ha).

The outputs provided are also not readily usable with ArcGIS Pro and ArcMap, the main GIS platforms used in EDC. For example, the ground data needs to be converted from .xyz format into feature class (multipoint data) or into .las files in order to maximize the LiDAR tools available in said software (Weitz and Taylor, 2017). Another limitation in the output is the difference in image rendering of the 2014 and 2016 orthophotos (see Fig. 12). The same parameters for image processing should have been used in order to achieve a seamless look when viewed together. The tiles of the orthophotos also contained unnecessary pixel values along the tile edge/boundary that made mosaicking (or stitching) of the 2014 and 2016 tiles challenging.

Furthermore, it would have been more beneficial if the outputs included 3D polylines of the pipelines in order to have a readily available reference map of pipelines in SNGF. Although pipelines were included in the digitization, these were limited to what could be seen on the aerial photos. Areas where pipelines were obscured by tree canopies or were otherwise indistinguishable were omitted. As an update, EDC has recently undertaken LiDAR-based 3D as-built surveys of all its surface facilities to further update their engineering data.

Figure 12: Comparison of 2014 and 2016 aerial image rendering.

6. CONCLUSION AND RECOMMENDATIONS

The experience of EDC, particularly in SNGF, with regard to LiDAR-derived data has proven to be very useful. Since these high resolution data were acquired, many routine tasks benefited from the availability of topographic data and aerial imagery. Improvements can be noted not only in the application on civil works, but also on resource management and compliance to social and regulatory requirements.

While it is undoubtedly a useful source of information, the data derived from the two survey campaigns could have been maximized further if, during the survey campaign proposal, the outputs were specified according to the end user's needs, such as the availability of ground data in the form of .las files, or the transformation of detected pipelines into 3D polylines. Informing the survey contractor of the main software or platforms being used to process LiDAR-derived data would also be helpful in determining which outputs to produce. Nonetheless, utilizing open-source GIS and remote sensing (RS) software should continue to complement the use of licensed software, as currently practiced for landslide hazard assessment (Amora, 2015).

On the application side, the digitized data from the aerial photos have increased the number of GIS data available for access in EDC's geodatabase. It should be noted, however, that the GIS data are lacking in attribute data. Digitized pipelines, for example only contain the length per digitized segment. Other pipeline configurations, such as type of pipeline, dimension, or total length need to be incorporated into the GIS data to maximize the available information. The created web maps could also be updated with other spatial data. For instance, plotting the location of first alert reports or incidents related to health, environment, safety, or security can show possible spatial relationships with potential geohazards, cluster of residential areas, and the like.

For future LiDAR survey campaigns, a more targeted approach in terms of what data needs to be acquired and identifying the objectives for acquiring such data need to be emphasized. As the outputs of the survey campaign are beneficial to many aspects of EDC's operations, it is imperative for such a holistic strategy to be devised. This also provides the advantage wherein all groups (e.g., engineering, resource management, corporate social responsibility) are working on the same high quality and reliable outputs (Ussher and Hochwimmer, 2015). Likewise, providing training and development to focal persons involved in map making and GIS data management are necessary to ensure that the LiDAR data is being used to its full potential. This should also include possible acquisition and learning of new tools and software which can process LiDAR data and derivatives, such as those discussed by Weitz and Taylor (2017) and Hedges and Crawford (2017).

Finally, LiDAR is just one of the RS methods which can aid in geothermal resource assessment and monitoring. To complement it, other RS methods or surveys should be regularly employed. Thermal infrared (TIR) imaging to detect heat surface anomalies, interferometric synthetic aperture radar (InSAR) to monitor crustal deformations, and multi-spectral and multi-temporal optical imagery to validate reforested areas and refine strategies of reforestation programs are some applications that EDC is already exploring and should continue to learn from.

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