Overview of ground-based generator towers as cloud seeding facilities to optimize water resources in the Larona Basin

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Abstract. The Larona River Basin which cover an area of 2477 km^2, including the three cascading lakes: Matano, Mahalona, and Towuti Lakes, is a strategic watershed which acts as the water resource for three hydropower plants that supply 420 Megawatt of electricity to power a nickel processing plant and its supporting facilities and electricity need of the surrounding communities. The maximum and minimum operating levels of Towuti Lake are 319.6 meters (asl) and 317.45 meters (asl) respectively. Total live storage between these two elevations is 1,231,500 m^3. Currently, the operation average outflow from Towuti Lake to the power plants is 130.1 m^3/second which is resulting in a total annual outflow volume of 4,103,000 m^3. By comparing the outflow volume with the live storage volume, it is obvious that present live storage has a limited capability to carry over the capacity from wet to dry years. During a dry year, the outflow drops to 100 m^3/second. Thus, the optimization of water resources management in the Larona Basin is important to fulfil the need to produce the energy sources. To deal with the decrease of the Lakes water level, the Weather Modification Technology in the form of cloud seeding is needed to produce rain that will increase the water volume in the Lakes. The dispersion of cloud seeding material into the targeted clouds can be done by surface seeding using the Ground-Based Generator (GBG) which utilize towers to release cloud seeding materials. The tower locations should be in certain altitude or higher locations and amounts in order to operate effectively with optimum results. The water discharges generated from the process is expected in accordance with the planning. The weather modification process is inefficient when the discharge is overflow the spillway channel. Cost incurred is in approximate of US\$ \$11,133,258.36 if the company is utilizing Diesel Power Plant and Steam Power Plant instead of the weather modification technology.

1 Introduction

The Larona River Basin which cover an area of 2477 km^2, including the three cascading lakes: Matano, Mahalona, and Towuti Lakes, is a strategic watershed which acts as the water resource for three hydroelectric power plants (PLTA) which supply electricity needs

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for PT. Vale Indonesia Tbk's nickel mining operation and its surrounding areas [1]. The total installed power in the hydropower plants is 420 MW, consisting of a 3x60 MW from the Larona power plant, 2x65 MW from the Balambano power plant and a 2x55 MW from the Karebbe power plant, all of which are in cascade systems [1, 2].

The three hydropower plants operate by utilizing the water resources from the aforementioned cascading Lakes in the Larona River Basin channeled through the Larona River to the plants' turbines (Fig. 1). The drop of the Lakes water volume will affect the optimal operation of the hydropower to efficiently support PT. Vale Indonesia's nickel ore smelting operations in Sorowako. Lower than average rainfall has significantly impacted the Matano and Towuti Lake's water volume [1, 3]. Minimum elevation limit of Towuti Lake for optimal operation of the hydropower plants is 318.00 meters. The drop of the water level in the Towuti Lake will disrupt the capacity of the three PLTA to serve the need of nickel production processes. In turn, PT. Vale Indonesia will need to operate alternative electricity sources, like diesel generators and other sources which drive higher costs [1, 3].
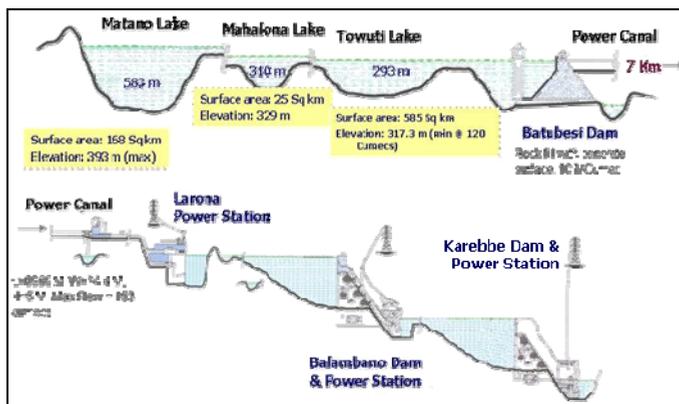

Fig. 1. Three lakes and hydro power plant cascade systems.

To maintain the water level of the Lakes for the PLTA to operate in their optimum capacity, the company need to utilize Weather Modification Technology (TMC) as an integrated part in the management of water resources. TMC is terminology for human effort to modify weather with a specific purpose through cloud seeding, to increase the intensity of rainfall in a designated area. Seedling materials are fired to the clouds through aircraft or ground-based seeding facilities known as the Ground-Based Generator (GBG) [4-8].

2 Study of weather modification technology (TMC) using GBG

2.1 Ground-based generator towers

The static weather modification technology system or better known as Ground-Based Generator (GBG) is an on-surface, static medium or system to disperse seeding material into clouds which takes advantage of valley winds and slopes topography. GBG technology in cloud seeding can reduce our reliance on aircraft usage, the most expensive component in the weather modification operation. This alternative technology has the advantage of being much cheaper than using an airplane [4-8].

GBG technology is intended primarily for cumulus and orographic cloud seeding around the mountainous area that cannot be reached by aircraft for safety reasons. The results of this study have shown that TMC utilizing a static system of GBG is quite useful to complement the aircraft-based TMC, as long as it meets the geographical requirements

and the method of cloud growth. The seed ingredients used in GBG technology are hygroscopic flares that are burned at the top of towers (Fig. 2 and Fig. 3). The particles from the combustion of hygroscopic flares, carried away by the valley wind, will be dispersed into the targeted clouds around the tower locations [9].
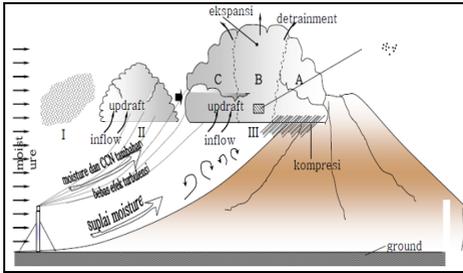

Fig. 2. GBG towers illustration.

Fig. 3. GBG towers PT. Vale Indonesia.

2.2 Geographical conditions

The target area is the Larona River Basin which covers a 2477 km^2 area (Fig. 4). The catchment and lake area are presented in Table 1. Along the Larona River, there are three large lakes as seen in Fig. 4, i.e. Matano Lake (165.9 km^2), Mahalona Lake (23.6 km^2), and Towuti Lake (562.2 km^2). Larona watershed is geographically located near the equator and flanked by the Bone Bay to the West, and Tolo Bay to the East makes this area has distinctive rainfall characteristics. The Larona River Basin is on a mountainous range with an altitude of between 500 to 1300 meters above sea level [10].

Fig. 4. Matano, Mahalona, and Towuti Lake as a target area for cloud seeding.

Table 1. Catchment and lake area of Larona River Basin.

Catchment area	km^2	Lake area	km^2
Towuti lake outlet	2447	Matano	165.9
Towuti lake outlet to Batubesi Dam	29.9	Mahalona	23.6
Upper catchment to Batubesi Dam	2477	Towuti	562.2

2.3 Natural rain process

Evaporation drives by convection or by the presence of hills or mountains will make the moisture condense at a certain level. As it is hygroscopic, and when condensation takes place, the particles will turn into liquid drops (droplets) which then collectively form

clouds. Provided there is sufficient humidity, especially in the layer below the cloud base, condensation will turn the droplets to a size of about 30 microns which physically visible in the form of more clouds. Shall the particles grow more massive, by about 40-50 microns, the particles will drop faster and act as "collectors" in their way down as they will attract other smaller liquid drops into much larger drops (the collision process). This process is reciprocated and propagated to all parts of the cloud and fall like the rain with a drop size of about 1000 microns or greater [9, 11-17].

2.4 Types of clouds for seeding

Targeted clouds in the TMC activities are active cumulus (Cu) which are characterized by their cauliflower-like shapes (Fig. 5). The cloud's area formed from convection processes. The cumulus clouds are divided into three types [11], namely 1) Strato cumulus (Sc), that is cumulus cloud in the formation process, 2) Cumulus, 3) Cumulonimbus (Cb), that is a huge Cumulus cloud or several huge cumulus clouds which merge into a gigantic one. The cauliflower-like Cumulus clouds (Cu) are clouds targeted as seeding clouds in the TMC activities. These clouds are categorized as low clouds since they have a base height lesser than 2 km. Cb is a low cloud which grows vertically with peaks reaches high clouds.
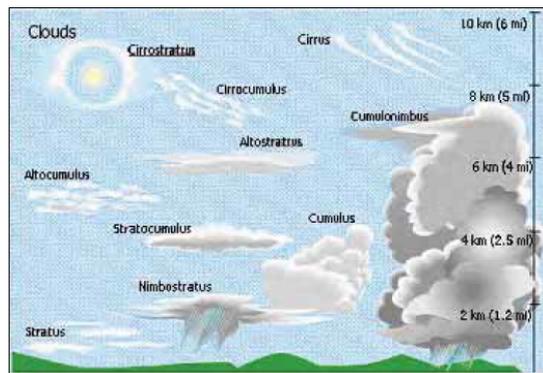

Fig. 5. Types of clouds based on characteristics and altitude.

2.5 Hydropower operation

The current operation of the Larona Hydroelectric Facilities relies on the active storage in Towuti Lake. The maximum and minimum operating levels of Towuti Lake are 319.6 meters (asl) and 317.45 meters (asl) respectively (Fig. 6). Total live storage between these two elevations is 1,231,500 m^3. Currently, the average operation outflow from Towuti Lake to the power plants is 130.1 m^3/second which is resulting in a total annual outflow volume of 4,103,000 m^3 [1, 3]. By comparing the outflow volume with the live storage volume, it is obvious that present live storage has a limited capability to carry over the capacity from wet to dry years. Routing studies support this observation. During a dry year, the outflow drops by 100 m^3/second. The total available flow from the Larona Basin in average is 138 m^3/second per year, 7.9 m^3/second of which is spilled from the Batubesi Dam. An increase in available storage volume would increase energy production by eliminating or at least reducing the spill. Thus, an increase in volume will expand the average rate of flow to the power plant by the ratio of a spill to average flow (7.9/130.1) or 6.07% [1, 3].
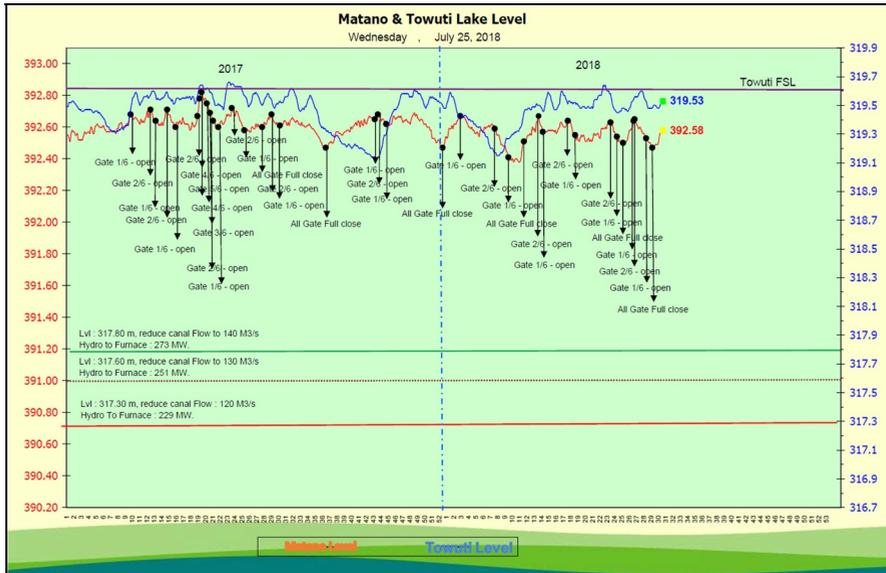
Fig. 6. Matano and Towuti lakes level.

3 TMC implementation

Prior to implementing the weather modification/ cloud seeding technology, some studies had been carried out such as to locate the towers site and clouds in the target area, to gauge the rainfall rate and rain prediction, as well as to analyze the economic factors, especially the incurring operating costs shall the technology fails to be implemented [2, 8].
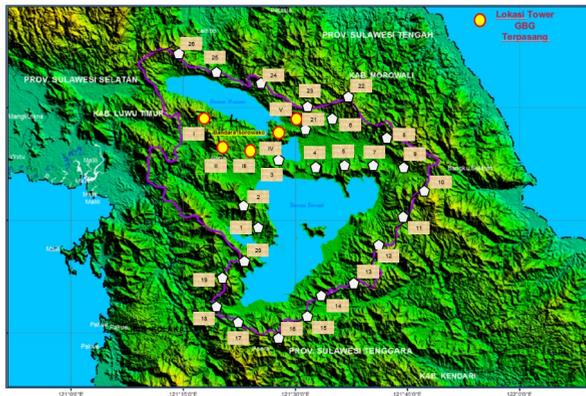
3.1 Plotting tower location

Fig. 7. Plotting tower location in Larona River Basin.

GBG tower locations are selected according to the aspects of cloud growth potential and local air circulation system to optimize the operation of seedling materials projected from the top of the GBG towers into the clouds through the air flow system around the locations. To select the locations of GBG tower (Fig. 7), during the initial stage (design), the followings are considered: limited to an area of 2477 km^2, the presence of clouds in the area

with an altitude < 2 km from the ground surface of site locations, the height of the tower measured from sea level (potentially > 300 meters) [2, 6-8, 18].

3.2 Existence of clouds in target areas

The presence of clouds above the Larona watershed is determined by competent experts on radar monitoring based on a full day (morning to evening) observations of satellite imagery and airport radar. Currently, radar monitoring is used for aircraft-based cloud seeding to identify potential rain-clouds, including the clouds locations, size, and movement. Meanwhile, GBG Towers operation has not utilized the airport radar. Historical clouds data will need to be obtained from the Climatology and Geophysics Meteorology Agency to determine the right location of the GBG Towers. In that way the facilities are situated close to clouds or be able to trap the clouds and produce sufficient raindrops, to increase the normal water level feed to the hydropower plants. Here is one example of data from BMKG regarding cloud conditions (Fig. 8) [6, 11, 15].
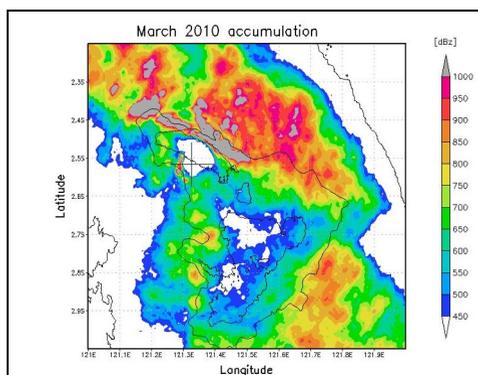

Fig. 8. One month accumulated data during March 2010.

3.3 Constraints variable and objective function

The objective function of this research is to optimize the location of the GBG Tower including the number so that it matches the target of cloud seeding with flares so that the clouds can rain and fall in the Lake area which serves as a water supplier to the Hydroelectric Power Plant. Before determining its purpose function, the following are the equations of the variable and its constraint functions [12].

3.3.1 Larona river basin

Determine the constraint variable for the lake water level and elevation as follows [1]:
a. Limitation of Larona Watershed Area: $A < 2477 \text{ km}^2$.
b. The expected water level (target elevation) is between the minimum water level of 317.45 m above sea level and a maximum elevation of 319.6 m above sea level or 317.45 m above sea level < Target Elevation < 319.6 m above sea level.

3.3.2 GBG tower and flare material

Determine the variable constraint for 1 GBG Tower capacity and flare material [2]:
a. The area affected by rain with a circular area with r (radius) is: 1 km^2.

b. The number 1 of the GBG Tower contains as many as 8 sticks of flares.
c. Estimated number of 1 flares can produce rainfall of 1-5 mm/hour, if 8 flares, the resulting rainfall is 8-40 mm/hour.
d. The duration of cloud seeding by GBG Tower for 4 hours.

3.3.3 Coordinate and elevation of tower points

Effective tower location based on topographic conditions and historical cloud data are [2]:
a. Cloud height from the tower point coordinates < 2 km.
b. The elevation of the tower point is > 300 m above sea level.

3.3.4 Constraint function

Some equation functions (constraints) obtained from the constraint variables are [1, 2, 19]:
a. The target elevation is the expected water elevation following the GBG Tower operations in the Larona river basin [1].

$$317.45 < (R.10^{-3}).n + 317.45 < 319.6 \qquad (1)$$

where R = Rainfall (mm), n = Total of GBG Towers.

b. The flare shooting from the GBG Tower will produce rain that fall circularly in the radius of the towers, so the following equation is used to calculate the impacted areas which are limited around the Larona river basin [2].

$$\Pi. r^2 \ x \ n < 2,477 \qquad (2)$$

where Π = Phi (22/7), r = Circle radius (km), n = Total of GBG Towers.

c. The volume of water in Towuti Lake derived from the difference between the minimum and maximum elevations is used in the equations to calculate the addition of rainfall generated from the GBG towers operations [1, 2]:

$$A. \ n. \ R < V \qquad (3)$$

where A = Area of Towuti Lake (km^2), n = Total of GBG Tower, R = Median rainfall flare seeding for 4 hours (mm), V = Towuti lake volume of between minimum and maximum elevation (m).

d. Debits generated by towers must be greater than the discharge required by the hydroelectric power plant [1]:

$$n. \ Q_{tower} > Q_{hydropower} \qquad (4)$$

where n = Total of towers, Q_{tower} = Debit 1 tower (m^3), $Q_{hydropower}$ = Debit hydropower (m^3).

3.4 Objective function

Some constraint variables and constraint functions of the previous equation are concluded that the objective function can be formulated as follows [2, 4-7]:

$$F \ (n) = Max \ (n. \ R) \qquad (5)$$

where F (n) = Function number n GBG Tower, R = Rainfall resulting from flare seeding by GBG Tower (mm).

4 Results and discussion

Based on the constraint variables, the function of the constraints and objective functions of the equations above, the number of towers to be installed optimally and adjusted to the cloud positions can be determined. The amount of additional rainfall will be calculated using the Weibull program [1-7, 19].

4.1 Total towers

By calculating the known values, such as the radius of the area affected by cloud seeding via the tower r = 1 km, seeding with 8 flares on 1 tower that produces rainfall (R) between 8-40 mm, 4 hours of seeding duration and the resulting R in estimate of 32-160 mm, the median value of R is 96 mm. If R-value is included into Eq. 1 and Eq. 3 and the area of Towuti Lake of 562.2 km^2 plus the volume of water between the minimum and maximum elevations of 1,231,500 m^3 is included in Eq. 4, the three equations depicted in the coordinate diagram will resulted in the number of towers to be installed: n = 21 towers.

4.2 Monitoring additional rainfall

To ensure additional water level (%), cloud seeding result will be presented in the following formula, considered the number of GBG towers and its location are determined [18]:

$$Q = ((Qa - Qp)/Qa) \times 100\% \qquad (6)$$

where Qa = Actual inflow (m^3/sec) when there are TMC, Qp = Prediction of inflow (m^3/sec) if there is no TMC, Q = Addition of inflow (%).

Table 2. Prediction inflow (m^3/sec) Larona River Basin using by Weibull.

Probability	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
30%	145.81	162.42	235.96	330.05	287.27	246.55	153.88	101.62	74.70	81.31	155.05	178.41
40%	128.31	142.90	207.64	290.45	252.80	216.96	135.41	89.43	65.74	71.55	136.45	157.00
50%	116.65	12.94	188.77	264.04	22.82	197.24	123.10	81.30	59.76	65.05	124.04	142.73
60%	100.32	111.75	162.34	227.08	197.64	169.63	105.87	69.92	51.40	55.94	106.68	122.75
70%	85.15	4.85	137.80	192.75	167.77	143.98	89.86	5.35	43.63	47.48	90.55	104.19
80%	57.16	63.67	2.50	129.38	112.61	96.65	60.32	3.84	29.28	31.87	60.78	69.94
90%	46.66	51.98	75.51	105.62	91.93	78.90	49.24	32.52	23.91	26.02	49.62	57.09

To predict Inflow if there is no TMC operation, Weibull method is used as seen in Table 2. The Weibull method is used to calculate water inflow prior to TMC operation TMC operation is usually based on the prediction of lower rainfall (below normal) for the next few months which will directly impact to reservoir inflow. Based on the calculation, the predicted inflow during TMC operation is measured with a Weibull method which resulted in a probability between 70% and 80% (below normal). In theory, cloud seeding operation with these GBG towers will increase the rate of rainfall by about 10-15% of its natural rate, which is equivalent to 10-15% addition to its natural inflow (predicted inflow). The number of additional water thanks to the implementation of TMC with GBG, to the level of probability of 80% and water addition rate of 15%, will be calculated in Table 3 [14].

Table 3. Inflow prediction, additional inflow, and additional volume inflow with assuming Weibull prediction 80% and additional inflow 15%.

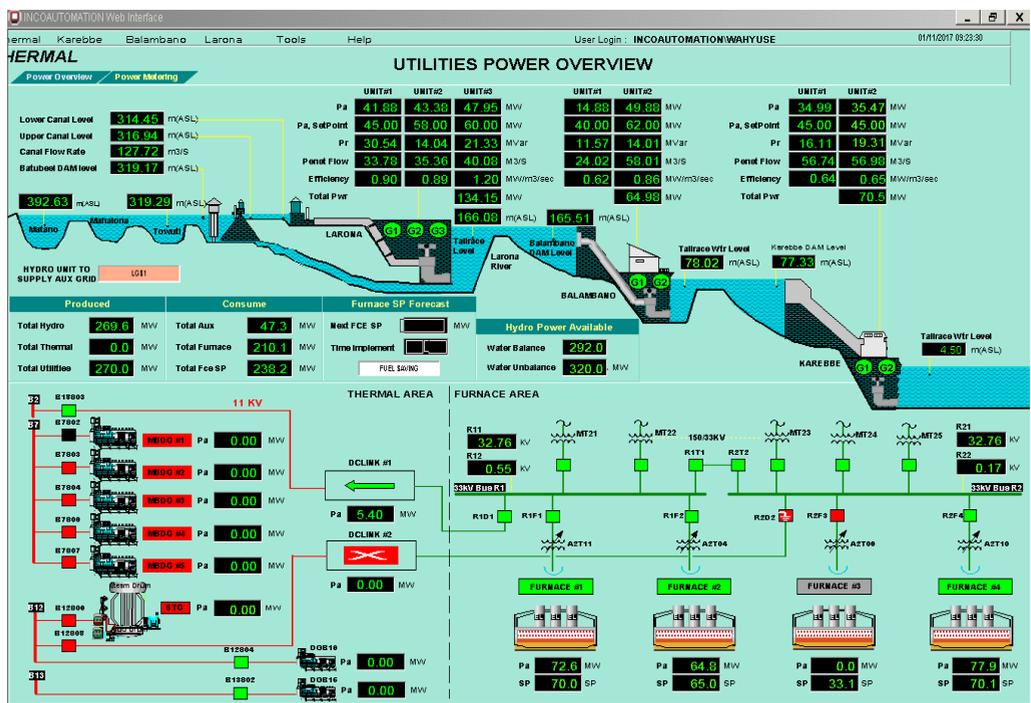| Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prediction Inflow (80%) (m^3/sec)	57.16	63.67	2.50	129.38	112.61	96.65	60.32	3.84	29.28	31.87	60.78	69.94
Additional Inflow (15%) (m^3/sec)	8.57	9.55	0.38	19.41	16.89	14.50	9.05	0.58	4.29	4.78	9.12	10.49
Total Inflow (m^3/sec)	65.73	73.22	2.88	148.79	129.50	111.15	69.37	4.42	33.67	36.65	69.90	80.43

Fig. 9. Scheme of power plant PT. Vale Indonesia Tbk.

Table 4. Potential loss – thermal steam turbine generator (maximum severity 13 month).

No	Description	Quantity	Unit	Remarks
1	Operating time	9,360.00	hrs	
2	Avaibility	1.00	%	
3	Power setting	40.00	MW	
4	Effective power	0.88		
5	Average power	329,472.00	MW	(1)*(2)*(3)*(4)
6	Gross energy	455.00	MWH	
7	Calcine	724,114.29	mt/hr	((5)*1000)/(6)
8	Ni calcine	2.11	%	
9	Recovery Ni rkp to Ni prod	0.89	USD	
10	Ni matte	13,565.43	mt/hr	(7)*(8)/100*(9)
11	Lbs Ni	29,906,621.04	USD	(10)*1000*2.20462
12	LME price	6.39	USD	
13	LME factor	0.78		
14	Production cost	4.03	USD	
15	Benefit/loss margin	0.95		(12)*(13)-(14)
16	Potential additional loss	28,399,327.34	USD	(11)*(15)
17	Potential loss/month	3,549,915.92	USD	(16)/8

Table 5. Fuel consumption calculation.

Thermal plant	Power capacities		Fuel consumption		Fuel price		Yearly operating		Yearly fuel consumption	
	as per SLA (a)	Unit	Rate (b)	Unit	Value (c)	Unit	Physical avaibility assumption (d)	Hour (e) - (d) + 365 + 24	as per SLA (a)*(b)*(c)*(e)	Unit
STG	20	MW	2.02	Brl/MWH	73.88	USD	91.08%	7,978.608	23,814,166	USD/year
MBDG	30	MW	245	Ltr/MWH	0.62	USD	91.08%	7,978.608	36,417,159	USD/year
CAT	23	MW	270	Ltr/MWH	0.62	USD	91.08%	7,978.608	30,768,784	USD/year
Total Fuel Price									91,000,109	

5 Conclusions

The drought occurs around the Larona River Basin decreases the water flow which in turn lower the electrical energy supply to the energy-intensive nickel processing plant. TMC application in the form of GBG towers installation system is an effective and efficient approach to accelerate rainfall to increase the expected water inflow. Additional direct inflow will increase the sufficient electrical power needed nickel production processes. The calculation table below shows how production loss will potentially occur when the plant is powered on the thermal plant instead of PLTA. Cost incurred per month is US\$ 3,549,915.92 + (\$ 91,000,109/12) = US\$ 11,133,258.36 versus weather modification technology cost at US\$ 122,685 per month [4].

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