CLIMATE- AND WEATHER-RELATED FACTORS IN MAIBARARA GEOTHERMAL OPERATIONS

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ABSTRACT

Implementing mitigating strategies of energy facilities to anticipated increases in extreme weather events and climate variability requires documenting which climatic factors affect facilities and understanding the process by which they impact specific equipment and operations. Such knowledge is vital if adaptations are to be effective in reducing potential losses in operational disruptions, business continuity and company profitability. In Maibarara, the effects of air temperature, wind patterns, rainfall, thunderstorms, and typhoons on two relatively new generating units – the 20MW Maibarara-1 (M1) commissioned in 2014 and the 12 MW Maibarara-2 (M2) in 2018 – are documented.

Though far from exhaustive, our study shows that increases in air temperature, even when seasonal, have the most direct, continuous, and substantive consequences, especially on their impact on cooling water and condenser performance. Extreme weather events like severe thunderstorms and typhoons also cause disruptions that can be significant but in a far less sustained manner. Moreover, the effects of weather and climatic factors on geothermal operations are mediated by the physical lay-out of the Maibarara project and its general environmental setting.

1. INTRODUCTION

In 2012, the Asian Development Bank called on the region's power sector to adapt to the increasing threats of climate risks citing electric power in the Asia–Pacific as "a vulnerable sector in a vulnerable region" (ADB, 2012, p xiii). Among power generation sources, the ADB report identified fossil fuel, nuclear, hydro, and wind power plants as especially vulnerable to climate sensitivities while listing geothermal and solar facilities as less susceptible to projected climate change impacts. In this paper, we report on selected climatic and weather-related factors in the operations of the Maibarara geothermal field in southern Luzon, the only new commercial geothermal development in the Philippines since ADB's 2012 call for action. We also document initial and practical mechanisms adapted in response to variations in the immediate atmospheric environment surrounding the Maibarara facility.

1.1 Location and Geographic Setting

The 32 MW Maibarara geothermal power project, ~70 km southeast of Metro Manila, comprises the 20MW M1 plant commissioned in February, 2014 and the 12 MW M2 unit that went on line to the Luzon grid in April, 2018. The general geologic setting, development history, and basic operational design of the project have been described elsewhere (Olivar et al., 2011; Maturgo, 2015; Maturgro et al., 2015; Paulino et al., 2015). In relation to this study's objectives, the important geographic characteristics of the project are the following: 1) location at ~200 m elevation on the western gently-dipping flank of Mount Makiling volcano rimmed to the north, east, and south by the volcano's foothills and open to the west coincident with its ring plain; 2) development is within the multiple-use zone of the Makiling National Park, bordered to the east by the forested core of the park and to the west by the ring plain undergoing rapid urbanization and commercialization; and 3) a tropical monsoon climate, with a dry season from January to May, and wet season from July to November; mean temperature in Mount Makiling ranges from 25.9ºC to 29.3ºC and annual rainfall averages 1,645 mm to 2,229 mm (Combalicer et al., 2010).

1.2 Facility Lay-out and Operational Scheme

A unique feature of the Maibarara project is its compact design and construction where nearly all operating components of the 32MW facility, save the transmission line, is contained within a 9-hectare area (Fig. 1). Due to land availability and ownership constraints, the limited area was factored in the project's design and construction, leading to reduced environmental footprint, shorter pipeline lengths, closer distances between infrastructures, faster construction completion, and more integrated subsequent operations and maintenance (Maturgo et al., 2015).

For the M1 facility, two production wells in the pad A steamfield's deep well-cellar supply two-phase fluids in the adjoining separator. A 370-m long steam pipeline conveys separated steam to the to the power station to the west. The plant's Fuji condensing turbine-generator produces electricity at 13.8kV which is subsequently stepped-up to 115kV in the nearby switchyard or substation (Fig. 1) before transmittal to the grid ~4 km away via 28-m high steel poles of MGI's own dedicated transmission line. Upstream, hot brine from the pad A separator is channeled to a silencer prior to dumping into a thermal pond for dilution and cooling before reinjection in pad RA wells.

The two M1 production wells in pad A actually produce steam equivalent to 27 MW. To fuel the M2 power station (Fig. 1), the excess 7 MW steam is piped into the M2 plant interface where it mixes with about 8-9 MW steam coming from the M2 separator supplied by a single production well in pad RA. As in M1, the 12 MW M2 plant output at 13.8kV is ramped up to 115kV by its own dedicated transformer in the site substation prior to grid delivery in the same transmission line. The pad RA thermal pond receives and cools down the separated hot brine from the M2 separator and cooling tower condensates from both M1 and M2 plants before being piped onto a pad RA reinjection well.

Figure 1. Overview of the 32 MW Maibarara geothermal facility, looking southwest. Extent of development is 613 m long (from left to just outside the right edge of photo) to 150 m wide (at center of photo). Note heavy tropical forest vegetation enclosing much of the facility which has an areal footprint of 9 hectares.

2. CLIMATE FACTORS IN MAIBARARA

Power facilities, especially generating plants, are normally expected to operate for 25-30 years. Such life spans make them vulnerable to growing risks from climate change and extreme weather events. For example, higher air and water temperatures can reduce generation output through their effect on cooling efficiency, if not through outright reduction in output of hydro power stations due to enhanced evaporation (ADB, 2012). Similarly, more frequent storms will subject power stations and transmission facilities to higher risk of damages and outages. Thus, for new facilities such as Maibarara, documenting and understanding how such environmental changes relate to day-to-day operations become even more critical to ensure that the plants can overcome these challenges and operate profitably and safely in the years ahead. Among the climate or weather factors relevant for consideration in Maibarara are typhoons, rainfall (and related flooding), thunderstorms, air temperature, and wind patterns.

2.1 Typhoons

Since starting commercial operations in February, 2014, the Maibarara facility has faced at least nine (9) typhoons; the tracks of six that made landfall in Luzon island are shown in Figure 2. Two of those storms crossed close to the Maibarara facility with contrasting impacts. When Typhoon *Glenda* (international name *Rammasun*) hit the region on July 15, 2014, just five months after start of commercial operation, it was packing winds with maximum speed of 120 km/hr and drenching the area with 160 mm of rainfall. The storm tripped the power plant and also ripped away the cooling tower sidings (Fig. 3). The susceptibility of geothermal cooling towers to storm impact in the Philippines was also seen in 2009 Typhoon *Yolanda's* (*Haiyan*) damages to the cooling towers in EDC's Leyte geothermal field (Shoshan, 2015). Two years later, Typhoon *Nina* (*Nock-ten*) hit the site on December 26, 2016 with wind speed of as much as140 km/hr and 39 mm of rainfall but did not cause any significant damages.

On the other hand, storms crossing Luzon hundreds of kms north of Maibarara, such as Typhoon *Ompong* (*Mangkhut*)

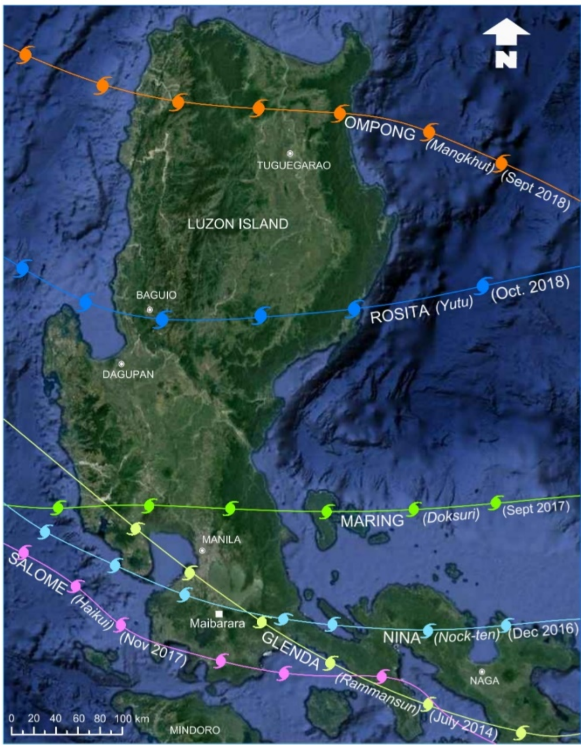

Figure 2. Tracks of selected typhoons crossing Luzon island, 2014-2018, with international storm names in parentheses and italics.

Figure 3. Cooling tower sidings of 20MW Maibarara-1 plant blown away during Typhoon *Glenda* in July 2014.

and Typhoon *Rosita* (*Yutu*) in 2018 inflicted some damages to MGI's assets due to rain-induced flooding.

2.2 Rainfall and Flooding

In the Philippines, excessive rainfall is by far the most common and significant trigger of flooding. Annual rainfall in the country ranges from <2,000 mm in western Philippines to >4,000 m on the east with a mean value of 2,379 mm (Delfin, 2005). In Maibarara, the highest annual rainfall amount recorded is 3,047 mm in 2017 while the lowest full year rainfall to-date stands at 956 mm in 2018 Fig. 4).

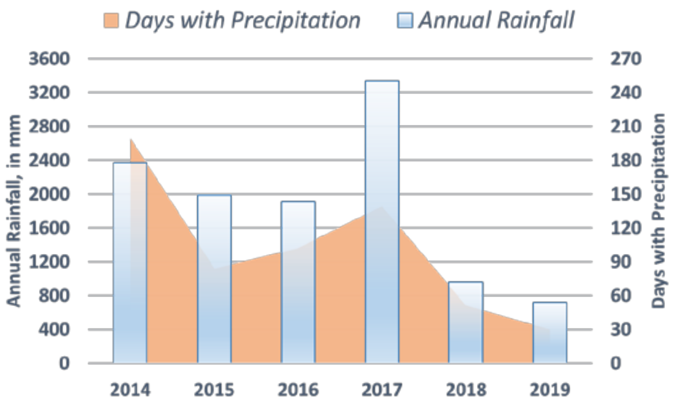

Figure 4. Plot of annual precipitation (in mm) and number of days with measured precipitation, from 2014 to 2019 (to-date).

Rain-induced flooding has not been a major recurring operational problem in Maibarara. This is largely because the facility sits at a relatively high elevation, no large and permanent rivers drain the site, and a well-built and maintained drainage system rings the 9-hectare operating facility. However, MGI's Logistics Station, its administrative compound, located ~4 aerial km southwest of the geothermal plant, had been inundated by heavy rains from Typhoon *Ompong* (*Mangkhut*) in September 2018 and to a lesser extent by Typhoon *Rosita* (*Yulu)* a month later due to poor road drainage in Sto Tomas town. Despite the flooding of its office, mess hall, and staff house, power generation and operations were unaffected.

2.3 Thunderstorms and Lightning

Although rare, lightning from severe thunderstorms are observed on site and in a few cases have caused operational problems (Table 1). Those events tended to occur during the the dry season, in the early part of the year.

High current and voltage from lightning strikes likely exceed the grounding capacity of some field devices leading to damages in some electrical components, such as transmitters.

Table 1. Lightning-related problems recorded during severe thunderstorms.

Date	Equipment Affected	Observations
10 Jan. 2015	MB-14RD Pressure Transmitter	No readout during thunderstorms
22 May 2019	Power Plant Gland Steam Controller	Transient alarms in distributed control system
22 May 2019	Power Plant Lube Oil Temperature Control Valve	Transient alarms in distributed control system
22 May 2019	Transmitters in M1 Separator and Blow-off Valves	Damage to DIN carrier and power conditioner module

2.4 Air and Water Temperature

As reported in other studies (Contreras-Lisperguer and de Cuba. 2008; McColl and Palin, 2009) one possible impact of climate variability in geothermal power generation is the reduced efficiency of cooling water system due to increases in air and water temperature. In Maibarara, the cooling water system installed in the M1 and M2 units are designed and operated along the lines well described by Richardson et al. (2012). Specifically, the installed cooling towers are both multi-cell, mechanical draft, counter-flow type that sprays and drops mixed condensates from their tops to the basin. From there a cold well channels the cooled fluids to the condenser to contact and condense the steam exhausted by the turbine. The mixed cooling water and condensed steam are then pumped back into the cooling tower to re-start the cycle.

In M1, the cooling system has been designed by Fuji for an average wet bulb temperature of 25°C, cooling water temperature of 31°C, and condenser vacuum pressure of 0.122 ksc (abs). The M2 cooling unit used slightly higher design parameters, namely wet bulb temperature of 28°C, cooling water temperature of 34°C, and condenser vacuum pressure of 0.142 ksc (abs). This change in the design parameters for the M2 cooling system to be installed in the same specific area and using similar processes as the M1 cooling tower was due to a documented localized increase in mean ambient temperature on site by 2016 when Fuji was designing the M2 plant.

The performance of the cooling tower and the condenser for the M1 (Fig. 5a) and M2 unit (Fig. 5b) between late 2017 and mid-2019, with M2 already operational, cannot be ascribed to weather-related factors alone. But when known plant equipment, grid, or resource-related effects are isolated, the effects of changes in air and water temperatures on the performance of the cooling system are quite direct and significant. For instance, between April and July 2019, wet bulb temperature exceeded the designed temperature of 25°C and 28°C in the M1 and M2 cooling towers, respectively.

Cooling water temperatures in both units increased correspondingly (Fig.5a-b) and this insufficient cooling deteriorated the condenser performance. To compensate for the increased condenser pressure, turbine inlet pressure had

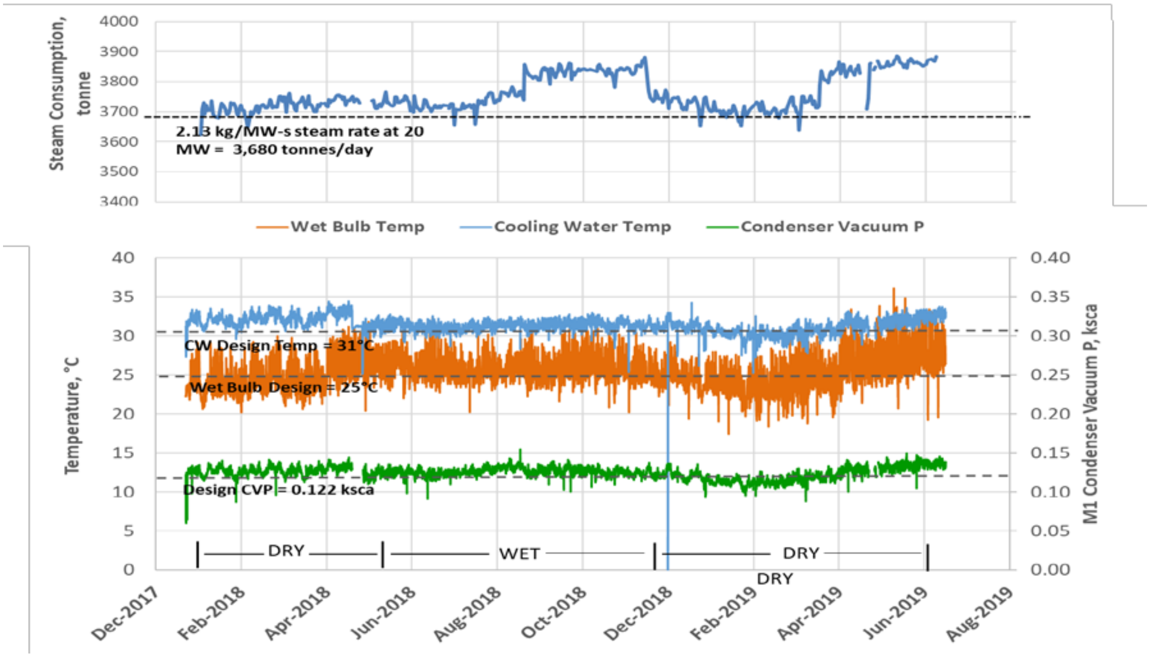

Figure 5a. Wet bulb temperature, cooling water temperature, and condenser vacuum pressure of M1 cooling water system, Dec. 2017 to early Aug, 2019, with corresponding M1 unit steam consumption.

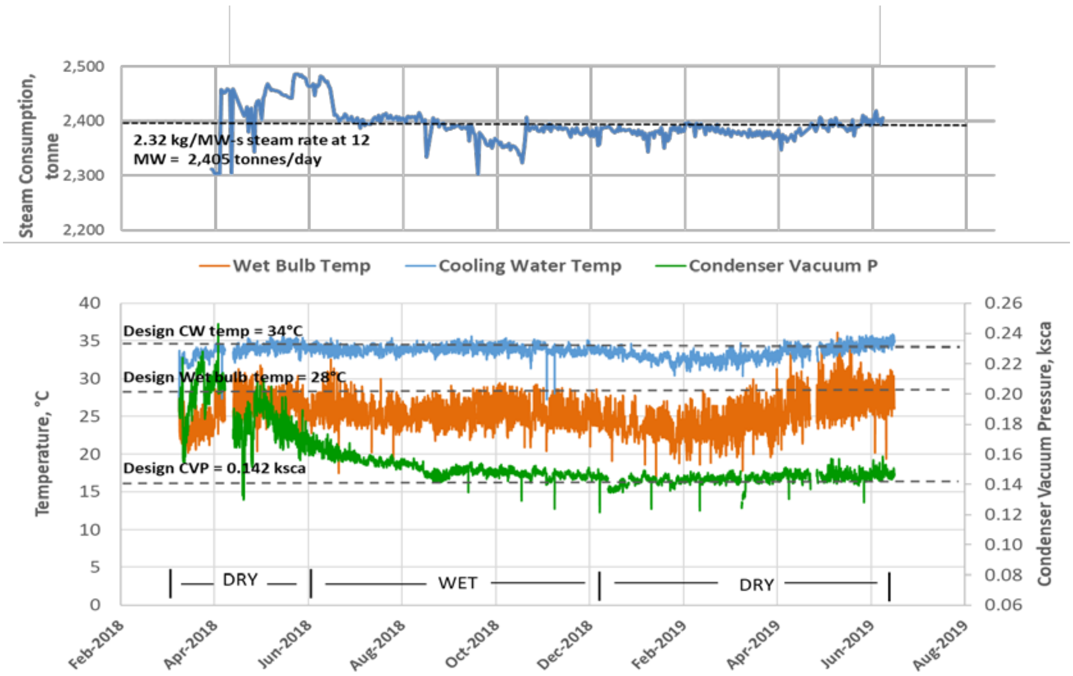

Figure 5b. Wet bulb temperature, cooling water temperature, and condenser vacuum pressure of M2 cooling water system, April 2018 to early Aug. 2019, with corresponding M2 unit steam consumption.

to be increased in order to allow more steam to generate the same MW output. In short, given constant operations or equipment functioning, increases in ambient air temperature during late summer in Maibarara lead to higher steam consumption than normally required.

On the other hand, M1 cooling water temperature and condenser vacuum pressure were high from Dec. 2017 to April 2018 even when wet bulb temperature was steady (Fig. 5a). This was due to the high turbine chamber pressure ratio which necessitated a higher turbine inlet pressure. Similarly, the very high condenser vaccum pressure in M2 during the early months of its commercial start-up was linked to high

NCG content of steam. This high NCG content is gradually declining over time which reflects as well on the decreasing condenser vacuum pressure in M2 up to present (Fig. 5b).

Figure 6. Location of Maibarara geothermal facility on the western flank of Mt. Makiling and surrounding natural and built environments. Contours show expected H_2S concentrations in ppm arising from Maibarara operations (Pahunang, 2018). Note H_2S values, especially in the outlying communities and industries, ranging from 0.01-0.03 ppm, are well below the government ambient H_2S standard of 0.07 ppm.

2.5 Wind Pattern

The wind pattern in the area consists of east-northeast winds predominant from October to April and southwesterly winds from June to September (Pahunang, 2018). In May, during the transition from the northeast to the southwest monsoons, winds originate from the west or south. In terms of wind class frequency, light winds of 1-5 m/s speed predominate ~76% of the year. But during the peak southwest monsoon months of July-August and peak northeast monsoon months of December and January, higher wind speeds between 5-8 m/s become more frequent.

The importance of wind patterns on Maibarara routine operations lie in at least two areas : 1) the dispersion of daily H_2S emissions to outlying areas, and 2) the effects of occasional well test discharges on adjacent infrastructures and vegetation.

Modelled dispersion of H_2S from Maibarara sources, including cooling towers, silencers, and rock mufflers, shown in Figure 6 predict H_2S values in the outlying residential and industrial areas to be 0.01-0.03 ppm, well below the government's imposed limit of 0.07 ppm (Pahunang, 2018). This prediction is validated by on-ground independent 3rd-party monitoring where ambient H_2S values are not detected (or below instrumental detection limits) in four different points downwind of Maibarara.

Two-phase plumes from well testing discharges, though infrequent in Maibarara, can also have important adverse though transient effects.

Figure 7. Discharge test of Well MB-15D.

In early Aug., 2017, fluids from MB-15D well discharge (Fig. 7) were carried by prevailing winds and later deposited salts on the post insulators of the nearby switchyard and transmission poles. These deposits apparently acted as conductors that caused electrical current to cross across these equipment, leading to a line-to-ground fault that tripped the plant. Apart from the cleaning and removal of the salts on the insulators as the plant was on shut-down, some of the insulators were damaged and had to be replaced.

site, such minimal damage is due to the very good drainage system ringing the facility and the use for landscaping of vertiver grass, a pereniial bunchgrass whose roots 2-4 m deep help in runoff retention and soil protection. The flooding of MGI's administrative grounds in 2018 have not been repeated by simple engineering improvement in the camp's drainage system.

Table 2. Summary of effects on Maibarara operations of selected climatic or weather factors. Relative frequency and severity are ranked from 1 (most frequent ; most severe) to 5 (least frequent, least severe).

Climate or Weather Factor	Operational Impact	Relative Frequency	Relative Severity	Adapation
Typhoon	Outages, Damage to Cooling Tower (CT), Transmission Pole (TL)	4	2	Insurance provision ; strengthening of TL footings and CT sidings ;
Rainfall (and Floods)	Minor landslides, road scouring, inundation of staff quarters	2	5	Drainage systems enhancement and maintenance; vertiver grass landscaping
Lightning and Thunderstorm	Transient signal loss to physical damage of electronic components	5	4	Maintenance and testing of grounding cables
Air and Water Temperature	Sub-optimal condenser performance ; lower plant output ; more chemical dosing	1	1	Increase in turbine inlet pressure ; optimal chemical dosing system ;
Wind Pattern	Outage (in worst case) ; transient effects of well discharge on vegetation	3	3	Discharge protocol modifications ;

3. IMPACTS AND ADAPTATION

Table 2 summarizes the operational effects of climate or weather factors in Maibarara, including their relative frequency and severity as well as the corresponding adaptation that MGI took for each.

Although wreaking the most physically dramatic damages, severe typhoons are actually infrequent in Maibarara. For example, of the at least 9 typhoons that affected Luzon island since start of operations, only one of the two that swept through the site caused severe damages. The cooling tower damage described earlier is symptomatic of the typhoon's tendency to hit tall or high-standing structures including communication towers, building roofs, and transmission poles which all occurred in Maibarara due to Typhoon *Glenda*. The plant tripping during this storm, however, was not due to damages within the Maibarara facility but because of sections of the Luzon grid transmission downed by storm elsewhere. Damages from Typhoon *Glenda* led MGI to enhance the footings of our transmission poles, strengthened the sidings and vertical piping inside the M1 cooling tower, and to modification of our insurance coverage.

From 2014 to 2018, the total annual rainfall and the number of days with precipitation appear to be generally decreasing (Fig. 4). Although it can be said that rainy days are still more frequent than actual stormy days in Maibarara, the effects of rainfall by themselves and through floods have been much more muted than those from typhoons. On the power facility

Severe thunderstorms with accompanying lightning have been the least frequent weather event and with equally lesser monetary loss in Maibarara. Damages range from temporary loss of electronic signals, equipment alarms, to actual damage to some electrical and electronic components such as field transmitters. Nonetheless, the only realistic response that we have implemented to date to minimize damage is the frequent testing and maintenance of the equipment's grounding cables.

Presently, the most important climate variability with very significant and recurring impact on Maibarara operations is increases, even if seasonal, in air and water temperature. During late summer (April to June) up to July, increased cooling water temperature results in sub-optimal condenser performance. To produce the same MW of power, turbine inlet pressure has to be temporarily raised to allow more steam input because of this poor condenser performance. A rough and preliminary estimate suggests that every 0.1 ksc (g) increase in inlet pressure translates to an additional 0.25 kg/s steam consumption. Separately, insufficiently cooled main cooling water requires more caustic soda and biocide treatment to maintain water pH and control bacterial fouling, respectively. After a few years' of tentative chemical dosing treatment, MGI with the help of Thermal Chemistry Ltd. devised a systematic and effective dosing program that addressed algal growth, sulfur deposition, and pH concerns (Addison, 2016).

Daily dispersion of H_2S emissions and the occasional discharge plumes from well testing are the operations where wind patterns have the most impact. Predominant wind directions preferentially disperse the emissions to the northeast and southwest where ground concentrations dilute the H_2S to less than 0.01-0.03 ppm, much lower than the regulatory limit of 0.07 ppm. To minimize adverse impacts of occasional well tests on electrical facilities, MGI revised its discharge protocol. The discharge blow-off spool was restructured to allow for a “vertical” discharge angled away from the switchyard and transmission poles. And though it is unavoidable to discharge a well once heat-up conditions are reached, MGI personnel will schedule and time the discharge considering forecasted wind speeds and directions. And in extreme cases where discharge will waft through the substation and electrical posts, protocol gives them authority to limit or cease the discharge operation to avoid further damages.

4. CONCLUSION

Our study, though far from exhaustive, has identified key climatic factors and weather events that have consequences in the short operational life thus far of the 32MW Maibarara geothermal facility. In part, these factors impact Maibarara due to the facility’s natural setting and the physical development of the project in a confined area, resulting in facilities and equipment built close to one another.

Seasonal increases in air and water temperature from late summer (April) to July result to higher cooling water temperature and condenser pressure than designed. This has the most direct, recurring, and economically significant impact because of higher steam consumption necessitated by increasing the turbine inlet pressure to adapt to this changed operating environment. Though far more infrequent, very strong typhoons and severe thunderstorms also cause substantial though short-term damages. Excessive rainfall, floods, and wind also have their varying operational effects and economic consequences that are less severe than those posed by temperature increases and strong typhoons.

The adaptive mechanisms that MGI took in response to the operational impacts of these climatic phenomena include physical engineering measures, modifications in operational protocols, and appropriate insurance coverage. The underlying adaptive philosophy is to undertake immediate and practical mitigating measures given that some of the ultimate causes of such climate variability or extreme weather on site maybe too complicated or too time consuming to resolve.

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REFERENCES

Addison, D. Maibarara Geothermal Inc. (MGI) – Maibarara Geothermal Power Station (MGPS) Cooling Water and Steam Chemistry Review. *Thermal Chemistry Report Number 20152010*, 86pp. (2016).

Asian Development Bank (ADB). *Climate Risk and Adaptation in the Electric Power Sector*. Mandaluyong City: Philippines: Asian Development Bank, 82 pp. (2012).

Combalicer, E.A., Cruz, R.V.O., Lee, S. and Im, S. Assessing climate change impacts on water balance in Mount Makiling forest, Philippines. *Jour Earth Syst Sci*., 119, pp. 265-283. (2010).

Contreras-Lisperguer, R. and K. de Cuba. The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region. Department of Sustainable Development, Organization of American States. www.oas.org/dsd/Documents/Effects_of_ Climate_on_Energy_DSD_Energy_Division.pdf. (2008).

Delfin, Jr. F.G. A review of the nature and impact of environmental disasters in the Philippines. *Phil. Geog Jour*, 49, pp. 1-42. (2005).

Maturgo, K. M. Converting well MB-15RD from reinjection to production, Maibarara geothermal field. *Proc. GEOCON 2015.* Makati, Philippines: Geological Society of the Philippines. (2015).

Maturgo, K. M., Fernandez, L. D., Olivar, M. M., Esberto, M. B., Callos, Jr., P. G., Isip, H. L., & Llenarizas, L. J. Challenges in the design and management of a 20-MW geothermal field: the Maibarara Geothermal Field (Philippines) experience. *Proc. World Geothermal Congress 2015.* Melbourne, Australia. (2015).

McColl, L. and E. Palin. *Vulnerability of global energy infrastructure to climate change—Scoping study.* Prepared by Met Office Hadley Centre for the Foreign and Commonwealth Office, UK. December (2009).

Olivar, M. M., Fernandez, L. D., Cruz, D. H., Isip, H. L., Tilos, R. E., Del Rosario, E. P. Resource characterization, reserve estimation and development scheme of Maibarara Geothermal Field, Philippines. *Proc 9th Asian Geothermal Symposium.* pp. 67-75. Kagoshima, Japan. (2011).

Pahunang, R.S. *Air Dispersion Modeling Study for the Maibarara Geothermal Power Plants located in Barangay San Rafael, Sto Tomas, Batangas*. (2018).

Paulino, I. C., Jr., Morala, P. E. C., Chavez, F. B., Murakami, T., Yamada, S. Combination of axial exhaust turbine and direct contact condenser: Maibarara Geothermal Power Plant. *Proc. World Geothermal Congress 2015.* Melbourne, Australia. (2015).

Richardson, I., Addison, S., and Addison, D. Biological Control of Cooling Water in Geothermal Power Production. *Proc. 2012 New Zealand Geothermal Workshop,* Auckland, New Zealand (2012).

Shoshan, G. Binary Geothermal: A Reliable Power Solution During Natural Disasters. *Proc. World Geothermal Congress 2015.* Melbourne, Australia. (2015).