RESERVOIR RESPONSE TO FULL LOAD OPERATION PALINPINON PRODUCTION FIELD VALENCIA, NEGROS ORIENTAL,, PHILIPPINES

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Abstract

This paper discusses the results of the monitoring of the changes in the physical processes of the jluid in the reservoir as well as the changes in the production well output characteristics as a consequence of the production and reinjection strategies implemented upon the full load operation of the Palinpinon 1 and the Palinpinon 2 power stations.

The initial response of the reservoir in the Palinpinon I area was the decline of reservoir pressure which induced the expansion of the two-phase region or the Steam cap' that developed in the shallow part of the reservoir as geothermal fluid was continuously extracted for power generation. However, cooler reinjectedjluid intrusions into the production area prevented :he further expansion of the shallow two-phase zone and has affected the steam production of some wells. As a stop gap measure, near-field injection at the Puhagan area was minimized. The bulk of waste brine was reinjected in the Malaunay and Ticala areas which are muchfarther away from the production sector. In spite of the changes in the reinjection strategy, reinjection breakthrough persisted and more wells were affected as the pressure differential between the production and reinjection areas became greater. The steam production in some wells were further aggravated by the intrusion of acidic inflows believed to be condensate type jluid resulting anhydrite depositions in the wellbore. Also, cooler inflows originating from the reservoir periphery at shallow levels caused calcite deposition in some production wells. This cooler inflow was the result of the cooling of the formation due to pressure drawdown. Thus, the steam production capability of the field continued to decline inspite of the work-overs and in-fill production drilling.

In the Palinpinon 2 area, the reservoir pressures were observed to he still declining even after about two years since the modular power plants in the Nasuji (December 1993), Balasbalas (November 1991) and Sogongon (January 1995) areas were commissioned. Reinjection jluid returns and thermal decline in the shallow levels of the reservoir similar to the Palinpinon 1 area are now being observed, however, steam production has not been greatly affected yet. Improvement in the production and reinjection strategy in Palinpinon 2 is now being undertaken.

1.0 Introduction

The Palinpinon Production Field (Fig. 1) is located roughly 15 kms. west of the coastal city of Dumaguete, province of Negros Oriental. Initial exploration studies of the field started as early as 1973. Upon the confirmation of the existence of a sizable geothermal reserve, half of the field, the Palinpinon-1 Production Field, was developed and consequently a 112.5 MWe power station was constructed which begun commercial operation in 1983. The generated power was supplied initially only to the island of Negros but was later extended to Panay island through the Negros-Panay submarine cable. After a decade, three modular power plants in the Palinpinon-2 area sprouted, adding another 80 MWe of installed capacity to supply the island of Cebu through the Negros-Cebu submarine cable.

As the heat was continuously mined for power generation, the reservoir response was closely monitored. Well testing and measurements, hand-in-hand with geochemical monitoring, was regularly programmed and implemented by PNOC-EDC. Based on the data gathered, the behavior of the field and the changes brought about by exploitation was fully understood. Consequently, reservoir management strategies and policies were formulated and implemented to optimize the use of this energy resource making it sustainable at least for the plant life of 25 years and eventually beyond.

In the Palinpinon field where compact development strategy was adopted by PNOC-EDC, rapid pressure decline in the reservoir particularly in the production area was the immediate response to exploitation. As a consequence, there has been an overall decline in steam production due to the decreased mass flows from the productions and lowering of enthalpies caused by the intrusion of reinjection fluid into the production sector. In addition, the development of mineral depositions, i.e. calcite and anhydrite, which restricts the flow of brine in the wellbore has also contributed to the decline in steam production.

2C Field And Reservoir Overview

The Palinpinon Field is one part of the 133,000 hectares Southern Negros Geothermal Field which covers almost one-half the peninsular area of the Negros Island (Fig. 1). The other part being termed the Baslay de Dauin Field.

The field lies within the coalescence of recent andesitic volcanic complexes of Cuernos de Negros, Mt. Guinsayawan and Guintabon and Balinsasayao. Major Structural features mapped in the area include the NE trending Ticala, Nasuwa and Puliagan Faults; as well as NNW-N-NNE trending Okoy, Nasuji and Sogongon faults (Fig. 2). Although these structures provided the major permeability in the field, lateral permeability associated with

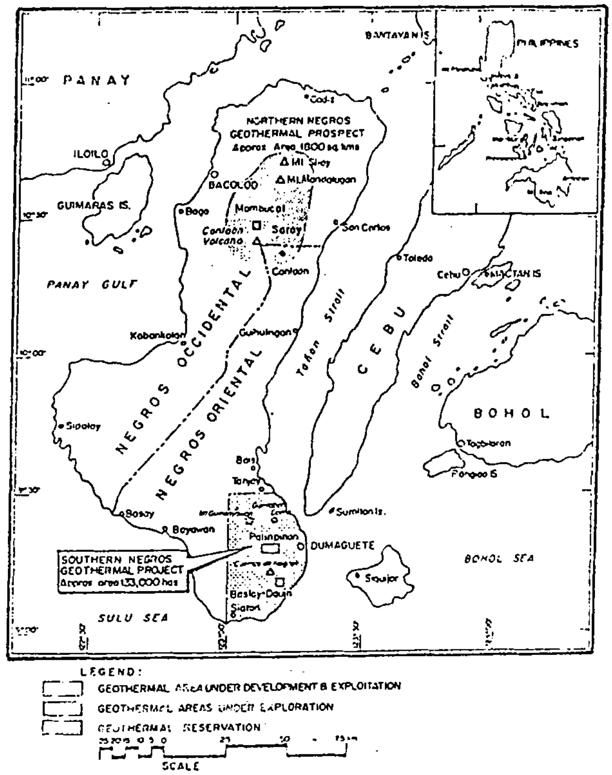


Figure 1. Location Map of the Palinpinon Geothermal Field (After Urbino, et. al., 1988)

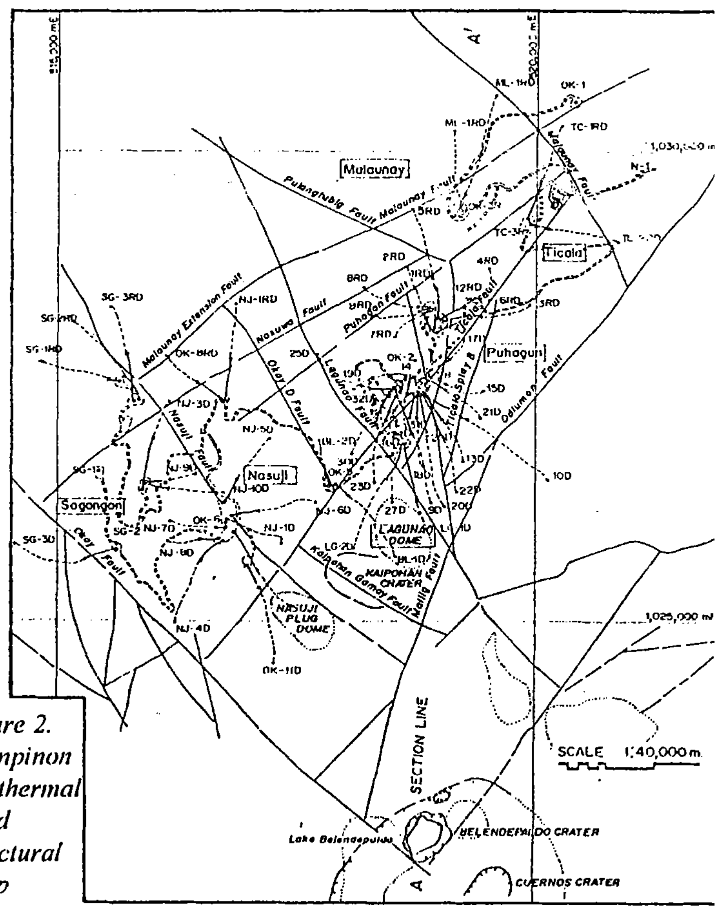


Figure 2. Palinpinon Geothermal Field Structural Map

sedimentary formations wcrc also encountered, c.g. So. Ncgros Formation. Tlicsc structures, while playing major role in tlic fluid circulation **of** tlic systcni. provided good communication bctwcen thc rcinjection **and** production sectors.

Tlic rcscrvoir was initially liquid dominated with localized two-phase zones at shallow levels. The hydrological flow of the system as conceptualized based on chemical and measured physical data is **shown in** Fig. 3. **Hot fluid** having temperature greater than 320°C upflows beneath tlic arca south of Puhagan, bifurcates at shallow levels to **form** the two outflow structures of thc systeni **as** patterned by the temperature contours of Fig 4. The flow towards the northeast to the lower elevations of the Okoy valley was said to be associated with

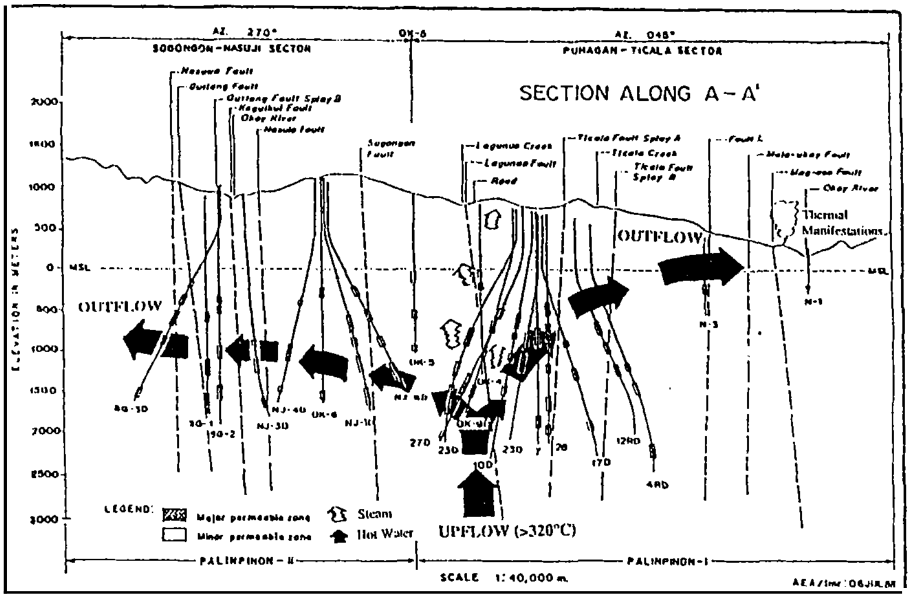


*Figure 3. Hydrological Flow Model of the Palinpinon Geothermal **Field** (After Urbino, el. **al.**. 1988)*

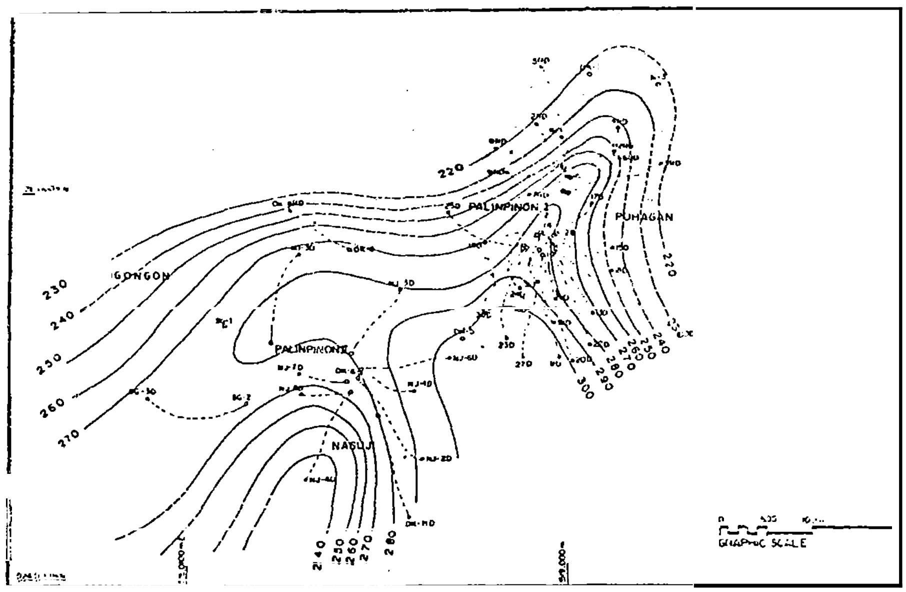


***Figure 4. Temperature Distribution of the Palinpinon Geothermal Field** Showing Directions of Fluid Flow (After Urbino, et. al., 1988)*

the Ticala Fault and the fluid was lcss diluted. This is the Palinpinon arca where the first **112.5** MWc power station of NPC was constructed. The weshvard flow, towards the Nasuji-Sogongon area, however, was acconipanicd with dilution of less mineralized and cooler fluid and was not associated with **any** structure. It was also believed **that a** minor upflow occurs beneath **the** Sogongon arca. **The** Nasuji-Sogongon is tlic Palinpinon 2 area where **three** modular power plants with a total capacity of 80 MWc arc situated.

3.0 The First 10 Years (1383 - 1993)

Thc 112.5 MWc Palinpinon I power statio:- begun commercial operation in 1983. It was designed to operate as a variable load station with typical load curves as shown on Fig. **5**. During the first year of operation. the average monthly power generation was low at 10 to 15 MWe as transmission lines across the Negros island were still being constructed. At this time the mass withdrawal rate ranged from 280 to 590 kg/s where about 53 kg/s to 240 kg/s was reinjected into wells drilled along the Puhagan area. Figure 6 shows the average rates of monthly mass withdrawal and reinjection and the average monthly station load During this period, the reservoir displayed an undisturbed state as there seemed to be a balancing effect of the mass extracted and that being reinjected. This was shown by the steady pressures in PN-7RD, PN-9RD and OK-12RD before 1985.

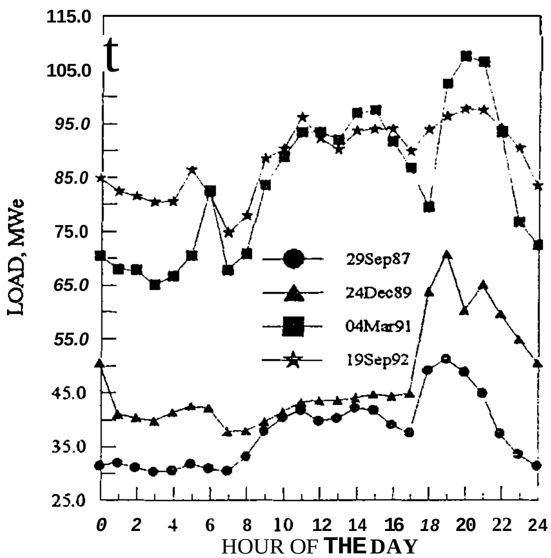


Figure 5. Typical Load Curves of the Palinpinon 1 Geothermal Power Plant (PGPP1). Gradual increase in station load was due to the completion of transmission lines across Negros and the interconnection of Negros-Panay grid.

From 1984 to 1989, the station load gradually increased as the transmission lines were completed. The whole island of Negros then had a peak demand of 54 MWe. Likewise, the rate of mass withdrawal increased from 325 kg/s to 538 kg/s and the rejection rate ranged from 154 kg/s to 326 kg/s which was distributed among PN-1RD, PN-2RD, PN-RE through PN-9RD and OK-12RD. It was during this period when two related fluid processes made an impact on the reservoir in response to esploitation - pressure drawdown and reinjection returns. These adversely affected the output of the production wells. In 1985, the pressures in the northeastern part of Puhagan, the reinjection area, started to increase due to waste injection but later declined when the bulk of reinjection load was shifted to the Ticala and Malaunay

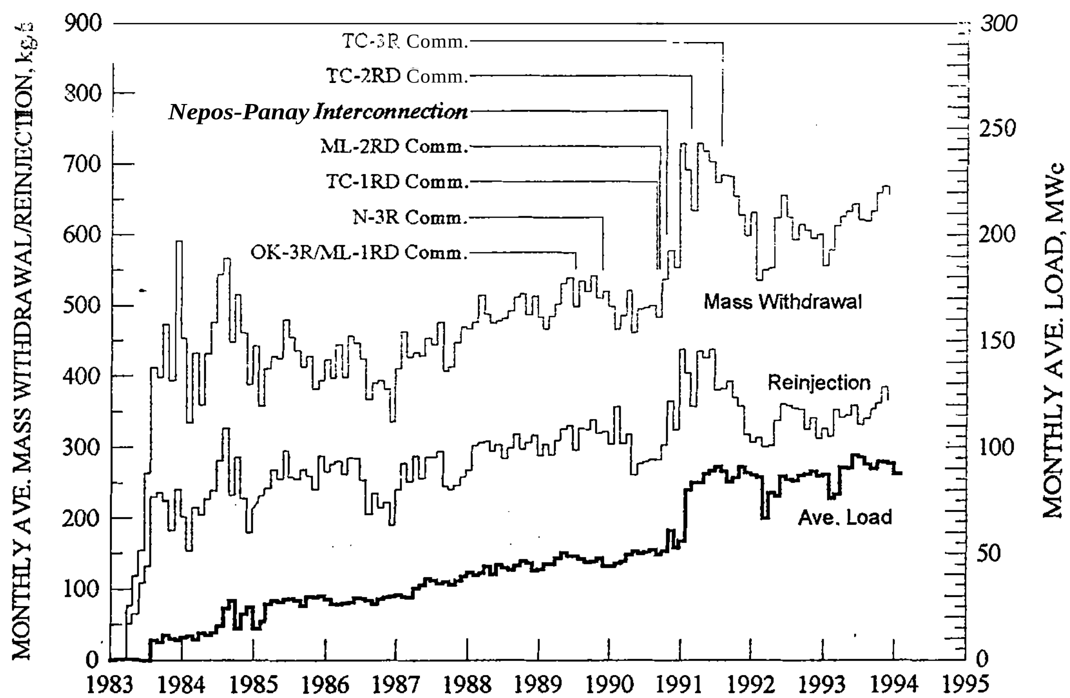


Figure 6. Palinpinon 1 Average Monthly Mass Withdrawal, Reinjection and Station Load

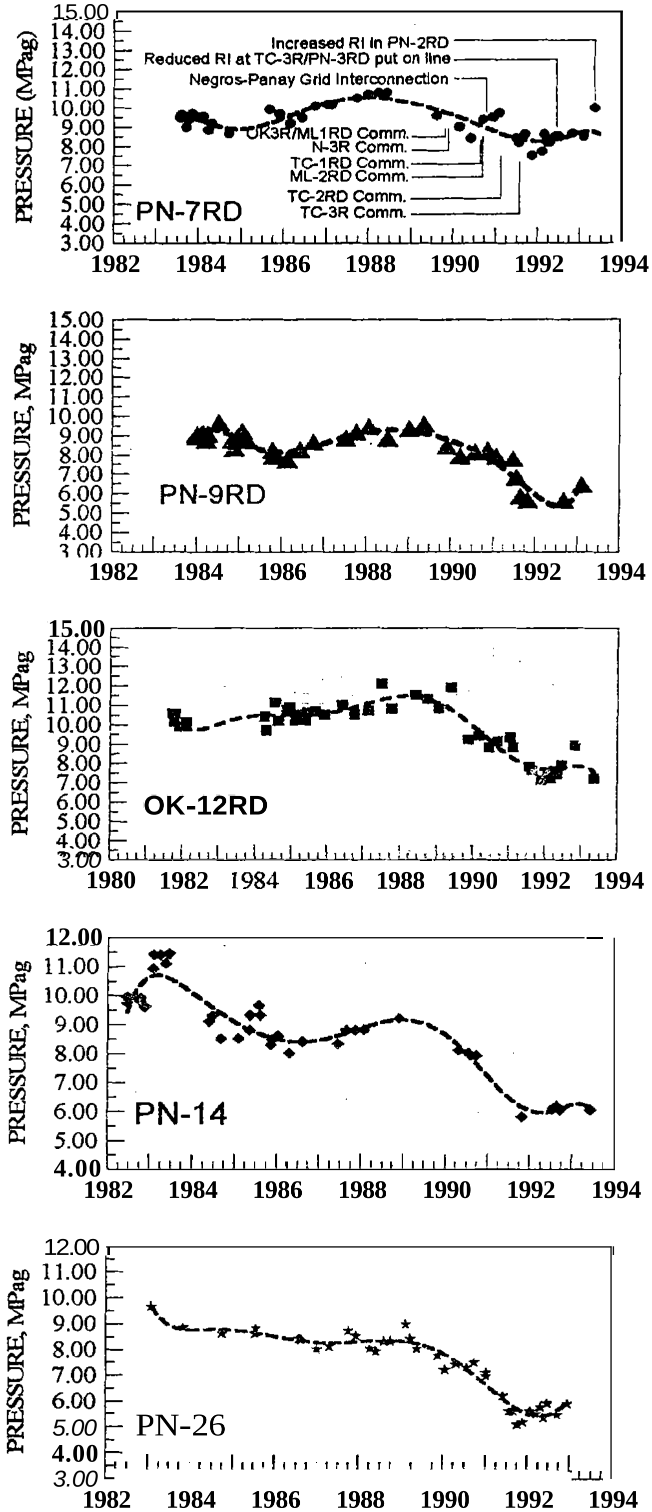


Figure 7. Pressure Trends of Selected Puhagan Wells

areas. Conversely, the pressures in the production sector had continuously declined as fluid was extracted for steam generation. Fig. 7 shows the pressure trends of some Puhagan wells. By 1988, the pressure drop in the central Puhagan area has reached 2.5 Mpa. Pressure drawdown as a result of fluid extraction caused boiling thereby increasing the fluid enthalpy of the wells. However, there is a corresponding steady or decreased mass flow.

On the other hand, reinjection fluid returns was induced by the pressure differential between the production and reinjection areas. Furthermore. this was enhanced by the good structural connections of the said areas like the Ticala and Puhagan Faults. Wells affected by reinjection breakthrough exhibit decreased enthalpies and increased mass flows like PN-26 and PN-29D in Fig. 8. Geochemical monitoring confirmed this observation by the increased chloride content of the discharged fluid In both wells, insufficiently reheated reinjection fluid returns which was injected at 160°C (saturation temperature of separated water at 0.68 MPaa) cooled the upper feed zones, the point of entry. This was manifested by the declining temperature trends in Fig. 9. Furthermore, reinjection returns downflowed through the well and eventually suppressed the hotter contribution from the bottom zones. This is illustrated by the temperature profiles of PN-26, PN-18D and PN-29D in Fig. 10. In the case of PN-26, the effect of cooling was so pronounced that the well ceased to produce commercially in 1988 and has since never recovered.

Realizing that there was a potential risk of output decline from the production wells due to reinjection breakthrough, in 1986 PNOC-EDC then decided to utilize the exploration wells OK-3 and N-3 for waste disposal and reduce the load at the Puhagan reinjection area. Additional reinjection wells (ML-1RD, ML-2RD, TC-1RD) were drilled and by 1990, the injection at the Puhagan area was lowered to 100 kg/s. This shifting of reinjection away from the Puhagan area resulted to the recovery of production wells. The enthalpies increased, but with corresponding reduced mass flows due to further drawdown of reservoir pressure as seen in PN-14, PN-26, PN-7RD, PN-9RD and OK-12RD. The net effect then was a steady steam supply just enough to meet the station demand for peak loads of

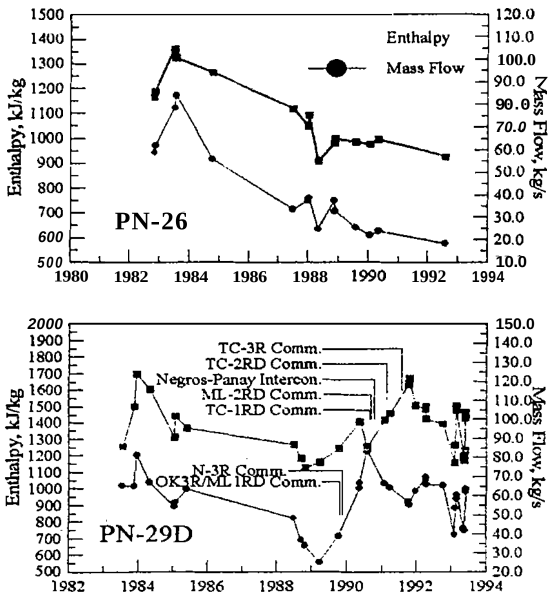
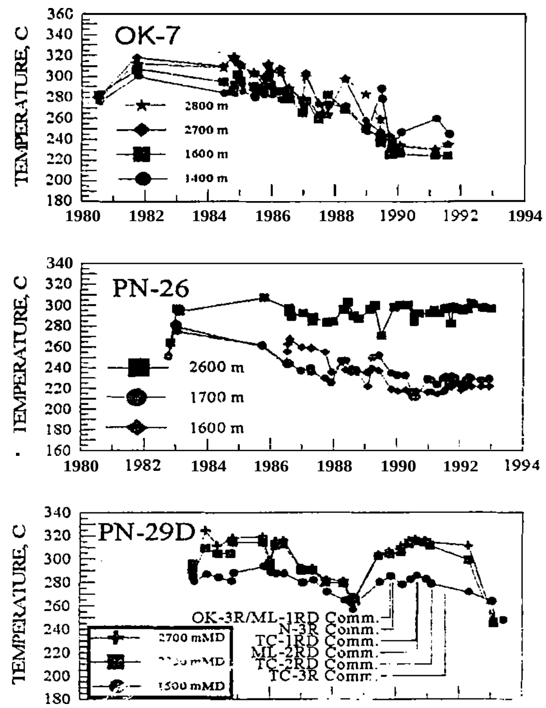
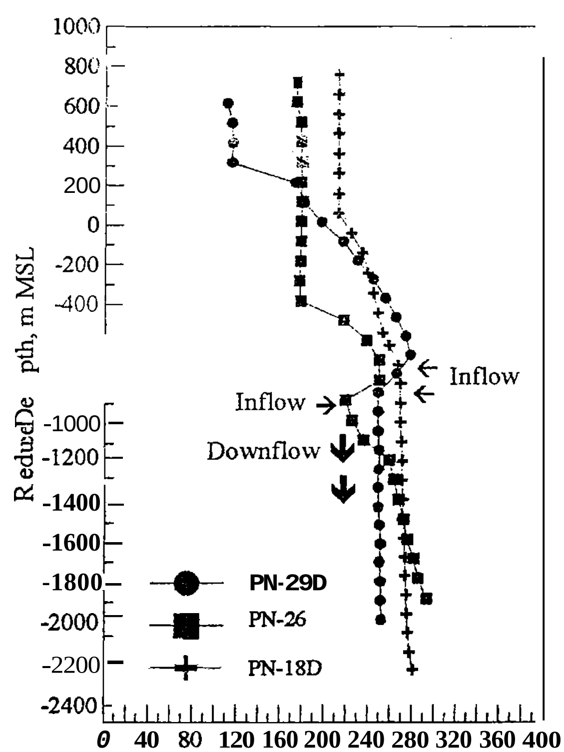


Figure 8. Mass and Enthalpy Trends of PN-26 and PN-29D



When the Negros-Panay interconnection was commissioned in October 17, 1990, the station load further increased Mass withdrawal rate also increased producing more waste brine for reinjection. The injection load at Puhagan then increased to 180 kg/s but was again reduced with the drilling of TC-2RD and TC-3R. Later TC-3R was cut-out due to its intersection with the Ticala Fault which provided good communication to the Puhagan production sector. PN-3RD was then re-utilized to absorb the load of TC-3R whch at full open. accepts brine at 230 kg/s. Further pressure drawdown was experienced due to the increased mass extraction that reached 729 kg/s in April 1991 and the problem of reinjection returns was further aggravated causing increased mass withdrawal in the late 1993.

The continuing reinjection returns has been a threat to the life of the reservoir. Although, a recovery was attained when the waste injection was shifted away from Puhagan in 1990, more pronounced decline rate resulted after Panay was interconnected and by 1993, the field capability dropped to 960 tph from a beginning of 1500



the Lagunao area where two wells with high enthalpies had been drilled and further reduction of injection at the Puhagan area by shifting the waste load farther away were two options being considered at that time.

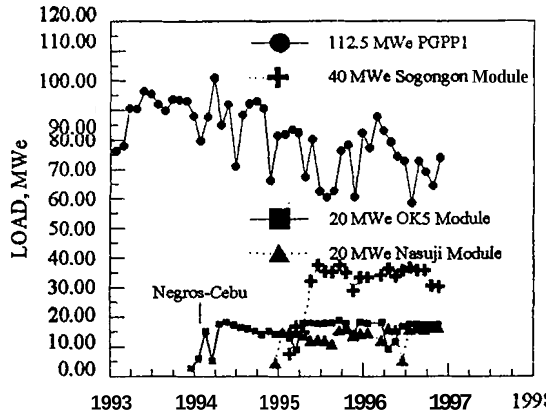


Figure 11. Palinpinon Power Stations Monthly Average Loads

4.0 The Field at Present

4.1 Plant Loading. Mass Withdrawal and Injection

The 112.5 MWe Palinpinon 1 Geothermal Plant (PGPPl) is currently operating at 75-85 MWe monthly average load which is just above the 75% plant factor limit. When the Negros-Cebu submarine cable was energized last January 26, 1994, about 70 MWe of electrical power from the Palinpinon 2 modular power plants was exported to Cebu. The 20 MWe Nasuji , 20 MWe Balasbalas and 2x20 MWe Sogongon modules were commissioned December 1993, November 1994 and January 1995, respectively. It is apparent in Fig. 11 that the P2PF stations were more base loaded than PGPPl. This was because NPC designated PGPPl as the 'frequency marshall' which will absorb any sudden changes in the Negros-Panay and Negros-Cebu grids.

In the P1PF, the present mass withdrawal from 23 wells ranged from 511 to 710 kgls but is seen to decline in 1996. About 350 kg/s is being reinjected into 8 wells. Meanwhile, in the P2PF area, the three modular power plants make up a total fluid withdrawal of 331 to 463 kgls from 13 production wells of which 171 to 237 kg/s is being injected into NJ-IRD, SG-IRD, SG-2RD and SG-3RD.

4.2 The Pressure Drawdown

Table I. Pressure Drawdown in Palin inon Geothermal Field

	Reservoir Pressure (MPa) Baseline	Current	Pressure Drop
P2PF	10.0		

Pressure drawdown is the immediate response of the reservoir to brine extraction. To date, the pressure drop has reached approximately 6.0 MPa in the PlPF area and approximately 3.0 MPa in the P2PF area since the precommissioning stage (Table I). In PlPF, the pressures has been stable in the past four years (Fig. 12) indicating equilibrium between the fluid withdrawn and those recharging the reservoir, including cold inflows and natural recharge. On the other hand, the pressures in the P2PF area are still declining even after two years since the commissioning of the modular power stations. It can also be seen in Fig. 12 that even during the pre-exploitation stage, the pressures in the P2PF area has been affected by the fluid extraction from PlPF suggesting that the two areas are interlinked. It is expected that the P2PF area will attain pressure stabilization in two years time based on the PlPF experience.

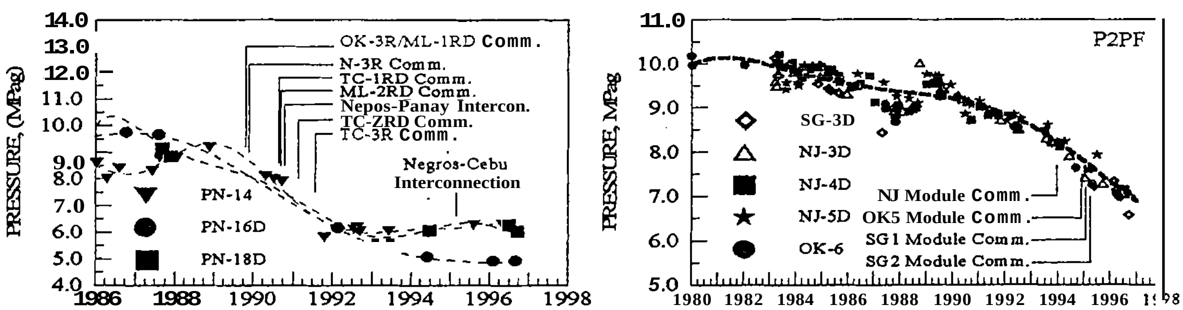


Figure 12. Reservoir Pressures in the Palinpinon I and 2 areas

As the pressures drew down due to exploitation, the hydrostatic levels in the wells have dropped particularly in the Puhagan production area where the water level contours on Fig. 13 have the depression. Boiling occurred in the upper level of the reservoir and has further expanded the steam/two-phase cap that had existed even before exploitation. This steam/two-phase cap lies **between** +100 m to -400 m relative **to** the mean sea level (MSL) and has an aerial extent as shown Fig. 14. It is exploitable with an approximated storage volume of 2.47 cu, km. Amistoso(1993) estimated its power potential to 35.5 We-years. It is, however, believed that the recharge into this cap is limited **by** the vertical permeability which is lower than the horizontal permeability and the stabilization of the reservoir pressure after the **full** load exploitation at P2PF. Big hole PN-33 was drilled to tap this zone.

In P2PF, the effect of pressure drawdown is evident in wells OK-6 and NJ-4D. Figure 14 plots their mass flows and enthalpies. Bore output measurements in OK-6 yielded a generally declining trend in mass flow with corresponding increasing trend in enthalpy. Although, pressure drawdown had raised the well's enthalpy from its baseline value of 1300 kJ/kg (1980) to 1500 kJ/kg (1996), its mass flow substantially dropped from 80 kg/s to **45** kg/s resulting to a net decline of steam flow from ***58*** tph to 65 tph.

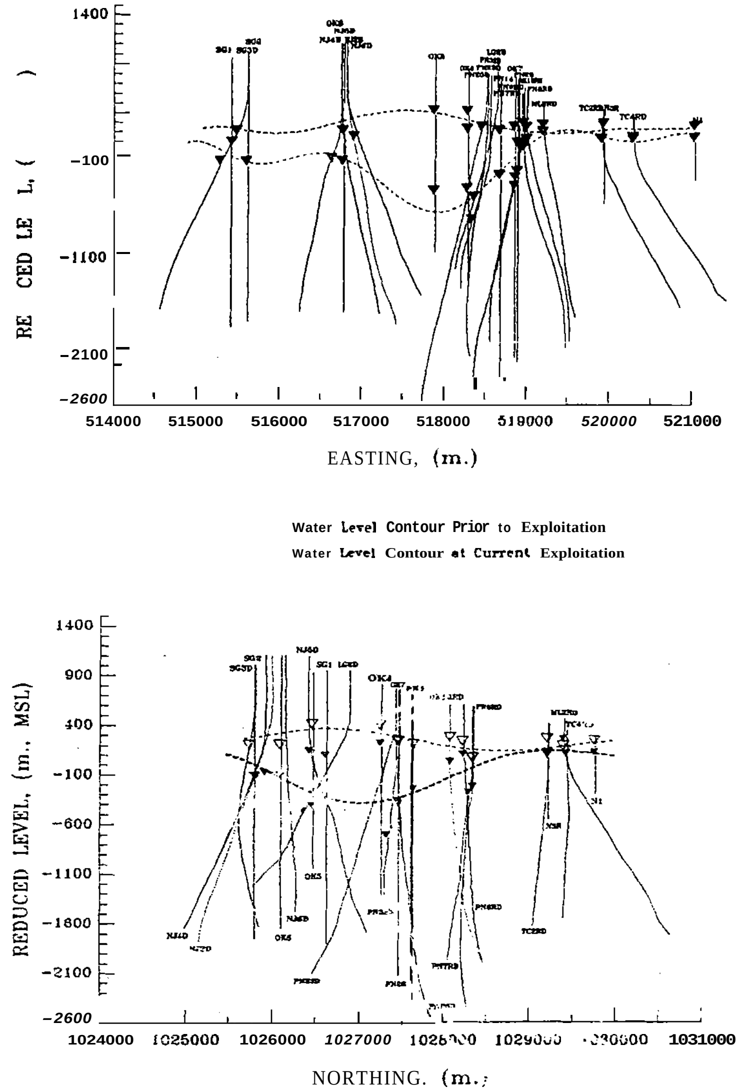


Figure 13. *PIPF* ***Vertical Contour*** *of* ***Water Levels*** *in* ***Shut-in/Slightly Bleeding*** *Production/Reinjection* ***Wells (After*** *Amistoso,* ***1993)***

Similar trends could also be observed in NJ-4D. Except, however, for the well's enthalpy which had almost remained at about 1220 kJ/kg, the mass flow had slightly decreased from 70 kg/s to ***55*** kg/s. The steam output is still within the baseline value of approximately 60 tph, however, the trend is apparently decreasing.

The relatively constant enthalpy of **NJ-4D,** despite of the pressure drawdown, was believed to be caused **by** the sufficiently faster recharge of a mixture of reinjection returns and cooler meteoric water entering the well at its upper feed zone which can counteract fluid boiling as pressure drops.

4.3 The Reinjection Breakthrough

The intrusion of the cooler reinjection fluid especially into the upper permeable zones of most production wells remained the main culprit to the sustainability of the life of the reservoir. The following production/reinjection strategies being adopted **by** PNOC-EDC such as:

(a) tlic reduction of infield injection at Puliagan **by** shifting tlic bulk of waste load to tlic Malaunay and Ticala areas;

(b) prioritization of utilization of high cnthalpy wclls;

(c) acidizing ***of*** preferrcd reinjcction wells, e.g. OK-3R and PN-2RD, to regain and even improve tlic original capacity which was daniagcd **by** mineral depositions and,

(d) lately, ccnicnt plugging of thc upper communicativc zones as had bccn donc in PN-2RD and PN-3RD.

With all these strategies iniplementcd, the reservoir condition was only benefited and improved in a short tcrm. **As** of lhc third quartcr **of 1996.** 35% **of** the production wcll complcment in **Puhagan** still displaycd reinjcction breakthrough (Hcrmozo and Mcjorada, **1996)** although reactive wcll utilization stratcgics and plant shutdowns during prcventivc maintcnancc schedule (PMS) allow on and off recovery of some production wells.

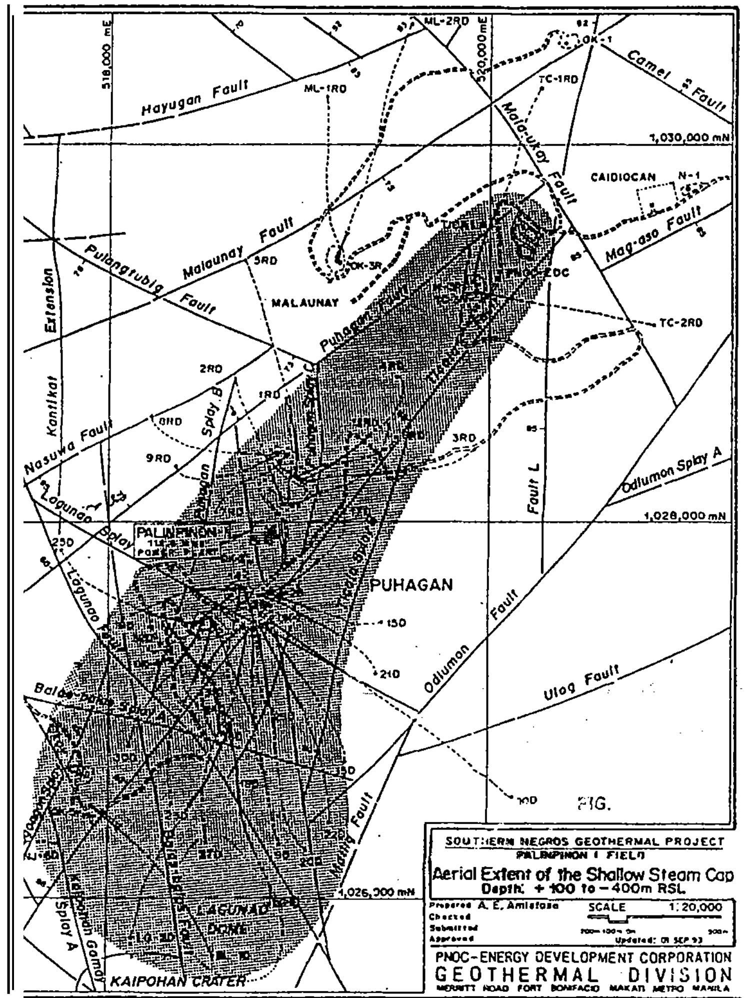


Figure 14. Aerial **Extent** *of Steam/Two-phase* Cap *at P1PF*

Table II shows a comparison of the reservoir pressures and temperatures at depths where reinjcction fluids made entry into the wells. It shows that esploitation induced pressure drawdown in PlPF has also lowered the reservoir teniperatures **by** 18 to 38 dcgrce in about 13 years. Ideally, boiling should have occurred with further pressure rcduction, howcvcr, current measured values indicate that tlie rcservoir fluid is at the sub-coolcd liquid condition. This can be mainly attributed to cooler reinjection returns.

On the lighter sidc, rcinjcction fluids intruding **tlie** production scctor **at** dccpcr Icvcls provcd to bc beneficial to the rcscrvoir **by** providing pressurc support. Monitoring showcd that reinjcction wclls intersecting the Odlumon Fault enhanced incrcascd steam flows on some production wells due to iiicreascd mass flows, e.g. OK-10D and PN-20D. It has becn obscrvcd that OK-10D declinc in steam flow due to pressurc drawdown (34 tons/hr) was much niorc higher than that due to enthalpy decline (11.4 tph) caused by reinjection returns. Hence, it **was** believed **that** the total shifting of injection away from the Puhagan may not bc wholly beneficial to the steam gcneration capability of the rcscrvoir (Amistoso, 1993). This was the main reason behind the just complctcd re-drilling of TC-3R (originally injecting to tlic Ticala Fault) towards tlic Odlumon Fault. Other wells intersecting the Odlumon Fault include the preferred wells TC-2RD and TC-4RD. Preferrcd wclls PN-3RD and PN-5RD also provide bcneficial support ***to*** the production sector.

At present, the phenomenon of returning reinjected **fluids** is king felt in the P2PF area. Geochemical tracer chloride detected in NJ-4D are currently at **4,300** ppm levcl compared to the baseline lcvel of 3,387 ppm. Likcwisc, in OK-6, thc rcscrvoir chloride has increascd from 3,400 ppin **to** 4,400 ppm (Hcrmozo and Mcjorada, 1996). This observation was supported by thc dccreasing lcmperaturc lrcnds. particularly in tlic upper feed zones, of these wells as shown on Fig. 16. However, the cooling effect of reinjection returns has not yet affected the steam production since the fluid is still at boiling state (the current measured temperatures are still **within** the corresponding saturation temperatures of the pressures, Table II). The substantial drop in the upper **feed** temperatures of NJ-4D in 1994 corresponded to the time when the pressure drawdown in area accelerated due to increased mass withdrawal as the modular plants were commissioned. Thus. at present. pressure drawdown is still **the** dominant fluid process in this area.

4.4 The Cold Inflow-downflow

Aside from reinjection returns. pressure drawdown has also induced **the** migration of cooler fluid into the reservoir. Three production wells, namely, OK-7, PN-18D and PN-29D were confirmed to be experiencing cold **fluid** inflows. **In** OK-7, the series of spinner surveys were able to measure 15 kg/s of inflow in November 1996. In these wells, the **fluid** downflows from the upper zone (1400-1600 mMD or -800 m to -1000 m MSL) quite strong enough to suppress the hotter fed from the **bottom** zones. In conjunction with the spinner surveys, downhole sampling was conduction in the wells. The chemical analysis of the recovered samples indicated that these are partially equilibrated, steam heated, acid sulfate fluids mixed with deep reservoir fluids. they are thought to be originating from the shallow condensate zones of the reservoir and has temperatures ranging from 220°C to 270°C (Hermozo and Mejorada, 1996). **Thus,** the sub-cooled state of the fluid at the upper zones of the wells **listed** on Table II **could also** be **caused by** these cold inflows. Ironically, for the term 'cold inflow', the temperatures of these fluids are still at the exploitable level, i.e. >220°C. Hence, one may recommend drawing the reservoir pressure further **by** about 2.0 MPa **and** allow boiling.

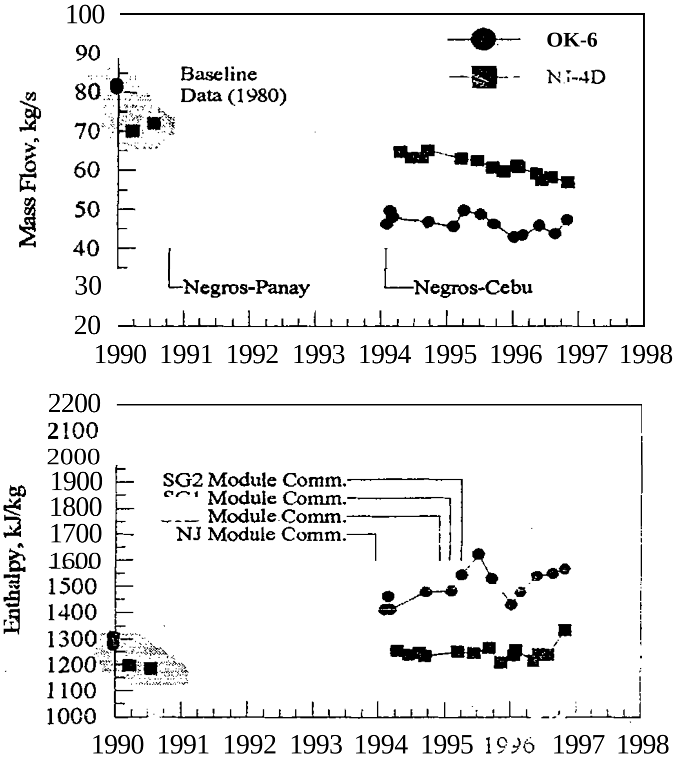
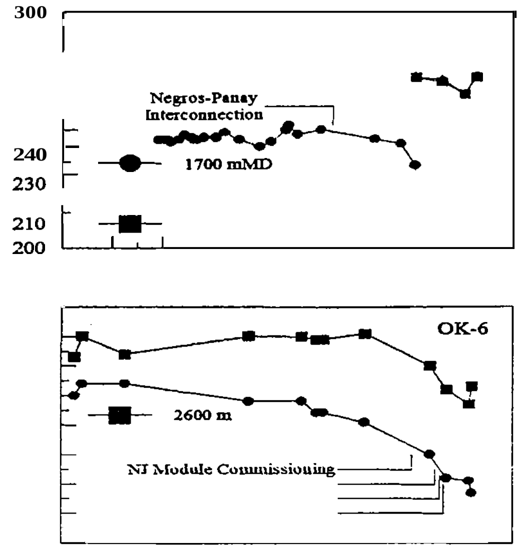


Figure 15. Bore Output Trends of Selected P2PF Wells

'able II.. Palinpinon Reservoir Pressures and Temperatures

Area/Well			Baseline	Current
P1PF	PN-14 (1600 m)	P, MPag	9.5	5.4
		Sat. T, °C	308	27[illegible]
		Measured T, °C	273	246
	OK-7 (1600 m)	P, MPag	8.7	4.7
		Sat. T, °C	300	261
		Measured T, °C	301	223
	PN-18D (1600 mMD)	P, MPag	7.4	4.7
		Sat. T, °C	289	261
		Measured T, °C	282	243
P2PF	NJ-4D (1700 mMD)	P, MPag	5.9	3.2
		Sat. T, °C	276	239
		Measured T, °C	246	230
	OK-6 (1400 m)	P, MPag	5.2	3.9
		Sat. T, °C	267	250
		Measured T, °C	266	246

OK-10D, PN-13D, PN-20D and PN-22D and in P2PF wells OK-11D, NJ-1D, NJ-2D and NJ-6D.



The initial generation capacity of PIPF was 1500 tph (157 MWe) and has dropped to 960 tph (90 MWe) in 1993 due to pressure drawdown and cooling caused by reinjected fluid returning to the production sector. With the detrimental effect of reinjection fluids to the production sector, the possible field capability decline rates were estimated at 42 to 162 tph/year (Sanniento, 1993).

During the first half of 1996, three production wells in PIPF, namely, PN-29D, PN-21D and PN-13D became non-commercial due to the combined effect of pressure drawdown, mineral blockages and reinjection returns (Sta.Ana, 1996). In addition, OK-7 which was cut-out in October 1995 for work-over and top zone plugging, failed to sustain discharge and has since can not be utilized. To date, six of the 25 producers are out of service losing about 39.5 MWe of steam capability (Table 111). Nevertheless, with the make-up and replacement well PN-33, the field was able to sustain the plant steam requirement of about 960 tph until the availability of Lagunao wells LG-3D and LG-4D. Upon the interconnection of Lagunao on October 25, 1996, the P1PF's current steam availability increased to 1,051.5 tph (Fig. 16) based on bore output measurements data. This has an equivalent capacity of about 110.0 MWe.

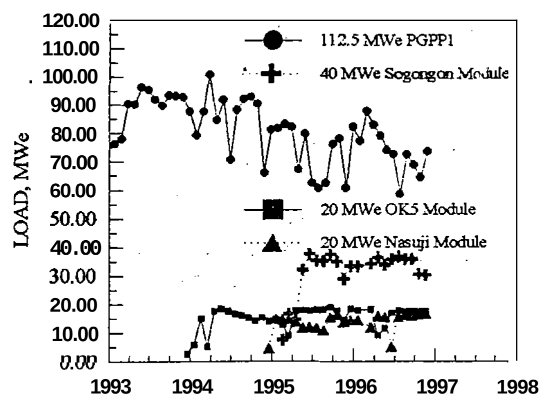


Figure 17. *PIPF* ***Steam*** Availability ***Trend***

In P2PF, although the negative effects of pressure drawdown and reinjection returns have been detected, the steam production has not yet been greatly affected Enough steam is still available to meet the demands of the three

Table III. Steam Availability at P2PF

Module	No. of Production Wells	Steam Available (tph)	Steam Available (MWe)	Plant Requirement (tph)	Excess Steam (tph)
OK-5	3	174.0	23.2	150.6	23.4
Nasuji	5	294.6	36.0	163.7	130.9
Sogongon	6	420.4	51.4	327.4	93.0

demands of the three modular power plants (Table III).

5.0 Conclusion, Current Reservoir Management Strategies and Recommendations

The Palinpinon field experience has demonstrated that in a system where the hydrological of fluid is associated with the geological structures, reservoir management is constantly faced with the problems of the detrimental effects of pressure drawdown and reinjection returns-the reservoir response to exploitation. To date, after 13 years of operation, the big pressure differential between the reinjection and production areas has caused massive reinjection fluid returns. Enhanced by the good geological connections and close proximity of the two areas, this has continuously threatened the steam production of the field The shifting of the bulk of injection load from Puhagan to Ticala and Malaunay in 1989 proved to be beneficial only in a shorter term and in turn contributed to more pressure drawdown. On the contrary, experience showed that deep injection. e.g. through the Odlumon Fault, could provide the needed pressure support to the reservoir while sufficiently reheating the injected fluid, thereby eliminating the cooling effect.

With the present understanding of the reservoir, production-reinjection strategies geared towards the sustainability of the resource to maintain enough steam supply to the power plant include:

(3) drilling of make-up and replacement wells;
(b) acidizing of wells to enhance permeability and increase acceptance of RI wells, productivity of production wells;
(c)) cement plugging of communicative zones in the wells e.g. PN-2RD, PN-3RD
(d) further reduction of injection at Puhagan in order to enhance the expansion of the two-phase cay:
(e) reduction waste load by prioritizing the utilization of high enthalpy wells, hence, the interconnection of Lagunao wells: and
(f) deep and hot injection into Odlumon Fault to provide pressure support to the reservoir .

It is also the belief that the current injection at Puhagan causes the 'bump' in the water level contour (Fig. 13). This prevents the fluid at the upper level of the reservoir to boil-off and remains at sub-cooled condition despite the dropping of pressures. Since, the temperature at this condition still warrants commercial exploitation, i.e. >220°C, it is recommended to allow boiling and produce steam from this level. This can be achieved by substantially reducing or totally eliminating the injection at Puhagan and transferring the waste injection farther away such as in N-1. Meanwhile, steam production could be augmented by tapping the inferred steadtwo-phase cap. For the worst scenario, substantial downloading of the power plants may be pursued to allow recovery of the field

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