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# Challenges in the Design and Management of a 20-MW Geothermal Field: the Maibarara Geothermal Field (Philippines) Experience

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## ABSTRACT

The Maibarara Geothermal Field is located approximately 70 km south of the capital city of Manila, within the volcanic zone associated with the Macolod Corridor. The proven reservoir area, about 2.5 km$^2$, is a liquid-dominated system with neutral-pH fluids and temperatures of more than 300°C. The field was put in commercial operation on February 2014. To date, two production wells supply steam to the power plant and three reinjection wells are used for injecting brine and condensate back into the reservoir.

Based on the initial behavior of the reservoir, additional capacity can still be tapped to add another 10 or 20 MW to the existing power plant. Continuous production data will be collected to verify this initial behavior.

The paper describes the design and operation of the Maibarara geothermal field including challenges to its reinjection and production schemes. Measures to ensure judicious use of the small reservoir and the surface facilities are also described.

## 1. INTRODUCTION

The Maibarara Geothermal Field is one of the two geothermal fields explored in Mt. Makiling. Early exploration efforts were conducted by Philippine Geothermal Inc. (PGI) that brought to the development of the Bulalo Geothermal Field, also known as Mak-Ban Geothermal Field. Electrical surveys, gravity survey, magneto-telluric (MT) survey, and shallow temperature gradient drilling of 60-150 m were done until late 1970's on the western flank of Mt. Makiling. These activities revealed a north-trending dumbbell-shaped MT low-resistivity anomaly (6.8 km x 2.6 km) that led to the drilling of twelve wells which proved the existence of Maibarara geothermal system (Olivar *et al.*, 2013).

Located approximately 70 kms southeast of the capital city Manila and bounded by the provinces of Laguna and Batangas is the Maibarara Service Contract with an area of 1600 hectares (Figure 1). Maibarara Geothermal Field started development through a joint venture company called Maibarara Geothermal Inc. (MGI) on February 2010 and commissioned its 20 MW power plant on February 2014.

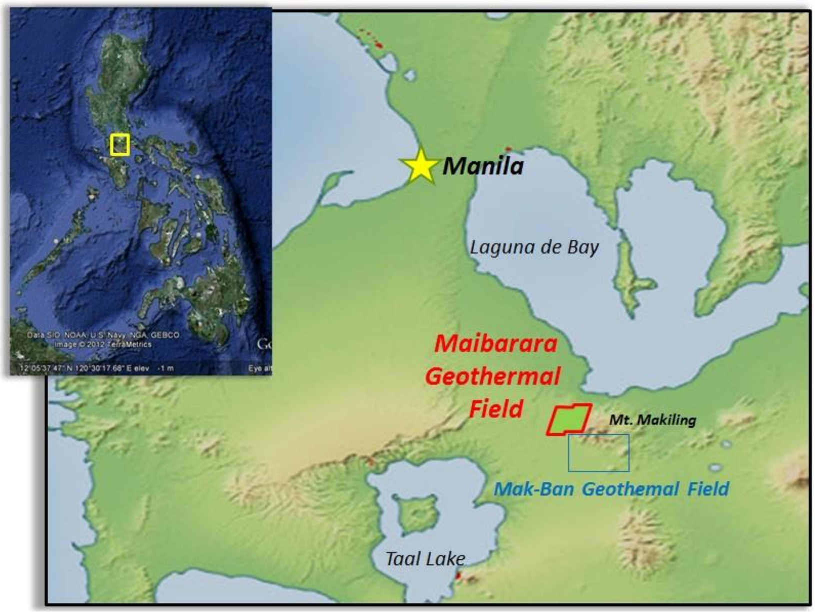


**Figure 1: Location of Maibarara Geothermal Field.**

## 2. FIELD DEVELOPMENT

Field development of Maibarara concession area was concentrated on the 2.5 km$^2$ proven resource area (Figure 2). Development commenced in early 2010 starting with the rehabilitation of the production pad and workovers of three PGI drilled wells Mai-6D, Mai-9D and Mai-11D in 2011. One additional production well MB-12D and one injection well MB-14RD for plant condensates were drilled by MGI in 2012 to complete the steam and reinjection requirements of the 20 MW power plant. The construction of the Fluid Collection and Reinjection System (FCRS) was completed in May 2013 and was commissioned in July 2013 while construction of the power plant commenced on April 2012 and was commissioned on February 2014. The power plant is a single-flash steam condensing turbine with a plant output of 20 MW. The FCRS and Power Plant site was developed in a compact setting covering a total land area of only 6 hectares (Figure 3). Mai-6D, Mai-9D, Mai-11D and MB-12D wells are anchored along a common deep cellar and convey fluids through the geothermal piping systems.

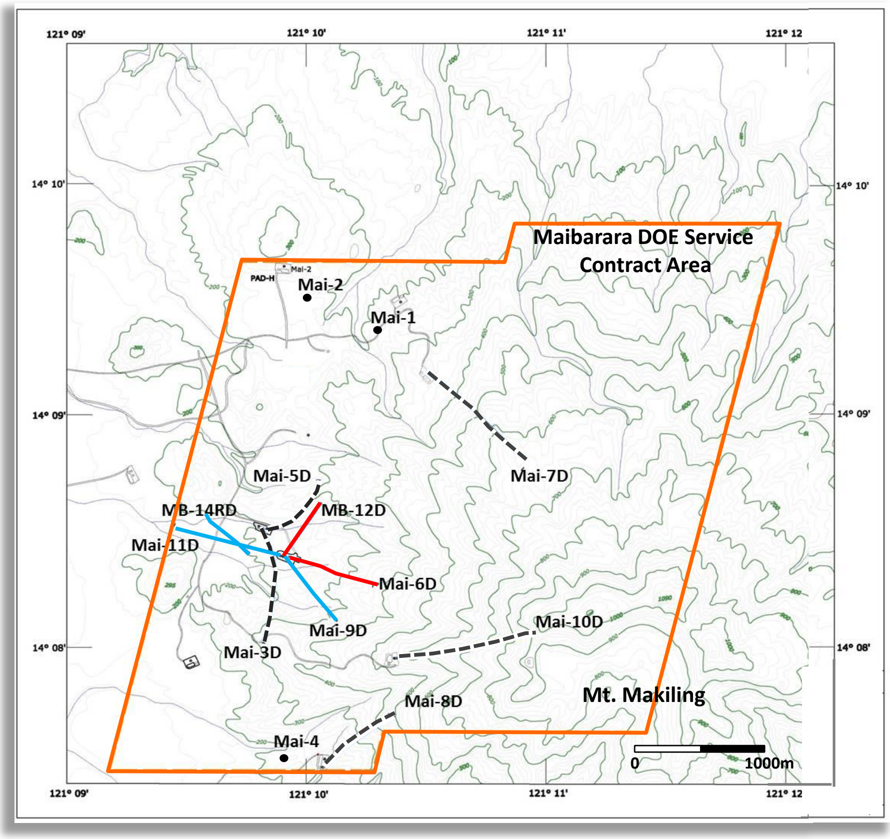


**Figure 2: Maibarara Service Contract area.**

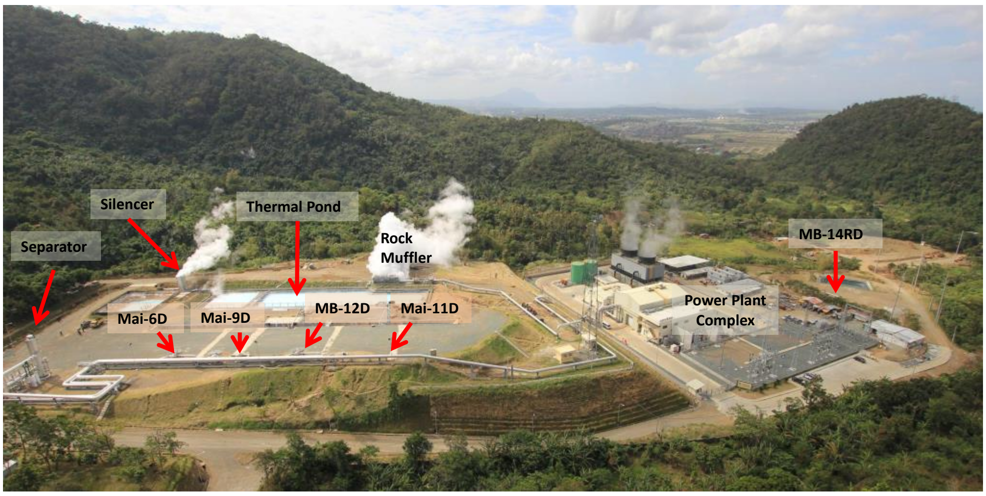


**Figure 3: Maibarara Field - FCRS and Power Plant site.**

### 2.1 Resource Characterization

Exploration works by PGI from the late 1970's to early 1980's resulted to the drilling of 12 wells at the Maibarara Geothermal Field. The presence of a high temperature geothermal resource was first established after the drilling of wells Mai79-11 and Mai3D. These two wells were drilled at the postulated upflow of the resource located at the center of the concession area. The drilling of 4 more wells (Mai5D, Mai6D, Mai9D and Mai11D) proved the existence of a commercially exploitable resource around a 2.5 $km^2$ area with estimated steam reserves of 700 MW-yrs.

2.1.1 Geology

The Maibarara Geothermal Power Project is located in the northwest flank of an extinct andesite stratovolcano, Mt. Makiling, belonging to a cluster of domes, maars, and volcanoes associated with the northeast-trending Macolod Corridor. Young, intense, and active volcanism within the 40-80 km-wide Macolod Corridor provides an ideal setting for the development of a geothermal system.

In terms of geology, Maibarara wells intersected, from the surface, a layer of tuff belonging to the Taal Formation. Subsequent rocks are composed of dacite and interlayers of tuff and andesite. Previous works classified this suite of rocks into Makiling Volcanics and the older Pre-Makiling Volcanics. At depths of about -2500 m, these volcanics were intruded by a hornblende-quartz diorite pluton as intersected by wells Mai11D and Mai3D. The Pre-Makiling Volcanics host the geothermal resource.

The wells encountered several faults during drilling and two major structural trends were identified: a NE-SW trending fault system and an E-SE oriented fault system. The NE-SW fault system includes the Bijiang faults and the almost parallel Maibarara, Nayon-ng-Kapos, and Kaplas faults. The E-SE fault system on the other hand, includes the Puting Lupa, Mapinggon, Mapinggon North, Mai9, and Siam-siam Faults. Subsurface projection of the faults can be correlated to known permeable zones in the wells. Furthermore, the Maibarara and Nayon ng Kapos Faults form the western and eastern boundary of the resource, respectively. Permeability in the field is also associated with lithologic contacts between tuff and andesite layers within the Pre-Makiling and Makiling Volcanics.

2.1.2 Reservoir Characteristics

The first two well drilled in the northern section of the field (Mai1 and Mai2) intersected low temperature formations (190°C to 240 °C) with temperature reversal profiles indicating the outflow region of the reservoir. Wells drilled at the center of field (Mai3D, Mai5D, Mai6D, Mai9D and Mai11D) encountered formations with good permeability and reservoir temperatures greater than 300°C. Flow testing of these 5 wells discharges highly two-phase fluids with enthalpies ranging from 1500 kJ/kg to 2300 kJ/kg indicating the existence of two-phase fluids in the upflow region. The two wells drilled in the south, wells Mai4 and Mai8D intersected formations with temperatures of 290°C to 300 °C but of poor permeability.

The top of the convective zone is shallowest in Mai-1 and Mai-2 which can be intersected at -50 mASL. At the center of the resource, the reservoir was first intersected at -400 mASL to -700 mASL while in the south; the top of the reservoir can be intersected at depth between -950 mASL and -1200 mASL.

2.1.3 Conceptual Model

The hydrogeological model of Maibarara geothermal field as illustrated (Figure 4) is based on the drilling results where fluids residing in the reservoir have neutral-pH with temperatures ranging from 300°C to 320°C. The zone between -800 mRSL to -1600 mRSL defines the most permeable area due to lateral formation permeability and contribution of faults. Also, a natural two-phase horizon exists possibly from -1200 mRSL to mean sea level. Mai-5D tapped fluids nearest to the chemistry and character of the parent or source water of the reservoir while fluids tapped by Mai-3D, Mai-6D and Mai-11D were formed by normal dilution of the parent water, and Mai-9D fluids are the most diluted among the wells. Mai-2, Mai-7D and Mai-10D, which possibly respresent the peripheral (edge) waters of the Maibarara system, have similar chemistry that are different from the fluids tapped by Mai-3D, Mai-5D, Mai-6D, Mai-9D and Mai-11D. Non-condensable gases (NCG) of the discharged fluids range from 0.4% to 1.6%.

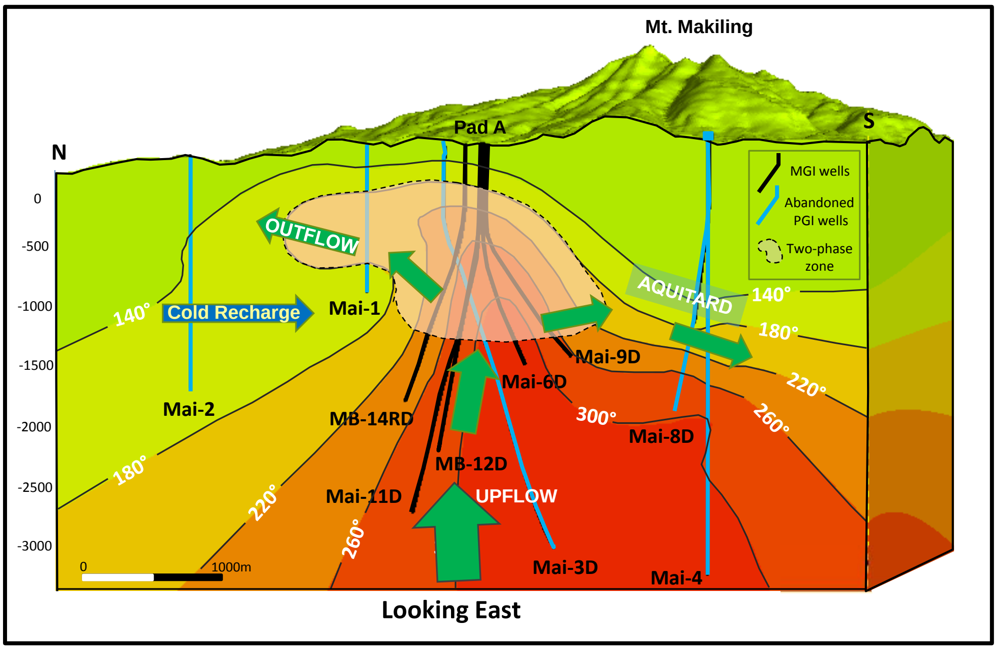


**Figure 4: Conceptual Model of Maibarara reservoir.**

### 2.2 Steamfield and Power Plant

The steamfield or FCRS site is developed on a very compact area, thereby the FCRS components (i.e. piping, vessels, rock muffler, cellar, etc.) are arranged in such a way that future drilling, maintenance and expansion works will not affect the continuous operation of the plant. The cellar itself and the production pipe trenches are some of the unique features of Maibarara. The cellar, which is 100 m long x 3.5m wide x 4.5m deep, can accommodate 9 wells. Presently, the cellar is anchoring 4 wells with a provision for 5 new wells. It is deep enough in such a way that its wellhead assembly components will not protrude to the surface, thus, if there will be future drilling of new wells, the rig can be easily erected above the cellar without hampering operations as the cellar can be readily prepared for this activity. The same with production branch lines where the piping runs beneath concrete-covered trenches before it comes out to the surface to join the array of pipelines to and from the separator vessel. Similarly, rig mobilization will not affect continuous operations of the FCRS.

The 20 MW power plant located at an elevation of 202 mASL is run by geothermal steam conveyed from reservoir through the FCRS. Interface conditions between the FCRS and power plant are established including steam characteristics to ensure consistency in the quality of steam delivered to the power plant at all times. The optimum steam interface pressure is around 6 kscg to 7 kscg and NCG of 2.5%. The power plant is designed and optimized as a single-flash, condensing steam power cycle based on the enthalpy and fluid flow characteristics of the production wells.

## 3. FIELD MANAGEMENT

The FCRS comprising mainly of geothermal piping systems interconnects the two (2) production wells Mai-6D and MB12D via a 30"Ø two-phase header going to a 20 MW separator. The two-phase fluid from the production wells are collected and directed to the separator vessel where it goes through the separation process with a separator pressure of 6.5 kscg. Separated steam is routed to the power plant interface through a 30"Ø steam line, while the separated water (brine) is re-injected back to the reservoir through the reinjection wells Mai9D and Mai-11D. A level control valve is installed on the hot reinjection line to be able to maintain water level at the separator. A dump line going to a permanent silencer is installed also in order to help arrest any rising water level at the separator in case of an upset. The steam line system is equipped with pressure relieving through the rock muffler to blow the steam whenever an upset in the power plant occurs. A pressure control valve (PCV) installed along the line going to the rock muffler controls the separator pressure and the interface pressure. Power plant utilizes MB-14RD as injector for its effluent and condensates. Figures 5 and 6 show the compact field layout and FCRS process diagram of Maibarara Geothermal Power Plant respectively.

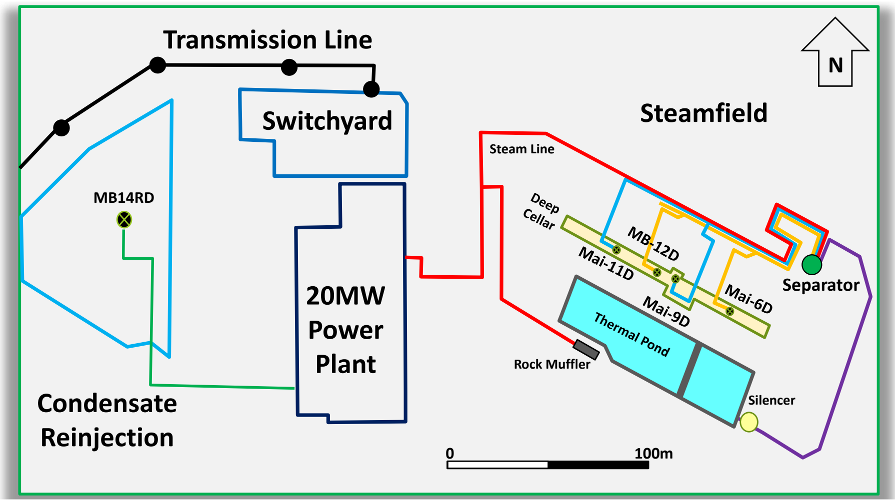


**Figure 5: Compact field layout.**

### 3.1 Commissioning and Field Activities

Right after completion of FCRS construction, steam flushing followed by opening, inspection and cleaning was conducted to remove the debris inside the pipelines, vessels and other FCRS components. Commissioning of the FCRS from June 2013 to October 2013 concluded when the power plant started to admit steam. During the commissioning period, all FCRS components, instrumentation system, safety components including steam quality and separator efficiency were all tested to validate if they are working according to design and sound global standards. After the tests, FCRS was then ready to supply the steam needed to generate 20 MW power.

Commissioning of the power plant started in October 2013 and was first synchronized to grid in November 2013. During the commissioning period, reliability and performance tests were conducted and finally declared commercial operation in February 2014 supplying 20 MW gross power output.

### 3.2 Operational Challenges

During steamfield commissioning, increased total brine flow of production well Mai-6D was observed while reinjection capacities decreased for Mai-9D and Mai-11D. Originally, Mai-9D was a reserved production well during field operation but converted as an injector to accommodate the combined brine flow of production wells Mai-6D and MB-12D. Based on parallel observations between the two injectors, it was hypothesized that reinjection capacities were consistently declining during injection of hot brine.

On the power plant side, reliability run and performance test of the concluded the commissioning activities at a steam consumption rate of 2.07 kg/s-MW. This indicates that plant efficiency is higher than the expected 2.2 kg/s-MW design steam rate. However, the power plant is currently struggling to maintain full load of 20 MW due to few suspected reasons such as increase in NCG level of the steam entering the turbine, scaling at the first stage of the turbine blades and increasing main cooling water temperature due to chemical treatment at the cooling tower.

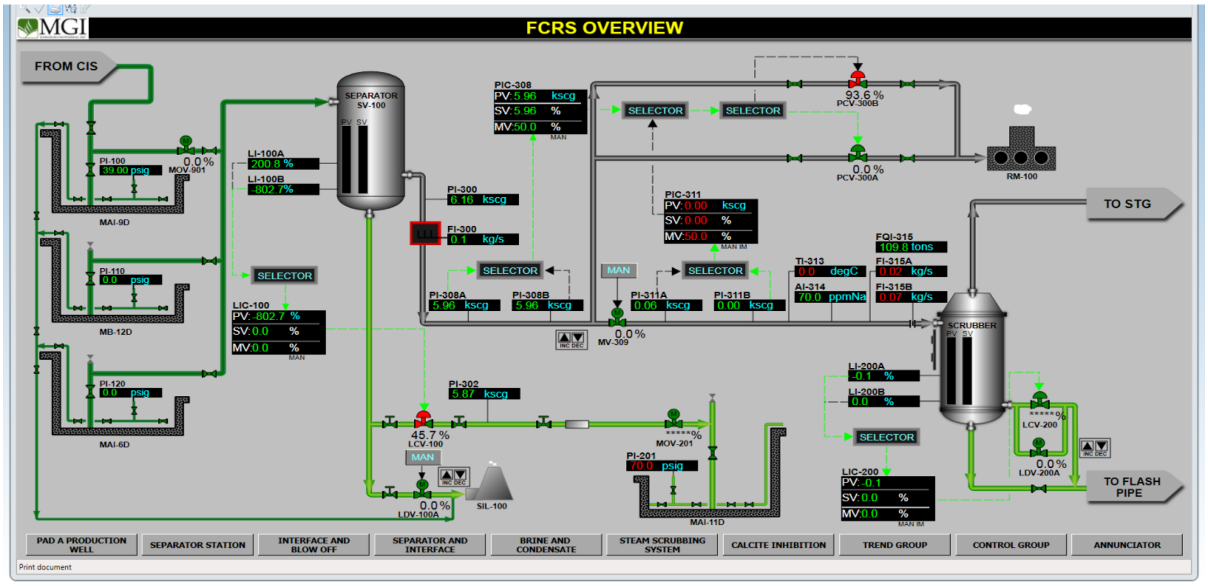


**Figure 6: FCRS process diagram.**

### 3.2 Strategies and Schemes

The combined steam output of the two production wells Mai-6D and MB-12D is more than enough to supply the steam requirement of the power plant in generating 20 MW. To minimize steam venting at the rock muffler, one of the wells is being throttled while the other is at full bore condition. Constant monitoring of the reservoir is conducted through fluid sampling for water and gas analyses. Tracer flow tests are also included in the activities to verify physical measurements of steam and brine flows, and enthalpies of the production wells Mai-6D and MB-12D.

The initial scheme of the reinjection system is to use the wells Mai-9D and Mai-11D as hot reinjection wells. The separated brine from the separator is conveyed through a 14"Ø line going to the hot reinjection wells. This scheme was implemented during the commissioning period. Initially, the wells accept the hot brine produced from the separator but the reinjection capacities were continuously declining with time due to the hot characteristics of the reservoir. Series of cold injection tests to prove that the wells accept cooler fluids provided the conclusion in switching to cold reinjection system by diverting all the brine to the dump silencer through the 14"Ø pipe dump line. Some amount of steam is discharged to the atmosphere while the brine is collected via the thermal pond to let it cool down to about $40^0$C before it is injected with the use of brine pump to Mai-9D and Mai-11D. Dilution of fresh water to thermal pond is also being done to help the cooling of brine and minimize the amount of silica before injecting to the reinjection wells. Intermittently, the two reinjection wells are flushed with fresh water to clean or disperse the silica in the well bore and push it to the formation. The cold reinjection system is operationally effective at the moment (Figure 7).

## 4. CONCLUSIONS

Maibarara Geothermal Power Project is a small and compact field susceptible to unexpected changes in resource characteristics. The natural two-phase horizon that exists possibly from -1200 mRSL to mean sea level can still expand and affect the current strategies and schemes to maintain viable operations. Targets for future drilling of new wells must be considered carefully to prevent immediate pressure drawdown and thermal breakthrough since the reservoir is small. Connections between wells must also be studied to sustain feasible production of the field. Managing a small scale geothermal field like Maibarara is challenging because of the small reservoir that can easily change its behavior due to the dynamic nature of fluids.

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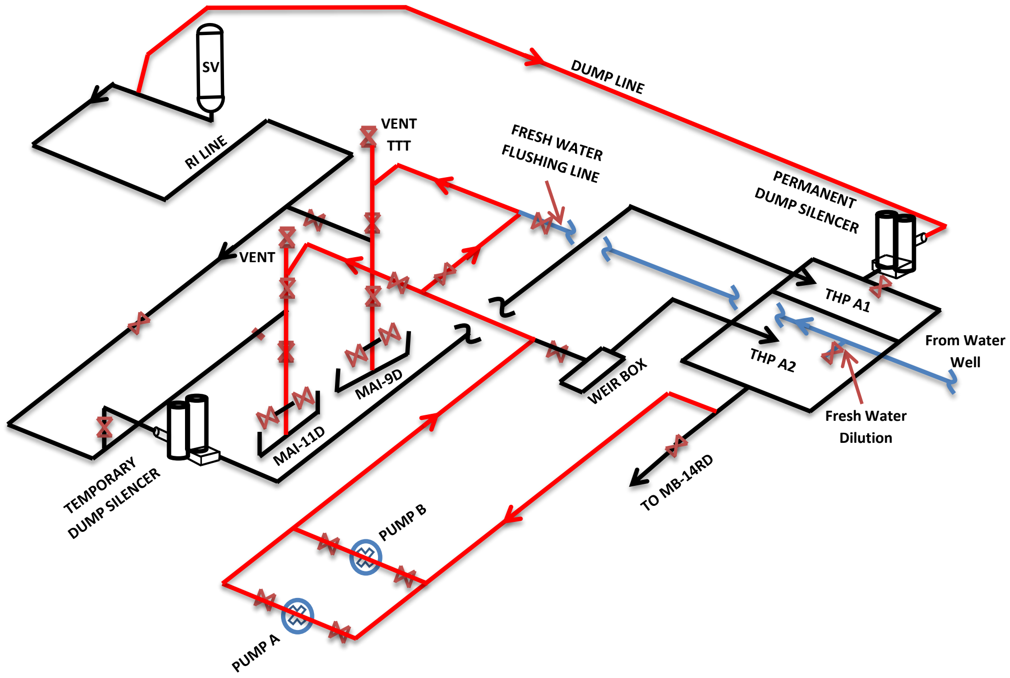


**Figure 7: Cold reinjection scheme on Mai-9D and Mai-11D.**