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SURFACE WATER POTENTIAL ANALYSIS AND GROUNDWATER CONSERVATION CONCEPT AT KAMOJANG GEOTHERMAL FIELD

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ABSTRACT

This study presents an analysis of water debit availability as reservoir recharge element to support steam productivity of Kamojang geothermal field since 1983. Currently, installed capacity of Kamojang is 200 MW. It is projected that the surface water debit availability can replinish fluid extracted from the reservoir. Through our study about surface water debit availability, it is expected that the groundwater conservation can be preserved therefore the geothermal fluid will still be able to supply the electric generation for the upcoming years.

Methods that are used to analyse water balance in this research is FJ. Mock's. While the method used to determine maximum rainfall analysis is Log Normal, Gumbel I Type, and Iwai Kadoya methods. Mononobe method is used to calculate maximum rainfall intensity for planning the implementation of articial recharge concept, while articial recharge concept analysis is derived from Darcy's Law (also known as rational method). From the calculation, it can be concluded that water surplus occured at Kamojang geothermal field area in October–May might reach up to 3.5 million ton/month, while in June–September the leak off surface water debit might reach up to 1.7 million ton/month. The implementaion of articial recharge at Kamojang geothermal field area is planned to be able to store the surplus of surface water in underground therefore there is no leak off surface water debit at dry season.

Key words *: Hydrothermal System, Water Recharge, and artificial recharge*

INTRODUCTION

Location

Kamojang geothermal field is located approximately 42 miles south east of Bandung, West Java province, at an altitude of ± 1500 meters above sea level on volcanic chain between Rakutak Mountain and Thunder (Pri Utami & PRL Browne, 1999). Geographycally, Kamojang geothermal field is located at UTM coordinates 9207000-9214000 mU and 806000-810000 mT (Setyobudi, 1999), which covers the area with an area of about 14 km2. Administratively, the field is located in the Village Laksana, District Ibun, Garut regency, West Java. Location Kamojang geothermal field in detail can be seen in *Figure 1* Geothermal Field Location Kamojang below.

Figure 1: Kamojang Geothermal Field

Status of Geothermal Field Kamojang

Kamojang field is one of a few steam-dominated geothermal reservoir. This field is operated by Pertamina Geothermal Energy(PGE). The first unit was installed 30 MW in 1982 but the developmet was started earlier in 1975. Prior to developing the first unit, the exploration survey was performed with the help of the New Zealand government in 1974. Soon, five exploration wells were drilled into depth of 700 m. Pertamina (now PGE) has continuously developed more units to supply electricity demand. The development of unit 2 and 3 were first conducted in 1987. Following the second and third unit, the first unit was increased its capacity from 30 MW to 140 MW and begun operating commercially. It was supplied by 26 wells drilled. In the recent years, the field is already occupied by 81 wells for both production and injection. In 2008, the total of 200 MW has been generated up to date. No further development was made to increase its capacity since then. After operating over 27 years, temperature reservoir of Kamojang has been declining by 2% to 7% (average 0.71°C/year or 0.29°C/year) or temperature drop is totaling of 14^{o}C. The decline rate of pressure and temperature was said to be impacted by the reservoir permeability (Suryadarma et al, 2005). The strategy of production and reinjection is also responsible for pressure and temperature loss in the reservoir. Furthermore, the geothermal fluid availability stored in the reservoir is highly correlated with the reservoir performance.

There are eight wells which are used as reinjection program. Three reinjection wells (KMJ-33, KMJ-18, and KMJ-40) are located in the relatively low permeability zone and the rest are located in the medium permeability zone. The reinjection program has not yet shown a good effect to maintain the production of geothermal steam in Kamojang, but it gives a good impact to impede the steam productivity decline.

Based on the calculation by Pertamina (using volumetric method), it is obtained the potential reserves are of 150-250 MW, with an area of 7.52-12.5 km^2. By further delineation using CSAMT (Control Source Audio Magneto Telluric) the area may reach larger area of about 21 km^2. Other calculation mentioned that Kamojang geothermal field has reserves of 140-360 MW (delineated from an area of 8.5-15 km^2) (Fauzi, 1999). While, Sanyal et al (2000) mentioned that the Kamojang geothermal field has potential reserves of 210-280 MW for 30-year production.

RESERVOIR KAMOJANG

According to Djoko Hantono et al study in 1996, based on the study of geosciences (geology, geophysics, and geochemistry) has a large reservoir of 14 km^2. The reservoir model of Kamojang as depicted in figure 2 is widely used in the calculation of artificial recharge.

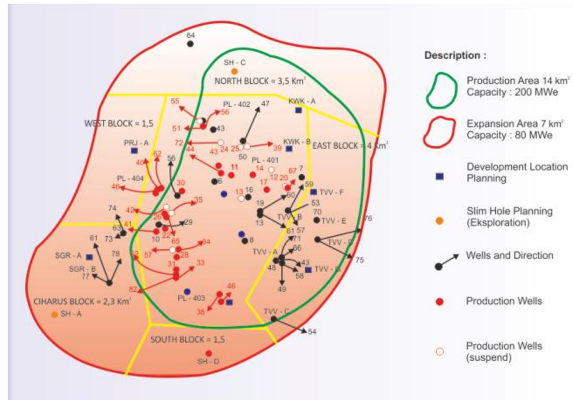

Figure 2: Area of Geothermal Reservoir Kamojang (Suryadarma, 2010)

CALCULATION OF POTENTIAL GROUNDWATER

In general, to determine water potential in a region, it is approached by having the watershed area as the observation area (Lindsley, 1978). The groundwater as called *base flow* flows with surface water (*run-off water*) into the river. In a smaller area, it is assumed the water balance occurs in which the groundwater movement may fill-up and be replinished by the water river naturally. The assumption used in this study to determine the groundwater potential is water balance (FJ. Mock, 1973).

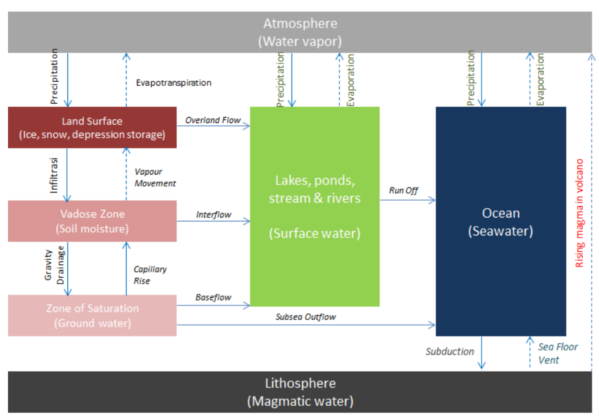

Figure 3: Hidrology Cycle (Fetter, 1994)

The water balance analysis is a study to calculate the water surplus based on rainfall and limited evapotranspirasi. The analysis is commonly performed in certain month. Water equilibrium (water balance) states that the amount of water entering (implemented as rainfall) is equal to the amount of water coming out (implemented in the form of limited evapotranspiration, soil humidity (soil moisture), and excess water (water surplus)). The analysis aims to calculate the equilibrium water potential of groundwater in a certain area based on climatological data such as rainfall, air temperature, solar radiation time, air humidity, wind speed, and others. In this study, it is analysed the water equilibrium (water balance) in Kamojang geothermal field by using climatological data that has been obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) in 2011.

BASE FLOW, DIRECT RUN OFF, AND RUN OFF CALCULATION

This calculation is performed to have the information of water content in the area of Kamojang geothermal field. Water content is expressed in base flow, direct run-off, and run off. In preliminary calculations, usually unit quantities are mm/year or mm/month given to a block or a rock with an area of 1 m^2 with a thick soil/rock from the surface to the base that is saturated zone (layer inpermeabel) thick depending on the area different areas (FJ Mock, 1973) as illustrated in *Figure 4.*

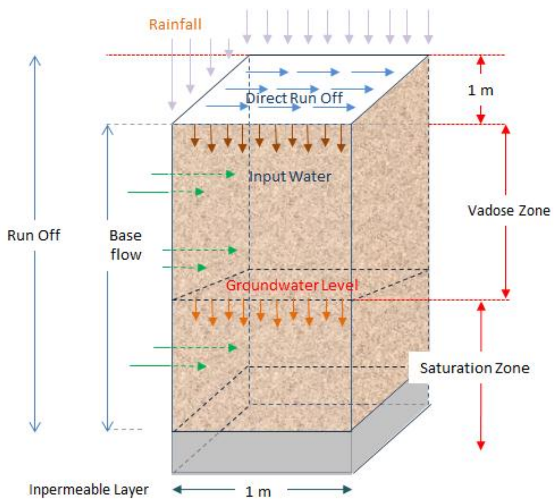

Figure 4: Illustration of hydrodynamic models of Water (FJ Mock, 1973)

RESEARCH METHOD

The flow chart of the study is shown in *Figure 5*. The general methodology is divided into two main parts. First analysis is concerning the maximum rainfall and the second is a hydro-meteorological analysis (analysis of soil water that focuses on meteorological conditions). Analysis of maximum precipitation is used to determine the artificial recharge, while the hydro-meteorological analysis is used to determine the equilibrium of water (water balance) that may exist in the area of study.

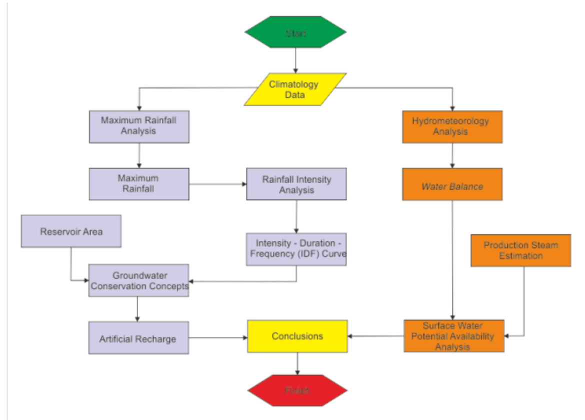

Figure 5: Research Method

Combined analysis of the surface water potential availability and artificial recharge concept is a result of the study. It is expected that through our study the conclusion and suggestions related to the preservation of surface water can be made. Surface water in the study is assumed as a function of water equilibrium conditions became subsurface water that replaces the fluid reservoir Kamojang.

MAXIMUM RAINFALL

The estimation of rainfall volume as a result of the maximum rainfall probability study would be beneficial for planning surface water utilization in the form of criteria design development of a water reservoir model in terms of both design and safety (EJ Plate, 1982). The methods that can be used for the application of probability distribution method are type I Gumbel, Log Normal, and Iwai Kadoya as described:

Type I Gumbel Method

The Gumbel type I or also called an extreme distribution method type I is commonly used to analyse maximum data, e.g. for maximum daily rainfall.

The equation of the density probability is:

$$\mathbf{f(x) = \alpha e\left\{-\alpha(x-\beta) - e^{-\alpha(x-\beta)}\right\}} \qquad \text{.........}(1)$$

Dimana,

- α = Concentration parameter
- β =The size of the tendency of converging

The cumulative probability distribution function is :

$$\mathbf{P(x) = \left\{e^{-\alpha(x-\beta)}\right\}} \quad \text{.................................}(2)$$

Assessment of parameters can be performed by the method of moments or by maximum likelihood. In this study we use moment method as discussed later. The r moment form of this distribution function is :

$$\mathbf{U'_{y,\gamma} = \int_{-\infty}^{\infty} Y^{\gamma} e^{-y-e^{-y}} dy} \quad \text{.......................}(3)$$

Where, y = α (x - β) is the reduction equation
Then substitute z = ey into the equation 11, thus:

$$\mathbf{U'_{y,r} = \int_0^{\infty} \left[(-\ln z)^r * z * e^{-z} * -\frac{1}{z}\right] dz} \quad ..(4)$$

The first moment is :

$$\mathbf{U'_{y,1} = \int_0^{\infty} \ln z * z * e^{-z} * \frac{dz}{z}} \quad \text{..................}(5)$$

$\int_0^{\infty} z * e^{-z} dz = \Gamma(1)$, according to Kendall and Stuart it becomes

$$\mathbf{U'_{y,1} = -\Psi(1) = \gamma_E} \quad \text{...............................}(6)$$

Where, Υ_E is Eulers constant ≈ 0,577
When the original variat restored to original shape: x = (y/α) + β, so

$$\mathbf{U'_1 = \beta + \gamma \frac{E}{\alpha}} \quad \text{..}(7)$$

Gumbel has shown that the second moment is the average value of a sample given by the equation:

$$\mathbf{\chi_2 = \frac{\pi^2}{6\alpha^2}} \quad \text{..}(8)$$

Thus the parameters α tan β, can be formulated as:

$$\mathbf{\alpha = \frac{1{,}2825}{\sigma}} \quad \text{...}(9)$$

and

$$\beta = \chi - 0{,}45\sigma \quad \text{.....................................}(10)$$

Where,

- χ = Sample average value
- σ = Standard deviation

Cumulative probability distribution of equation (equation 10), then the maximum rainfall for return period T is :

$$\mathbf{X_T = \beta - \frac{1}{\alpha} \ln\left(-\ln\left[1 - \frac{1}{T}\right]\right)} \quad \text{.................}(11)$$

Where,

$$\mathbf{T = \frac{1}{1-P(x)}} \quad \text{...}(12)$$

By inserting equations 17 and 18 into equation 19 obtained :

$$\mathbf{X_T = \chi - \left\{0,45 + 0,78\ln\left(-\ln\left[1 - \frac{1}{T}\right]\right)\right\} \sigma} \quad \text{..}(13)$$

The error is :

$$\mathbf{S_T = \delta\sqrt{\frac{\sigma^2}{n}}} \quad \text{...}(14)$$

Where,

- $\delta = \sqrt{(1 + 1{,}3K + 1{,}1K^2)}$
- $K = -\left\{0{,}45 + 0{,}78\ln\left(-\ln\left[1 - \frac{1}{T}\right]\right)\right\}$
- T = Return Period

<u>Iwai Kadoya Method</u>

The basic principle used in the calculation using the method of Iwai Kadoya is a change of variables (X) of the likelihood density curve of maximum precipitation to log X.

The calculation of how Iwai Kadoya will be formulated as below, where:

$$\mathbf{\xi = c \log\frac{x+b}{x_0+b}} \quad \text{......................................}(15)$$

Log (x_0 + b) is the average value of log (x + b) by the formula (i = 1,2,3, ..., n) and is given by (X_0, b, c, and x_0) is estimated from the formula-the following formula.
The first estimate of the value of x_0:

$$\mathbf{\log x_0 = \frac{1}{n}\sum_{i=1}^{n} \log x_i} \quad \text{..............................}(16)$$

Estimated value of b :

$$\mathbf{b = \frac{1}{m}\sum_{i=1}^{n} b_i, m \cong \frac{n}{10} \quad dan \quad b_i = \frac{x_s \ldots x_t - x_0^2}{2x_0 - (x_s + x_i)}} \quad \textbf{Error! No text of specif}$$

Estimated value of X_0 :

$$\mathbf{X_0 = \log(x_0 + b)} \quad \text{..................................}(17)$$

$$\mathbf{X_0 = \frac{1}{n}\sum_{i=1}^{n}(x_i + b)} \quad \text{................................}(18)$$

Estimated value of c :

$$\frac{1}{c} = \sqrt{\frac{2}{n-1}\sum_{i=1}^{n}\left(\log\frac{x_i+b}{x_0+b}\right)^2} \quad \text{.......................}(19)$$

$$\frac{1}{c} = \sqrt{\frac{2}{n-1}}\sqrt{\overline{X}^2 - X_0^2\overline{X}^2} = \frac{1}{n}\sum_{i=1}^{n}\{\log(x_i+b)\}^2 \quad \text{..}(20)$$

Where,

- x_s= Value of observations with sequence number m of the largest
- x_t=Value of observations with sequence number m of the smallest
- n = Number of data
- $m \cong \frac{n}{10}$ = Round number (rounded to the nearest whole number)
- Sometimes if the value is very small b, then tosimplify the calculation of values can be taken wb=0.

If the constants mentioned above has been obtained, then the rainfall is possible (probable rainfall) in accordance with the possibility of more arbitrary (arbitrary excess probability) can be calculated by the following formula

$$\log(x+b) = \log(x_0+b) + \left(\frac{1}{c}\right)\xi \quad \text{................}(21)$$

Calculations by the method of Iwai Kadoya should be implemented according to the following order:

1. The firstestimate of the value of x_0 obtained by equation 16 and b obtained from equation 17
2. Log (x+b) obtain and log (x_0+b) is obtained by equation 18
3. {log (xi +b)} 2 calculated and X_2 are calculated with the equation 20
4. By using the X_2 and X_{02}, then 1/ c_{is} calculated by equation 19

Values are in accordance with the possibility of any more variables obtained from normal and rainfall maybe estimated by equation 21

Log Normal Method

Method of calculation of the maximum rainfall of other commonly used is the normal log method, an extension of the normal distribution, the steps in the determination of precipitation by the normal distribution is by changing the rainfall data (X) into logarithmic form, expressed as Y = log X . Determine maximum precipitation using the equation:

$Y_T = Y + K_T S$ ....*(22)*

Where :

Y_T = Estimated value is expected to occur with a return period T
Y = The average value calculated variat
S = Staandard deviation of variat
K_T = Frequency factor, is a function of the opportunities or return period and type of distribution opportunities that mathematical models used for the analysis of opportunities. Value of the frequency factor can be seen in the table Gauss reduction.

Rainfall Intensity

If there is data in the field of rain per hour, then the intensity of rainfall is computed using the method of Talbot, Sherman, and Ishiguro (Loebis, J., 1992). If the existing rainfall data are daily rainfall data, to determine the intensity of rainfall can use the method Mononobe (Loebis, J., 1992) as follows:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3} \quad \text{......................................}(equation23)$$

where,

- I = Rainfall intensity (mm/hour)
- t = Rainfall period (hour)
- R_{24} = Maximum rainfall in 24 hours (mm)

Having done the calculations, can be determined rainfall intensity duration curves for several rainfall intensity and rainfall intensity equation was selected for the planning area. Then be made IDF curves (Intensity - Duration - Frequency) in accordance with the method selected.

ARTIFICIAL RECHARGE

Groundwater conservation technologies is a human effort to maintain and control suppletion rainwater / surface water in the catchment area (recharge) by removing or injecting directly into the aquifer in the context of preservation and sustainability of groundwater

There are two types of groundwater conservation technology :

a. Vegetativegroundwaterconservation technologies
b. Non vegetative method

Vegetative Method

Plants have parts that grow above and the part that penetrates to the bottom surface of the soil. Utilization of both parts of these trees will be a primary basis in the conservation of vegetative groundwater to flow directly when arriving at the soil surface, thereby slowing the water to flow, giving a chance to seep into groundwater through the nature of store volume of soil / rock (porosity) and permeability the geothermal field area Kamojang.

The roots and leaves in plants using water organisms in the area to support life in plants, it can directly reduce the water surface. Roots that have reached the position of the depth of groundwater aquifers are free, can drain the water into the aquifer. Thus the selection of a particular plant species will be an important effect on soil water conservation through vegetative to the shallow groundwater.

Effective or not a plant to reduce erosion or water flow in the surface height is influenced by the plant itself, as well as owned plant root system. Some groundwater conservation efforts that may be used in shallow groundwater conservation include:

1. Planting by using cover crops/shrubs on flat ground / low terrain
2. Reforestation in areas of open/barren, that is by replanting the forests bare

Non Vegetative Method

Based on the literature of Artificial Recharge is defined as an effort to increase the amount of water put in an artificial aquifer (Walton, 1970). Specifically Artificial Recharge has the objective:

1. Convert and collect runoff/flood water
2. Increase the amount of soil water availability
3. Reducing the rate of decline in groundwater
4. Reduce and prevent the intrusion of seawater
5. Entering the water to reduce the cost of shelter and plumbing
6. Collecting water in the rainy season and use itduring the dry season
7. Lower levels of sludge by filtration through soil media

The scope area of Kamojang geothermal field will be a a reservoir of water (adjusted to the results of the calculation of rainfall plan). Until now reservoir which is made for rainwater in the area of geothermal field Kamojang does not exist, so the excess water (watersurplus) when the rainy season can not be accommodated and the runoff water does notfunction optimally toreplace the existing groundwater in the area. In general, the presence of shelter (such as reservoirs) will increase the capacity of the existing catchment areas in the vicinity.

Artificial recharge modeled in research project use non-vegetative methods i.e. in the form of water dams which (reservoirs) are expected to hold water in the rainy season, water is stored, is designed to replace the input groundwater (groundwater) during the dry season. Artificial recharge which is planned in the study currently uses the formula of water storage by Darcy's law (rational method) which has the following mathematical equation:

$$Q_m = C*I*A \quad \text{.......................................}\textit{(equation 24)}$$

Where :

Q_m = Water debit (m^3/day)
C =Run off coefficient
I = Rainfall intensity (m/day)
A = Area (m^2)

RESULT AND ANALYSIS

Water Potential Availability

From the table, it can be described that in the wet months and several transitional months, the surface discharge is sufficient for steam production at 1.08 million tons/month to generate electricity generation of 200MW in Kamojang geothermal field. While in the transitional months (May and September) and dry months (June, July and August) the potential availability of surface water ranged between 100-500 thousandtons/month. As depicted in a *Figure 6*, the highest surface discharge occurs in January amounting to 4.5 milliontons/month. The supply in rainy season exceeds higher than in the dry months. In the dry months, the shallow ground water supplies 123 thousand tons/month at the lowest value, therefore efforts are required in order to have a balance within dry and months.

Values calculated by the potential availability of groundwater is done by using water balance data in 2004 to 2008.

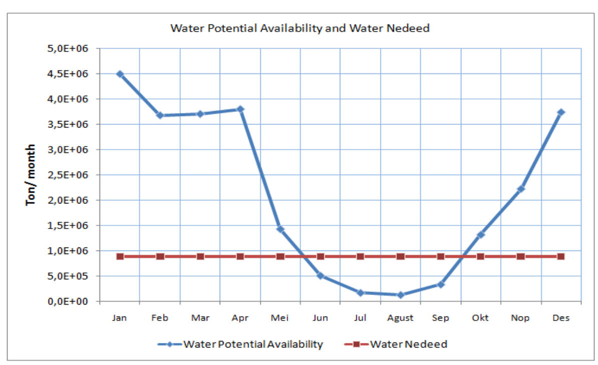

Figure 6 Water Availability & Water Nedeed

CONCLUSIONS

Based on the analysis and calculation, it can be obtained several conclusions, as follows:

1. Climatic conditions in the geothermal field Kamojang based on existing data has a rainfall patterns in region A (influenced by the monsoon Australia) which means it is highly dependant to the global climate conditions rather than regional or local climate

2. The water reservoir on the geothermal field Kamojang based on geochemical studies is derived from meteoric water (rain water) and not from magmatic fluid, therefore main water affixes (water recharge) can be obtained from the rain water in the geothermal field area.

3. From the water balance calculation, it can be concluded that there is a tendency of water affixes deficit in dry months (June, July and August) and a surplus of surface water in the rainy season and in a few months of a particular transition

4. By using the area reservoir of 14 km^2, it can be obtained value of the surface water discharge which may reach 4.59 million tons/month in the rainy season, and reach 123 thousand tons / month in the dry season

5. Supply of steam is used to generate geothermal power plants of 200 MW Kamojang amounted to 1.08 million tonnes/month (based on data in 2008), and when compared with the surface water is still below the value of existing (wet season) and is above the value in the dry season

6. From the calculation of the maximum rainfall with return period 10, 20, 30, 40, 50, and 60 can be btained a maximum planning artificial recharge with Log Normal method.

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