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# Managing Technical, Social and Environmental Challenges in Providing Water Supply for Geothermal Drilling Operation in Indonesia

Dorman Purba[1], Daniel W. Adityatama[2,1], Agung W. Mukti[3,1]

[1]ENERKA Bhumi Pratama, Cibis Nine Tower 11th floor, TB Simatupang, Jakarta Selatan, Indonesia

[2]Geoenergi Solusi Indonesia (GEOENERGIS), Cibis Nine 11th Floor, Jakarta, Indonesia

[3] PT Geo Dipa Energi (Persero)

dorman.purba@enerklaz.com; dorman.drilling@gmail.com

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## ABSTRACT

It is commonly known that geothermal drilling operations in Indonesia require more water supply compared to the drilling operations in oil and gas. This is due to the formation is dominated by faults and fractures that will lead to loss circulation of drilling fluid. Failure to continuously pump water into the wellbore can result in stuck pipes and well control issues, which can significantly increase the total drilling cost. Consequently, the drilling team should be able to provide a continuous supply of water to be pumped, especially when drilling in lost circulation zones.

As geothermal projects in Indonesia are typically located in mountainous areas, finding a suitable water source for drilling is more difficult than in the lowlands. The challenges commonly faced are insufficient water flowrate, low water pH, risk of interfering with local community water use, difficult terrain, and difficulty in obtaining associated permits due to the water source located in the conservation area.

This study seeks to identify and map out various scenarios that the drilling team might face when searching for a water source for drilling. The scenarios described in this study are based on various cases collected from literature and interviews with drilling personnel in Indonesia. Based on these cases, this study then maps out the different solutions that have been carried out. Other alternative solutions that can be applied to the challenges are also identified along with their respective impact on social, environmental, and project costs.

This research discusses different methods of mapping the locations of water sources and their utilization by residents in the area, the steps and process of obtaining permits from the local community in the area and the local government to utilize the water from the source, selecting the most effective and efficient method in transferring the water to the drilling sites. Mitigation plans to anticipate the disruption of water supply during drilling operations are also discussed.

The result of this study is expected to help the Indonesian geothermal industry by providing integrated guidance on how to properly manage technical, social, and environmental issues in providing water supply for geothermal drilling projects.

## 1. GEOTHERMAL DRILLING IN INDONESIA

### 1.1 Challenges in Developing Geothermal Energy in Indonesia

The history of geothermal energy in Indonesia can be traced back to the early 20th century when the Dutch colonial government began exploring the potential for geothermal energy on the island of Java. However, it was not until the 1970s that the Indonesian government began to actively pursue the development of geothermal energy as a source of electricity.

1. Exploration: In the 1970s, the Indonesian government began to explore the potential for geothermal energy in several areas of the country, including the Kamojang area in West Java. This involved drilling test wells and conducting geophysical surveys to assess the size and quality of the geothermal resources in the area.
2. Early development: The first geothermal power plant in Indonesia, the Kamojang Geothermal Power Plant, was built in the Kamojang area in the 1980s. It was one of the first geothermal power plants in the world and had an installed capacity of 55MW.
3. Expansion and growth: In the following decades, the Indonesian government continued to invest in the development of geothermal energy. The Kamojang power plant was expanded several times, and new geothermal power plants were built in other areas of the country. By 2023, Indonesia had become one of the largest producers of geothermal energy in the world, with an installed capacity of over 2,356 MW.

In recent years, the Indonesian government has set ambitious targets for the development of geothermal energy by having 5,486 MWe installed capacity by 2030 (Direktorat Panas Bumi, 2022) to align with the country’s effort to mitigate the climate change. However, from the time Kamojang commercial power plant commissioned for the first time in 1983 until the end of 2022, the development of geothermal energy in Indonesia has only reached 2,356 MW installed capacity (ThinkGeoEnergy, 2023), which equivalent of 54 MW/year development rate to the installed capacity of geothermal power plants. Even though when viewed from the world's position, Indonesia is the country with the second largest PLTP in the world after the United States (ThinkGeoEnergy, 2023), when compared to the total reserves of geothermal energy owned, Indonesia only uses ±11%. As a comparison, New Zealand has used 38% of its total potential while the United States has used 21% of its total potential (Asokawaty et al., 2020).

Similar to other countries worldwide, Indonesia faces a number of challenges, including:

1. High exploration and development costs: Geothermal projects can be expensive to explore and develop, especially in the early stages. Drilling test wells and conducting geophysical surveys can be costly, and there is always the risk that a project will not yield a viable resource.
2. Complex and uncertain regulatory environment: Geothermal projects are subject to a variety of regulations at the national, regional, and local levels. This can make it difficult for developers to navigate the regulatory environment and can increase the risk of project delays or cancellation.
3. Lack of infrastructure: Many geothermal resources in Indonesia are located in remote areas, which can make it difficult and expensive to access them. This can include building roads, power lines, and other infrastructure to support a geothermal project.
4. Environmental impacts: Geothermal projects can have a variety of environmental impacts, such as deforestation and the potential for groundwater contamination. Mitigating these impacts can be costly and time-consuming.
5. Social and community impacts: Geothermal projects can also have social and community impacts, such as displacement of local communities and land-use conflicts. Developers need to address these impacts and engage with local communities to ensure their support and minimize the risk of project delays or cancellations.
6. Competition with other energy sources: Geothermal energy competes with other forms of renewable energy sources such as solar, wind, and hydro power, as well as with fossil fuels. This can make it difficult for geothermal projects to compete in terms of cost and scalability.
7. Technical challenges: Building geothermal power plants and drilling geothermal wells require a high level of technical expertise and knowledge, which can be difficult to find. Additionally, geothermal wells can be more prone to clogging and scaling than oil or gas wells, which can lead to production issues and increased maintenance costs.

Overall, while geothermal energy has the potential to provide a significant amount of clean, renewable energy, the process of geothermal project development is complex and can be challenging. To achieve its national target of 5,486 MW in 2030, around eight years from now, Indonesia must address these exploration project challenges, which requires a combination of technical expertise, careful planning, and engagement with local communities and stakeholders. The Ministry of Energy and Mineral Resources (MEMR) reported that the government has issued 63 geothermal concessions with total estimated capacity of 13,517.5 MW. From this data, it is indicated 22 locations are still under exploration stage with total estimated capacity of 4,011 MW. Table 1 shows the list of some geothermal prospect areas/concession areas that are still in the exploration stage and may contribute to the achievement of the aforementioned national target.

**Table 1: List of Geothermal Prospect Areas/ Concession Areas in the Exploration Stage (Direktorat Panas Bumi, 2022)**

| No | Name of the Prospect Area / Concession Area | Location | Estimated Capacity (MWe) | Developer |
|---|---|---|---|---|
| 1. | Tulehu | Maluku | 31 | PT PLN (Persero) |
| 2. | Gn. Ungaran | Central Java | 150 | PT PLN (Persero) |
| 3. | Atadei | East Nusa Tenggara | 40 | PT PLN (Persero) |
| 4. | Songa Wayaua | North Maluku | 42 | PT PLN (Persero) |
| 5. | Danau Ranau | South Sumatera | 210 | PT PLN (Persero) |
| 6. | Oka Ile Ange | East Nusa Tenggara | 50 | PT PLN (Persero) |
| 7. | Kepahiang | Bengkulu | 254 | PT PLN (Persero) |
| 8. | Gn. Sirung | East Nusa Tenggara | 152 | PT PLN (Persero) |
| 9. | Tangkuban Perahu | West Java | 375 | PT PLN (Persero) |
| 10. | North Patuha (WKP Patuha) | West Java | 55 | PT Geo Dipa Energi |
| 11. | Candradimuka (WKP Dieng) | Central Java | 50 | PT Geo Dipa Energi |
| 12. | Candi Umbul Telomoyo | Central Java | 92 | PT Geo Dipa Energi |
| 13. | Gn. Arjuno Welirang | East Java | 302 | PT Geo Dipa Energi |
| 14. | Gn. Rajabasa | Lampung | 283 | PT Supreme Energy Rajabasa |
| 15. | Rawa Dano | Banten | 385 | PT Sintesa Banten Geothermal |
| 16. | Baturaden | Central Java | 258 | PT Sejahtera Alam Energy |
| 17. | Telaga Ngebel | East Java | 120 | PT Bakrie Darmakarya Energi |
| 18. | Seulawah Agam | Aceh | 223 | PT Geothermal Energi Seulawah |
| 19. | Gn. Lawu | | 332 | PT Pertamina Geothermal Energy |
| 20. | Kotamobagu | North Sulawesi | 410 | PT Pertamina Geothermal Energy |
| 21. | Jaboi | Aceh | 107 | PT Sabang Geothermal Energy |
| 22. | Gn. Talang – Bukit Kili | West Sumatera | 90 | PT Hitay Daya Energy |
| **TOTAL** | | | **4,011** | |

Despite the compelling opportunity presented by the untapped geothermal resources, the effort to translate this opportunity into reality is quite challenging given the high uncertainty and substantial upfront capital expenditure required to drill deep geothermal exploration wells.

In the context of Indonesia, the challenges of geothermal exploration projects are intensified by the addition of several factors such as (Adityatama, 2020; Poernomo, 2015):

1. Geothermal prospect / exploration areas are usually located in volcanic setting with many geohazards, very minimal road access and hilly terrain.
2. There is still a lack of understanding of the local community living around the geothermal prospect area regarding geothermal projects. This often results in a low level of community acceptance on geothermal exploration projects.
3. Number of geothermal exploration experts in Indonesia, from all discipline (e.g., geoscience, drilling, environmental, social), is less than the number of exploration projects to be completed. Combined with the absence of a certification program for geothermal exploration experts, geothermal exploration projects in Indonesia are often carried out by personnel with an inadequate level of competence.
4. In the exploration phase, usually there is not yet certainty of the electricity prices, which create difficulties for investors in making decision to spend the exploration budget.

### 1.2 Exploration Drilling Challenges

Generally, all personnel involved in a geothermal project are aware that the existence of exploration wells is very crucial for the decision-making process towards the next stage. However, the author in this study suspects that not all personnel are well informed about the challenges faced when carrying out exploration drilling activities, either challenges from technical or from non-technical aspects, such as regulation/legal, social and environmental)

Some of the challenges in geothermal exploration drilling in Indonesia can be summarized as follows:

1. *Low accuracy of subsurface data* - at the exploration stage the available subsurface data are generally still formed based on the interpretations of surface studies so that drilling planning will be carried out based on data with very low accuracy. The challenges that will be faced are generally in the form of various surprises from formations at unexpected depths, such as massive lost zones, reactive formations, unconsolidated formations, shallow steam pockets, deeper top of reservoirs, paleosol formations, etc. Realizing that the geoscientific prognosis provided by the geoscience team may not match actual conditions, the drilling team must make a mitigation plan for various scenarios or potential subsurface hazards that will be encountered. Failure to make a mitigation plan will result in an increase in drilling costs and the worst thing is that the drilling of the well will not be completed.

2. *Newly formed exploration team* – currently in Indonesia, companies conducting geothermal exploration activities are generally newly formed companies with a combination of several sponsoring companies. The implication of a new company is that the team is built by combining several key personnel who might be their first time working together and are not familiar with each other's working method and communication styles. Furthermore, due to the shortage of geothermal personnel, geothermal companies often recruit personnel from other similar industries such as oil and gas or mining. Although similar, the challenges of drilling in the geothermal environment are quite significant different when compared to the oil and gas and mining environments. The failure of geothermal companies to build a competent and well-communicated exploration team will cause exploration projects to run slower and ultimately increase project costs.

3. *Higher project costs compared to development stage drilling* – despite the explanation of the two points above regarding the lack of subsurface data and the exploration team being generally newly formed, the cost of exploration drilling itself is generally higher than the cost of drilling at the development stage. This is because the number of wells drilled in the exploration stage is usually less than wells drilled in the development stage. The number of these wells affects the prices proposed by the providers of rigs and supporting services. The more wells drilled, the lower the price.

4. *Low acceptance of local communities* – not only from the technical side, but exploration challenges also come from the non-technical aspect, especially those related to local communities. In the exploration stage, people living in geothermal prospect areas in Indonesia are generally have not properly educated about the benefits of geothermal projects for their livelihood. Often, geothermal companies focus too much on planning from the technical aspect and forget about engagement with local communities, resulting in community rejection.

5. *Indonesia does not yet have a geothermal drilling database* – Indonesia does not currently have a database that collects and integrates data and lessons learned from geothermal drilling activities from all geothermal development companies in Indonesia. The existence of this database will certainly make it easier for geothermal developers to learn from other developers so that the same mistakes can be avoided. In the absence of this database, each geothermal development company can only learn from their respective projects.

### 1.3 The Importance of Drilling Water Supply

In geothermal drilling, the production zone is usually a loss zone (Finger & Blankenship, 2010). This means curing the loss zone is not preferable as it might harm the well productivity. Therefore, it is almost a certainty that at some point, the drilling must be continued even in the event of loss circulation.

The loss circulation will reduce the cold fluid column inside wellbore, reducing hydrostatic pressure. Apart from causing stuck pipe, this condition can also lead to steam blowout due to the fluid inside wellbore is getting hotter and flashes, with no sufficient water column to prevent the steam from rising to the surface. Therefore, the continuous and reliable water supply for geothermal drilling is very critical for the success of geothermal drilling, both in terms of drilling performance and also in terms of safety.

### 1.4 Research Objectives

The purposes of this paper are as follow:

1. Provide overview of typical quantity of water and water supply infrastructure required for geothermal drilling in Indonesia.
2. Discuss potential technical and non-technical challenges in securing fresh water supply for geothermal drilling operations in Indonesia. The potential mitigation options for those challenges is also discussed.

Literature review and case study from authors' experience were used to give an overview and examples of some of the challenges commonly faced in securing water supply for geothermal drilling.

## 2. REQUIRED WATER QUANTITY FOR DRILLING OPERATION

### 2.1 Typical Well Design in Indonesia

The current typical geothermal well in Indonesia use big bore type (13-3/8" production casing with 10-3/4" production liner) as shown in **Table 2** (Hartono, 2019) and Figure 10. Note that the big bore well offers more flexibility to step down the liner size in case of drilling problem as the big bore well can be stepped down twice up to 7" liner. However, this larger well diameter means more water is required to drill the well.

**Table 2. Typical big bore geothermal well design in Indonesia.**

| Section | Hole Size | Casing Size | Typical Depth (mMD) |
|---|---|---|---|
| **Conductor** | 36" / drilled using Auger | 30" | 30-60 |
| **Surface** | 26" | 20" | 300-500 |
| **Production casing** | 17-1/2" | 13-3/8" | 400-1400 |
| **Production liner 1** | 12-1/4" | 10-3/4" | 1100-2000 |
| **Production liner 2** | 9-7/8" | 8-5/8" | 1500-2500 |
| **Production liner 3** | 7-7/8" | 7" | 2000-3000 |

### 2.2 Water Quantity Estimate

The amount of water required for drilling varies from well to well, depends on well size and drilling condition, but may vary from 260-1200 gpm (Putranto, Iswara, & Bismoyo, 2018). The 1200 gpm is the typical maximum flowrate required for standard/big bore well as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. To estimate the water required for drilling, this study use big bore well with the total measured depth of 3,000 m or around 10,000 ft (**Fehler! Verweisquelle konnte nicht gefunden werden.**) and the total drilling duration of around 65 days.

As loss circulation is quite common in geothermal and difficult to predict, two scenarios are used to estimate the amount of water required for drilling:

<u>Scenario 1: Attempt to cure loss in 26" and 17-1/2" hole</u>

This scenario assumes that in 26" and 17-1/2" hole section any loss circulation encountered will be cured prior to continue drilling. It means that there will be no blind drilling to be conducted in surface and production section, while in the reservoir section (12-1/4") the drilling will be carried out even when encountering total loss circulation.

For the 26" and 17-1/2" section, the amount of water is calculated as follow:

Volume required = (Hole volume + Active system*) x 300%

The active system (mud tank and surface piping) is assumed to have the total volume of 2,000 bbls or around 318 $m^3$, while the 300% excess volume is the typical mud volume prepared by the mud engineer on the site.

For the 12-1/4" section, it is assumed that half of the hole section will encounter total loss and will be drilled blind. Therefore, the total volume required for drilling 12-1/4" section is as follow:

Volume required = ½ drilling duration x flow rate

Half of the 12-1/4" drilling duration is around 10 days, with the assumed flow rate required is 1,200 gpm. The result for this scenario is shown in the **Table 3**:

**Table 3. Water quantity estimate for scenario 1.**

| Hole Section | Water Required |
|---|---|
| 26" | 1,416 $m^3$ |
| 17-1/2" | 1,563 $m^3$ |
| 12-1/4" | 69,173 $m^3$ |

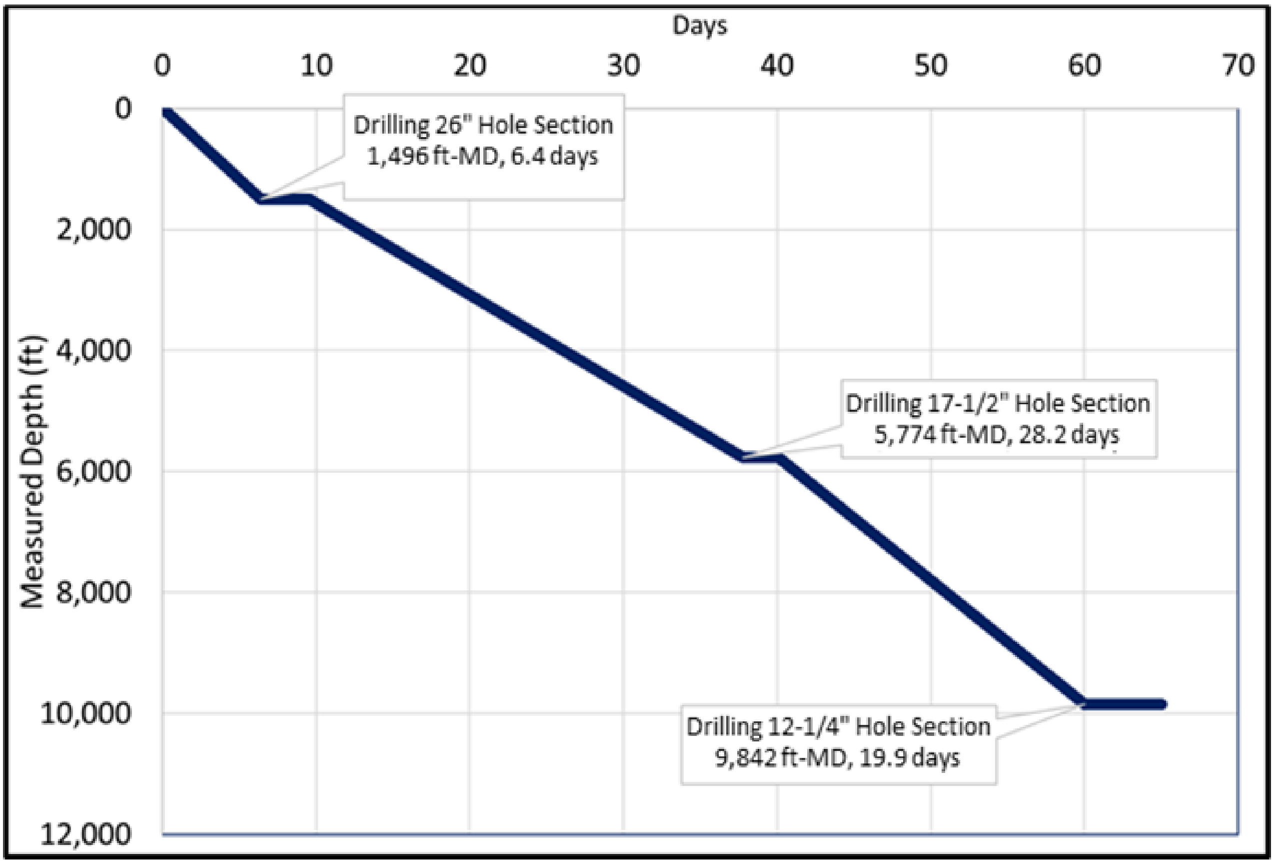


**Figure 1. Typical time-depth curve for 3,000 mMD well.**

Scenario 2: Blind drilling along the half of each hole section

The second scenario assumes that half of each hole section will encounter total loss circulation, thus there will be no fluid return to the surface. The result for the second scenario is shown in Table 3.

**Table 4. Water quantity estimate for scenario 2.**

| Hole Section | Flow rate | Water Required |
|---|---|---|
| 26” | 1200 gpm | 20,931 $m^3$ |
| 17-1/2” | 1200 gpm | 92,230 $m^3$ |
| 12-1/4” | 1200 gpm | 69,173 $m^3$ |

In practice, it is highly unlikely that the total loss circulation in 26” section will not be cured, as the drilling fluid pumped to the well has the potential to contaminate the groundwater. The utilization of aerated drilling also has the potential to reduce the amount of water to be used as there might be some fluid return to the surface.

### 2.3 Water Properties Requirement

The water is used for both drilling fluid and cementing. Therefore, the water properties are important to ensure that the drilling fluid and cementing can perform as designed. Apart from water compatibility with mud and cement, the water used or discharged from drilling activities should have no adverse effect to the environment. The typical water properties for drilling are as follow (Alamsyah, et al., 2020):

1. Should not contain any toxic materials such as Mercury [Hg], Fluorine [F], Boron [B], Arsenic [As], Cadmium [Cd], Aluminium [Al], Lead [Pb], etc. due to environmental concern;
2. The dissolved metal such as Fe, Cu, Pb, Zn, and Ag content should not be greater than 75 ppm;
3. The pH of the brine should be more than 5;
4. The density of the brine should not be greater than 8.5 ppg at a temperature of 25 $^oC$;
5. The brine temperature should not be more than 40 $^oC$;
6. Total hardness ($Ca^{2+}$ and $Mg^{2+}$) content should not exceed 100 ppm.

Those requirements above mean that no untreated geothermal byproducts such as brine (or condensate in some cases) to be used as base fluid for drilling fluid and cement. It is better to have fresh water for drilling purpose, even then the water properties should be carefully monitored, as in volcano hosted geothermal system in Indonesia the water sources sometimes have very low pH (Putranto, Iswara, & Bismoyo, 2018; PT Geo Dipa Energi, 2019).

### 2.4 Water Transfer Infrastructure

Geothermal well generally has larger hole sizes and volumes, therefore the pump and pits/ponds to store the water is generally bigger than for oil well of comparable depth (Finger & Blankenship, 2010; Purba, Adityatama, Umam, & Muhammad , 2019). As shown in the **Table 3** and **Table 4**, the quantity of water required for drilling is very high and it is highly unlikely that the water pond on the pad can accommodate it. Hence, instead of relying on the water pond on the well pad, it is important to have a capable water transfer system from the water source (rivers, lake, etc.) that can continuously supply the water at 1,200 gpm in case of the total loss condition. This is especially challenging as in most geothermal field in Indonesia, the water source is generally far from the well site and has very high elevation difference. Providing adequate water transfer system for geothermal drilling can be cost intensive.

NZS 2403:2015 dictates that the water supply used should have redundancy and backup equipment, and if there is only one set of water supply pumps available, the geothermal company should provide additional water storage and necessary piping to feed the water to the rig site. The water storage should be able to feed water to the rig site with the following requirement:

1. Feed the water to the rig site at the rate adequate to quench and control the well;
2. Have an adequate capacity that allows continuous quenching of the well for a period of no less than 12 hours.

Note that NZS only dictates the water storage should be enough to provide continuous quenching of the well, not necessary to continue the drilling. The inadequate water supply might stop the drilling and prolong the drilling operation, thus increasing the total drilling cost (Adityatama, Purba, Muhammad, Wiharlan, & Pasmeputra, 2020).

## 3. CHALLENGES IN PROVIDING RELIABLE AND ADEQUATE WATER SUPPLY FOR DRILLING

Geothermal prospect areas in Indonesia are mostly volcano hosted with high relief terrain (Umam, Muhammad, Adityatama, & Purba, 2018). This poses unique challenges as the well pad is located in mountainous area, with the water source situated far and in the lower elevation. The geothermal areas in Indonesia are also generally located in the protected forest, making the environment and social issue become critical.

### 3.1 Water Source Location

The distance and elevation difference of well pad and water source is proven to be very problematic for the geothermal developer, as it might require a lot of booster pump to be able to provide adequate water supply.

### 3.2 Water Usage by Local Community

Even if there are the fresh water source for drilling, it is likely that the water is also being used by the local community. Authors' experience in some geothermal drilling preparation planning shows that this might not be an issue during rainy season but will become a serious problem during dry season. However, if the flowrate of the water source is also limited even in the rainy season, the geothermal company will be unable to obtain water from that source at all. This is especially true for eastern parts of Indonesia such as southern part of Sulawesi and Nusa Tenggara islands, which are classified as equatorial savannah with dry winter climate (Putranto, Iswara, & Bismoyo, 2018). These areas are typically having very little freshwater sources such as lake or river available throughout the year.

### 3.3 Low pH Water

As the fresh water with neutral pH water is most likely have been used by the local community, the remaining options are to utilize the water source with less preferable properties, such as low pH. This kind of water source is less likely to be used by local community, as it might cause health problem. The source of this acidic water can be from volcanic crater lake, or river with low enough pH (<4).

Even though this water source might be used without any problem with the local community, but it requires certain precautions to avoid any damage or problems in drilling equipment. A proper treatment is required to increase the pH of the water and the pump should use a corrosion resistance material for the liner and/or impeller.

## 4. CASE STUDY

### 4.1 Ijen, East Java

Slimhole drilling campaign in East Java was conducted in 2016-2017 period. The water source for drilling is located 17 km from the well pad site and transported by truck. This caused problem as during total loss circulation, the drilling had to be stopped if the water pond had been emptied and the truck had not arrived yet (Sunarso, 2020).

The decision to invest in construction of water transfer facility from the water source was complicated at the moment, as the field is still in the exploration phase. The requirement to invest a high amount of capital for water supply infrastructure should be carefully considered with regards to the potential drilling problems or even steam kick or blowout.

### 4.2 Way Ratai, Lampung

Way Ratai is a geothermal field located in Lampung Province, Sumatra. During authors' experience in surveying the water supply and the well pad area, the water source is located at 9.83 km from the furthest well pad, with 317 m elevation difference (**Figure 2** and **Figure 3**).

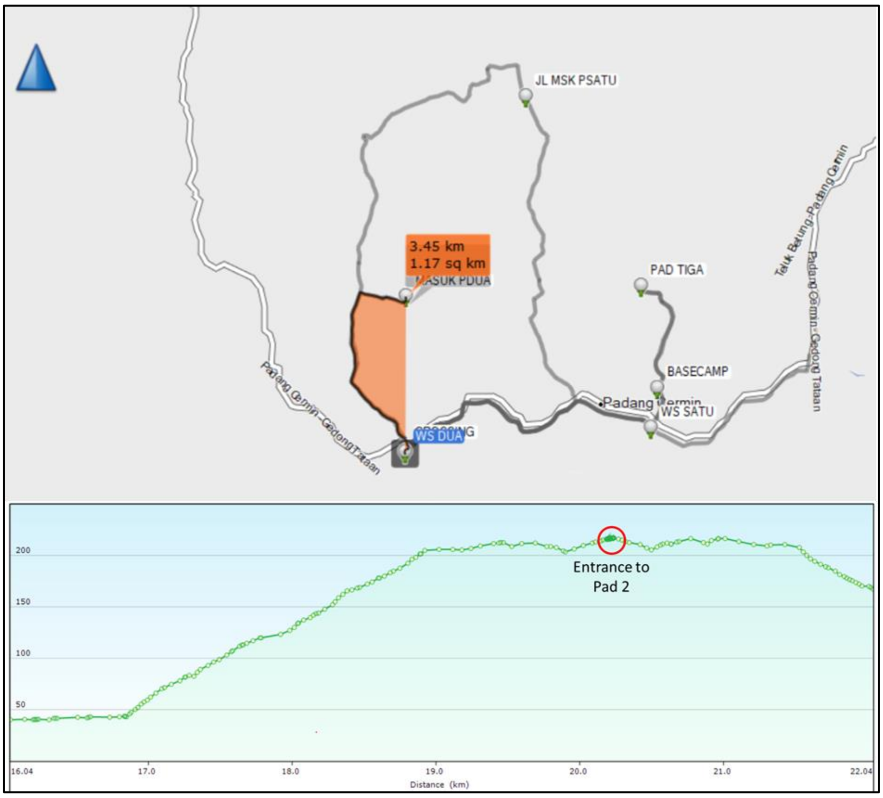


**Figure 2. Water source to the well pad 2 distance.**

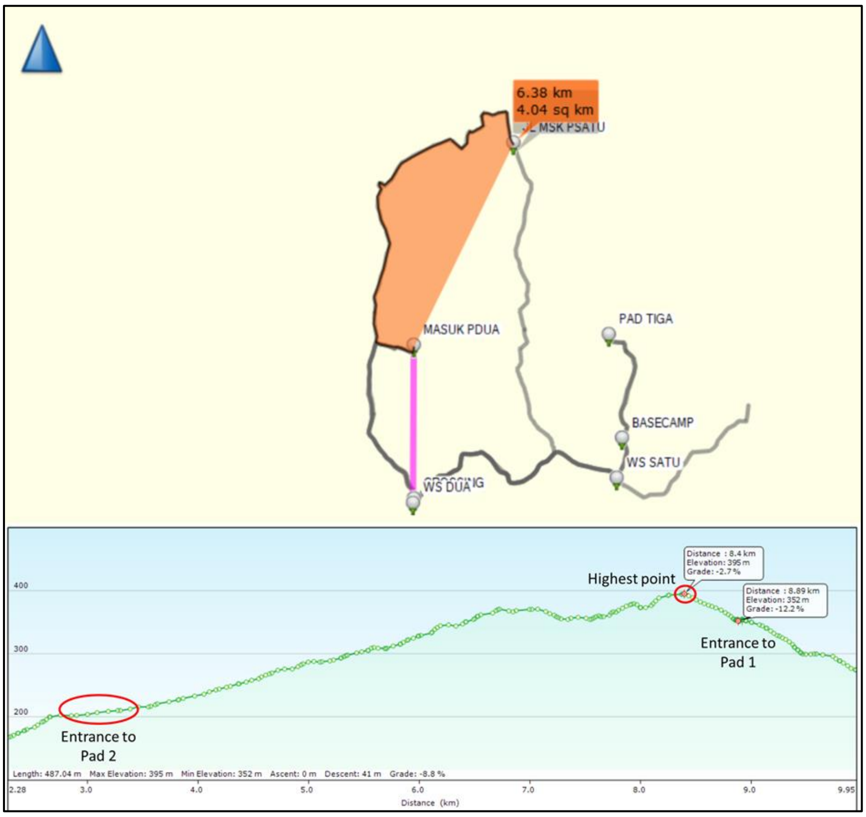


**Figure 3. Water source to the furthest well pad distance.**

One potential problem identified during site survey in Way Ratai was that the water source is adjacent to the community settlement. This can become an issue as the developer will put water pump in those areas and will disturb the local community (**Figure 4**). The geothermal developer has to install a pump house to reduce the noise and even pay some compensation for the disturbance to the local community. In Way Ratai context, the water pipeline is most likely to be built across the provincial road that require other permits to the local government and community. Failure to do so may cause the water supply infrastructure construction and/or operation to be stopped by locals, further delaying the whole project.

### 4.3 Sokoria

Sokoria is situated in Flores Island, Nusa Tenggara. As shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**, Flores Island is classified as savannah dry winter climate. Finding a reliable water supply was proven to be quite challenging due to the following reasons:

1. The river with neutral pH has a small flow rate (300 – 600 gpm) and is used by the local community, so it cannot be used by the developer.

2. The remaining river that is not being used by the community has very low pH of 2 and is located at around 8.5 km with 300 m elevation difference (**Figure 7**). However, this water source has a relatively high flowrate (8000-9000 gpm).

The summary of the water sources candidates for drilling in Sokoria is shown in **Table 5**. **Figure 5** shows the water supply survey in one of the rivers with preferable properties (neutral pH). However, the flow rate is very small (~300 gpm) and will not be enough to support drilling activity. Moreover, the water is also used by the local community. On **Figure 6**, the river has an adequate flow rate, but with a pH of 2.

**Figure 4. One of the river assessed in Way Ratai. Note that the river is located directly behind the settlement.**

**Table 5. Potential water supply candidates in Sokoria.**

| WDS | Location | Latitude | Longitude | Elevation (masl) | Elevation difference to MTB A wellpad (m) | Road Distance to MTB A wellpad (m) |
|---|---|---|---|---|---|---|
| WDS-01 | Nua Sada/Pancoran Wawotune | 8°47'13.59"S | 121°46'5.34"E | 1160 | 100 | 1,175 |
| WDS-02 | Tecoleco | 8°47'15.73"S | 121°46'8.42"E | 1111 | 51 | 1,100 |
| WDS-03 | Pancuran Mbujaria | 8°48'29"S | 121°46'38"E | 990 | -70 | 6,595 |
| WDS-04 | Loworia (Sokoria) | 8°47'40.79"S | 121°46'16.40"E | 858 | -202 | 3,746 |
| WDS-05 | Loworia (Roa) | 8°46'10.6714"S | 121°43'59.581"E | 740 | -320 | 13,700 |
| WDS-06 | Aebai (Roga) | *to be confirmed* | *to be confirmed* | 686 | -474 | 11,546 |

| Flowrate (GPM) | 26-Oct-16 | 3-Nov-16 | 4-Nov-16 | 31-Mar-17 |
|---|---|---|---|---|
| **WDS-01** | | | | |
| Timed-gravimetric/Volumetric | 2.5 | | | |
| **WDS-02** | | | | |
| Area velocity (floating object) | 62.2 | | | |
| Area velocity (flowmeter) | | 57.7 | | |
| **WDS-03** | | | | |
| Timed-gravimetric/Volumetric | 8.3 | | | |
| **WDS-04** | | | | |
| Area velocity (floating object) | 228.5 | 896.8 | | |
| Area velocity (flowmeter) | | 659.9 | | |
| **WDS-05** | | | | |
| Area velocity (floating object) | | | 8,735.2 | |
| Area velocity (flowmeter) | | | 9,725.0 | |
| **WDS-06** | | | | |
| Area velocity (floating object) | | | | 9,136.7 |
| Area velocity (flowmeter) | | | | 6,479.5 |

**Figure 5. Flow rate measurement and survey for fresh water supply in Sokoria.**

**Figure 6. Flow rate measurement on of the rivers. The flow rate is adequate but has a pH of 2.**

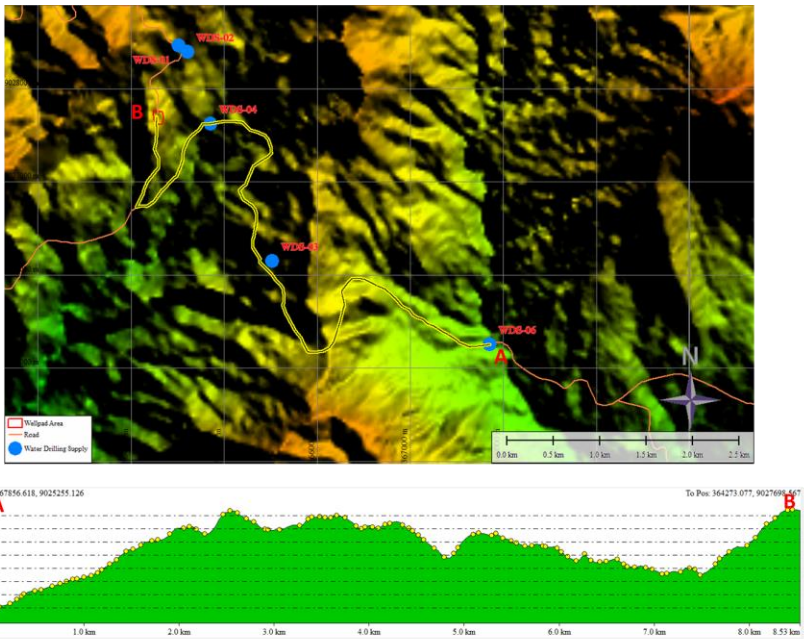


**Figure 7. The distance and elevation profile of the acid river with the well pad.**

### 4.4 Dieng

Dieng is a geothermal field in Central Java highlands at an elevation of 1800-2100 m above sea level. The field was initially developed in the 1990s. Currently, most of the plateau is intensely cultivated and there are a lot of villages and farms nearby the geothermal facilities (Hino, Itoi, Tanaka, Pambudi, & Khasani, 2013). In 2020, further development for Dieng Unit 2 is currently underway.

The problem with a brown field such as Dieng is that there are already a lot of settlements nearby, thus the water is also used by local community. Other water sources in the vicinity of geothermal facilities are acidic lake such as in the Merdada pond (**Table 6**).

**Table 6. Surface water bodies nearby Dieng Geothermal Facility (PT Geo Dipa Energi, 2019).**

| Water Body | Characteristics & flow rates | Suitability for drilling |
|---|---|---|
| **Merdada pond** | Acidic water, important irrigation water source | Not suitable |
| **Warna pond** | Acidic water | Not suitable |
| **Pengilon pond** | Acidic water | Not suitable |
| **Cidolok river** | Main river in the project area; 80-120 L/s average flow rates; main water source for farmland irrigation. Water extractions point already constructed | Suitable, with extraction restrictions (max. 20L/s during normal operation, no extraction during dry season) |
| **Tulis river** | 2.5km from project area; 100-150 L/s average flow rates; important water source for farmland irrigation; water extraction points already constructed. | Suitable, with extraction restrictions (max. 20L/s during normal operation, no extraction during dry season) |
| **Urang river** | Very low flow rates | Not suitable |

The average annual rainfall on the Dieng Plateau is around 260 cm, however, during dry season it can be as low as 3-8 cm per month. The potato agriculture in Dieng relies exclusively on the precipitation as the freshwater aquifer is very deep in Dieng (PT Geo Dipa Energi, 2019). The underground sources on the Dieng area is also prone to high $H_2S$ content.

As the agriculture industry is very important for the local community, Cidolok and Tulis river cannot be extracted during dry season, thus further complicating the drilling planning for Dieng Unit 2. To address this issue, other water sources should be identified. Several alternatives identified are:

- Utilising condensates from Unit-1 (can be up to 30 L/s flow rate). However, the water properties should be considered whether it requires further water treatment or not.
- Utilising brine from production well. This requires a complex water treatment plant as the geothermal brine contains a very high amount of dissolved solid and even heavy metal (Alamsyah, et al., 2020).

## 5. POTENTIAL MITIGATION OPTION

From the case study and literature review, typically water is in a short supply in the geothermal prospect area, while it is very critical for geothermal drilling for well control and prevent other drilling problem. Therefore, it is important to identify and provide water sources alternative to ensure enough fresh water for drilling. This study identifies several alternatives that can be used to ensure reliable water supply for drilling. Those alternatives can be used separately or in combination, depends on the water requirement and the actual condition on the drilling site.

### 5.1 Construct Robust Water Transport Infrastructure

After all water sources are identified and mapped, it is important to ensure that the water transfer system is properly built. Case study in Ijen showed that having a transfer pump with a pipeline is preferable instead of transporting the water using tank truck to ensure continuous water supply. The flowrate of the water source, distance and elevation difference between well pad and drilling site should be accurately measured to prevent any issues during operation (e.g. lack of booster pump due to higher head loss than expected). The pipeline specification and pump material should be carefully taken into account during engineering design process, as some water source might have lower pH and can be detrimental to pump and pipeline.

### 5.2 Drill Ground Water Well

If possible, drilling a water well can be an interesting proposition as it may not necessarily interfere with local community. However, authors' experience so far in geothermal projects in Indonesia never found any geothermal drilling that used artesian well.

### 5.3 Construct Water Treatment Plan for Acidic Water

In Eastern parts of Indonesia with equatorial savannah dry winter climate, the only viable water sources are the acidic volcanic crater lake with very low pH. To address this, Putranto et al., (2018) proposed a water treatment for acidic lake water with NaOH dosing (Figure 8).

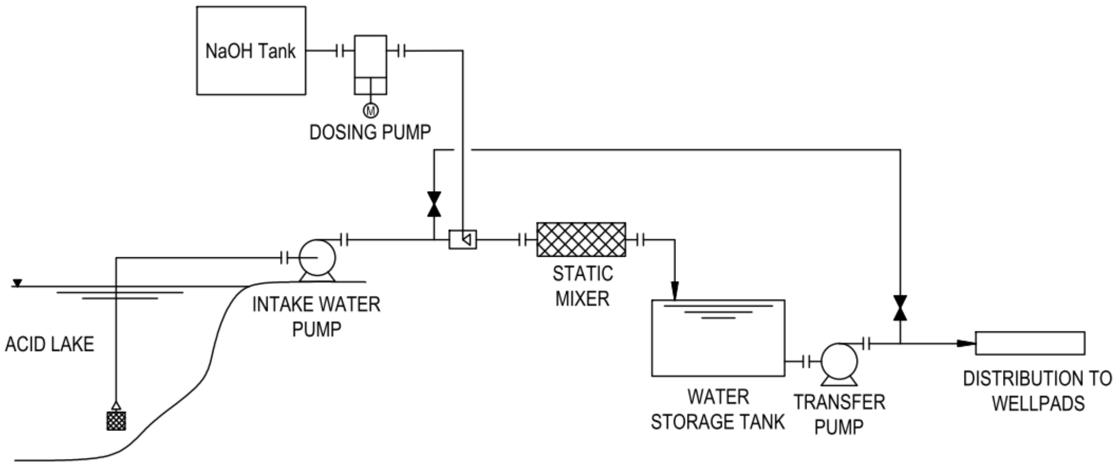


**Figure 8. Water treatment system for acidic lake water proposed by Putranto et al., (2018).**

This extra water treatment plan will surely require extra capital in the exploration phase. Therefore, its economic viability should be assessed first whether it is more economic to provide water treatment plant or other alternatives such as long pipeline and series of pumps.

### 5.4 Water Treatment Plant for Produced Brine

For a brown field with existing power plant unit such as in Dieng, the produced brine generally offers enough flowrate to cover drilling fluid requirement. However, it is most likely containing a lot of dissolved solid such as silica and other heavy metals, making it unsuitable to be used directly for drilling. As with acidic lake water treatment plant, the brine can be treated first to remove dissolved solid and heavy metals, with reverse osmosis as one alternative (**Figure 9**).

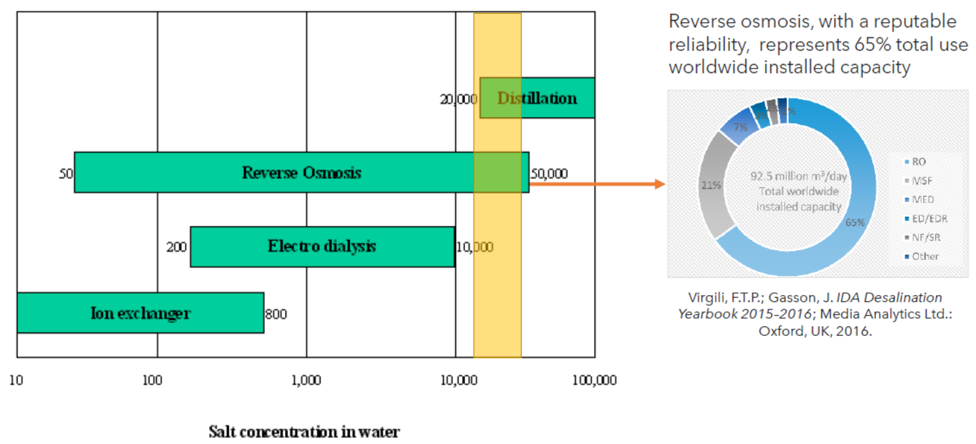


**Figure 9. Typical water treatment type based on Dieng brine properties (LKFT UGM, 2019).**

### 5.5 Ensure Good Communication with the Locals

Most of geothermal prospect area in Indonesia are located near people's settlement. Any installation of water transfer infrastructure such as Water Pump Station (WPS) and pipelines will surely disturb the local community in the form of noise, obstruction in the roads, etc. Ultimately, the water extraction from surface water sources such as river and/or lake can also be detrimental if the water is used by the locals for agriculture purposes such as in Dieng and Sokoria.

Therefore, it is crucial that the geothermal developer build and maintain a good relationship with the local community and inform the potential impacts that might rise from the drilling activity. Sometimes, it is necessary to give compensation for any discomfort the people suffer due to the water supply infrastructure construction and operation.

## 6. DISCUSSION

This study has given a brief overview of the importance of having a reliable water source in geothermal drilling, the typical estimate quantity required, and the requirement for the water transfer infrastructure needed. Generally, the water quantity required during total loss circulation cannot be 100% accommodated by the water pond constructed in the well pad. Therefore, it is important to have a reliable water transfer infrastructure instead to ensure continuous water supply for drilling.

Several challenges that might be encountered in finding and securing water sources for drilling are as follow:

1. The fresh water source might be located very far from the well pad and the elevation difference is very high. This might cause expensive investment in building water transfer system due to requirement of having a lot of pumps and pipeline.
2. The fresh water with neutral pH water is most likely have been used by the local community, the remaining options are to utilize the water source with less preferable properties, such as low pH.
3. Even if there are the fresh water sources available for drilling, it is likely that the water is also being used by the local community. In the dry season extracting water from this source is unlikely.

To address the difficulties in securing water supply for geothermal drilling, the following alternatives can be used:

1. Construct robust water transfer infrastructure with enough redundancy.
2. Drill ground water (artesian) well if possible.
3. Construct water treatment plant for water from acidic volcanic lake.
4. Construct water treatment plant for produced brine if possible.
5. Maintain a good relationship with local community.

Each of those options can be done in conjunction with each other alternatives. Further technical and economic feasibility study should be conducted to assess whether the selected option is the most cost-effective but still guarantee drilling success.

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