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DEVELOPMENT AND PRODUCTION PERFORMANCE OF THE TIWI FIELD

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ABSTRACT

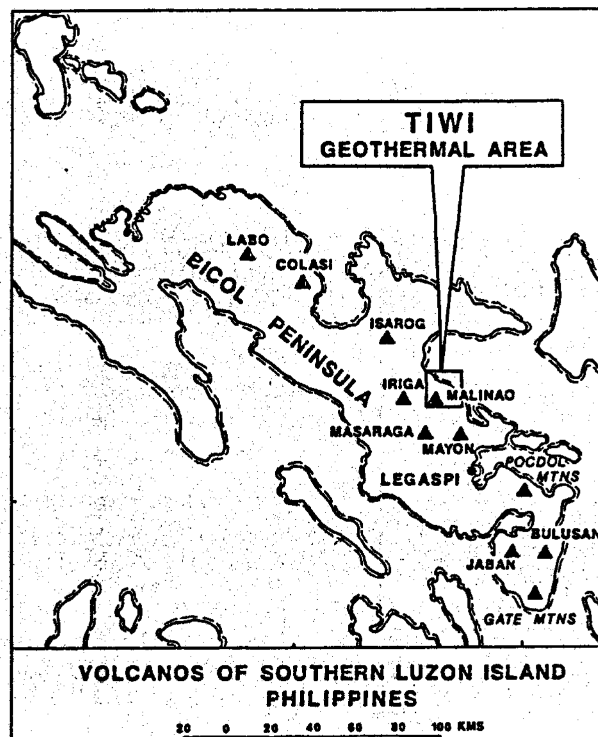
The Tiwi geothermal field on Luzon Island, Philippines, was developed during 1972-1982 by Philippine Geothermal, Inc. (PGI), the local subsidiary of Unocal Corporation, and the National Power Corporation. Exploratory drilling in 1972-1974 proved reserves for the initial 110 MW plant. PGI's continued drilling success combined with a national electric power shortage to accelerate field development. By the beginning of commercial production in 1979, six turbine generator sets were either installed or on order. In 1982, steam production exceeded eight million lb/hr (3600 Tonnes/hr) with the startup of Units 5 and 6.

Early production was marked by increasing enthalpy and falling liquid levels in the eastern part of the field. A major groundwater intrusion began in late 1982 through the former hot spring system. During 1983-1987, numerous wells were flooded with cold water and ceased flowing. In response, PGI moved development drilling west to largely unaffected areas and undertook a recompletion and stimulation program. In this same period, PGI began brine disposal in idle wells. Dedicated injectors have since been drilled in outlying areas to minimize production interference. These programs effectively halted the decline in generation by 1988.

In 1986, NPC adopted a policy of regularly operating five units, with one assigned to maintenance reserve. This has improved steam usage efficiency, and reduced curtailment due to maintenance downtime. In 1989, Tiwi achieved its highest output since 1985. Operating plant capacity factor was 83.2% and output averaged 157 GWh/month.

INTRODUCTION

The Tiwi geothermal area is located in the Bicol Peninsula of southern Luzon Island, on the northeastern flank of Mt. Malinao. This is one of the chain of Quarternary stratovolcanoes *(Figure 1)* which are the backbone of the island, and which formed along the west side of the subduction zone marked by the Philippine trench *(Datuin and Uy, 1979)*. The area had been noted as a thermal area for decades before the Philippine Commission on Volcanology began scientific work in 1962. That work led to the development of the Tiwi Geothermal Project (TGP) and the establishment of the Philippines' geothermal industry, now the world's second largest.



VOLCANOS OF SOUTHERN LUZON ISLAND PHILIPPINES

Figure 1

Tiwi is a mature development, having produced for over a decade. Its history can be divided into four chronological phases: preproduction exploration and testing, plant startups and early reservoir response, adjustments for injection and water influx, and lately, production stabilization. A summary of events which will be discussed in this paper is given in *Figure 2.*

PREPRODUCTION OPERATIONS 1967-1978

In 1967, the Philippine Commission on Volcanology demonstrated the commercial potential of Tiwi to the national government by successfully operating a 2.5kW turbogenerator with steam from a shallow well. Recognizing geothermal energy as a unique indigenous resource, the government passed legislation reserving geothermal energy rights to the public. In 1970, NPC was entrusted with the responsibility of developing those resources. The following year NPC contracted with PGI to develop the Tiwi field. By late 1972, PGI had completed the first successful deep geothermal well in the field, Naglagbong 1 *(Alcaraz, 1976).*

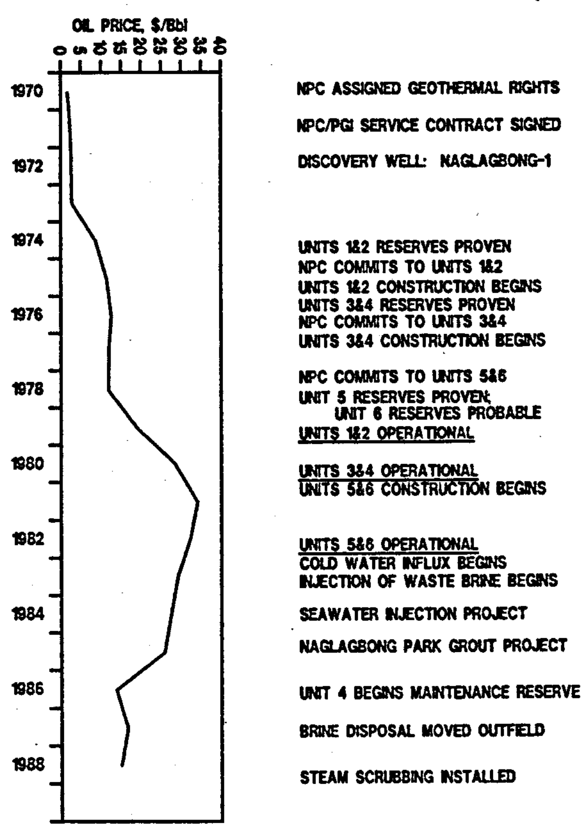


Figure 2. TIWI FIELD DEVELOPMENT HISTORY

The following year brought the first Arab oil embargo and OPEC price jump. This was a severe shock to the Philippine economy, which was dependent on oil imports for 95% of its energy *(Malixi, 1982).* A graph of representative prices paid for oil imports is shown on the left side of *Figure 2.*

Drilling was successful in delineating a large reservoir, and by 1976 reserves for four 55 MW units had been confirmed by eleven wells. Drilling accelerated thereafter, as shown in *Figure 3.* By mid-1978, when Units 1 and 2 were ready to start test runs, 29 wells had been drilled, which are highlighted in *Figure 4.* These wells established limits to the Naglagbong area only on the North, East and South.

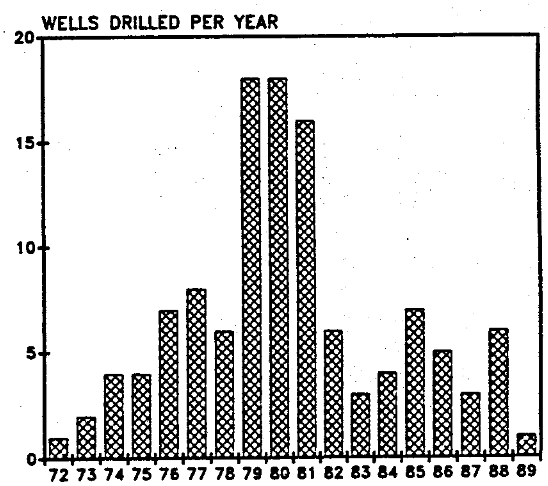


Figure 3. TIWI FIELD DRILLING ACTIVITY

About this time the second rise in oil prices began with the Iranian revolution, and NPC exercised an option to order the turbines for Units 5 and 6 on favorable terms. Although the reserves for the last unit were not yet considered proven, the risk was deemed acceptable since 420 hectares had been proven, and development drilling continued to bring in wells with high deliverabilities.

Several deep wells found alteration, high temperatures and lost circulation over wide intervals, suggesting a reservoir thickness greater than 2 km. This was consistent with the results of a 1976-1977 interference test of four wells, which detected no boundaries after nearly a year of production. The first large scale Tiwi production began in November 1978, for the initial testing of Units 1 and 2 in Plant A.

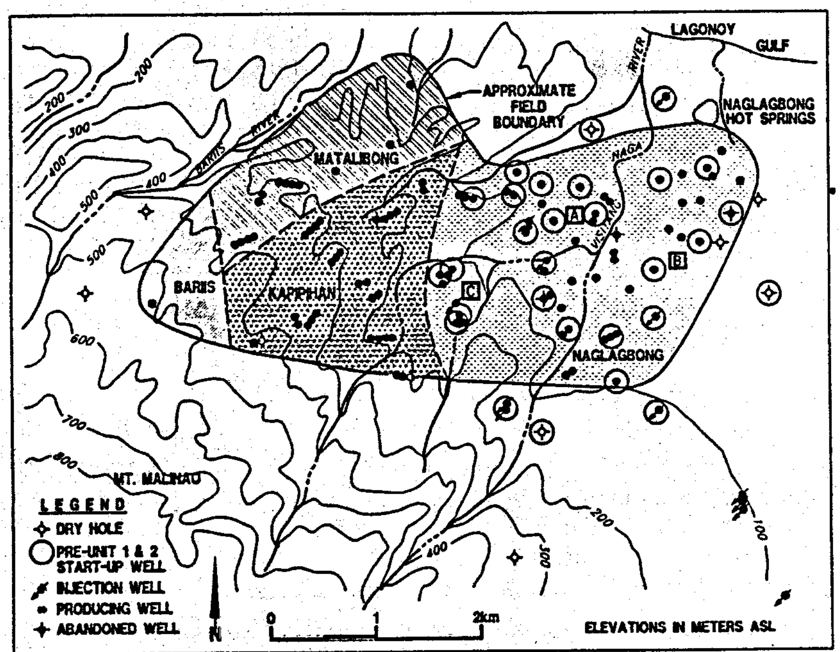


Figure 4. TIWI FIELD AND VICINITY

<u>POWER PLANT STARTUPS -- 1979 TO 1982</u>

Steam production exceeded 500 Tonnes/hour (1100 kph) for the first time when Plant A began commercial service in mid-1979 *(Figure 5)*. By late 1980, the rate was averaging more than 1600 T/h (3520 kph). The immediate response in the reservoir was a drop in liquid level and pressure. The wellhead pressure of Naglagbong 21 *(Figure 6)* shows the increase associated with steam cap formation.

Units 1-4 were constructed with dual entry turbines for maximum energy efficiency. As wells in the Naglagbong area began producing more steam, and the flash fraction in the high pressure separator system increased, the brine available to the low pressure system dropped by half in a year *(Figure 7)*. In 1982, the Plants A and B turbines were converted to single entry, while Units 5 and 6 were built that way.

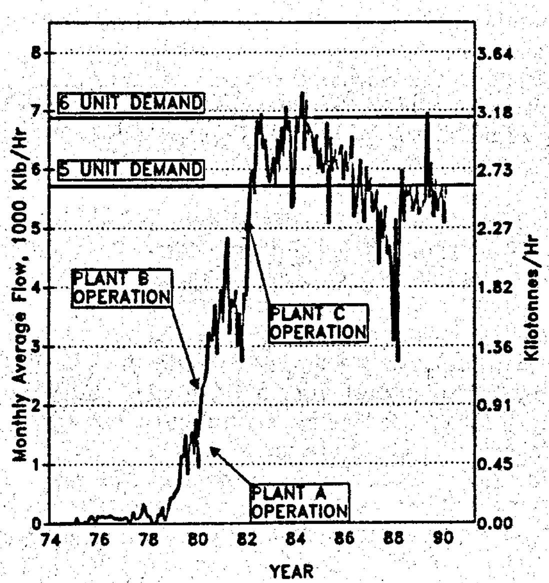


Figure 5. TIWI STEAM PRODUCTION

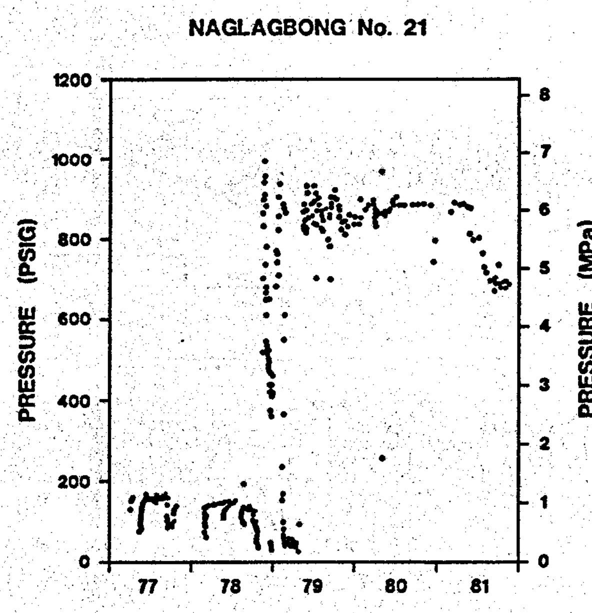


Figure 6. STATIC WELLHEAD PRESSURE

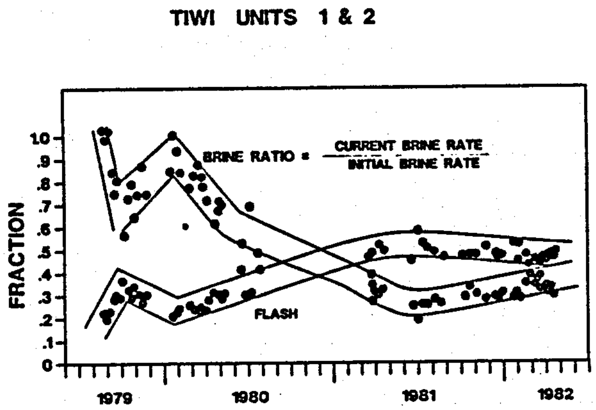


Figure 7. BRINE PRODUCTION AND STEAM FLASH

By 1982, it was clear that cold groundwater was entering the reservoir and reducing the enthalpy of produced fluid. This can be seen in the downtrending flash fraction in that period in *Figure 7.*

A program to re-evaluate the reservoir was undertaken in response to these developments. Additional deep wells were drilled, and cores were cut in the reservoir section of others. New spinner tools became available for high temperature use and were imported at this time. Injection tests with these tools showed that much of the high temperature rock in the area of Plant B contributed little fluid reserves. Most of the Naglagbong area ultimately was shown to have an effective reservoir thickness of less than 600 m (2,000 ft).

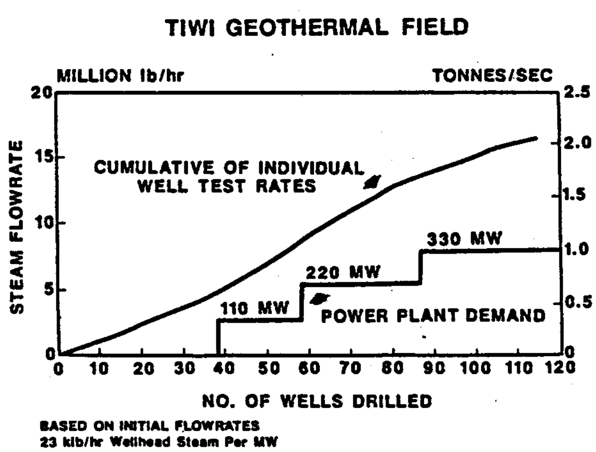


Figure 8. CUMULATIVE STEAM RATE AND DEMAND

Drilling continued for Plant C, with the major activity shifted west to the steeper terrain of the Matalibong and Kapipihan areas *(See Figure 4).* The graph of cumulative test rates in *Figure 8* shows the generous steam supply which was developed. When Unit 6 started up in 1982, a supply of 3840 T/h (8450 kph) was available, 25% more than required. The distribution of flow rates in January, 1981 is contoured in *Figure 9.*

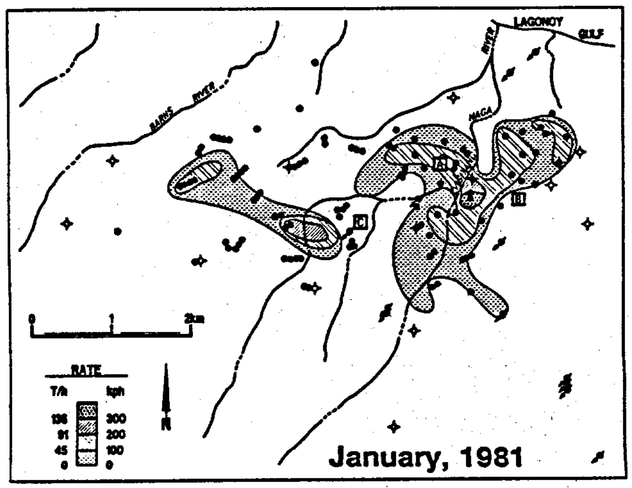


Figure 9. STEAM PRODUCTION RATES

WATER INFLUX AND INJECTION 1983-1986

Encroaching cool water made many wells in the northeast part of Naglagbong unproductive in 1983. Hydrologic surveys showed this was likely due to fresh groundwater entering the former outflow at Naglagbong Park *(see Figure 4).* Geochemical surveys confirmed that the inflowing water was fresh, and not intruding seawater. A cross section of Tiwi from Southwest to Northeast *(Figure 10)* shows the prevailing fluid flow patterns when production began.

Cold groundwater penetrates the reservoir in layers, and is tracked through temperature drops and chloride dilution. Naglagbong 4 is a typical well in which declining enthalpy *(Figure 11)* corresponds to a temperature reduction measured at only a single survey depth. This figure also shows that chloride dilution preceded the enthalpy decline by several months. Wellbore temperature surveys did not clearly identify the behavior for nearly a year longer.

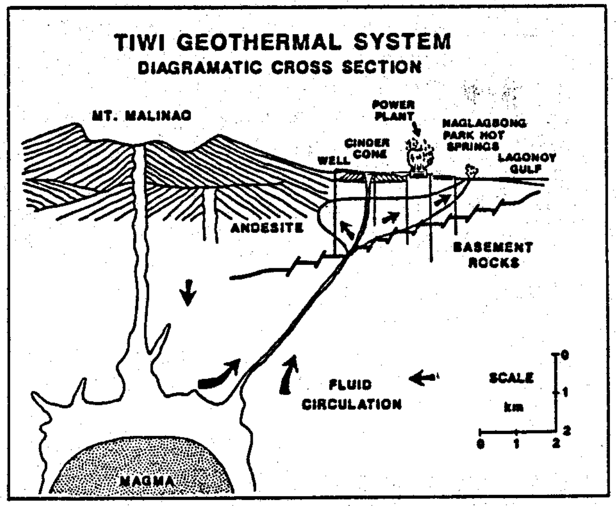


Figure 10.

The chloride dilution front moved rapidly West and South in 1983-1985, as shown in *Figure 12.* The 4000 ppm contour drawn in this Figure indicates substantial enthalpy loss, but not necessarily a cessation of production. The influx continues despite efforts to reduce it through cementing and mineral precipitation in 1985-1986.

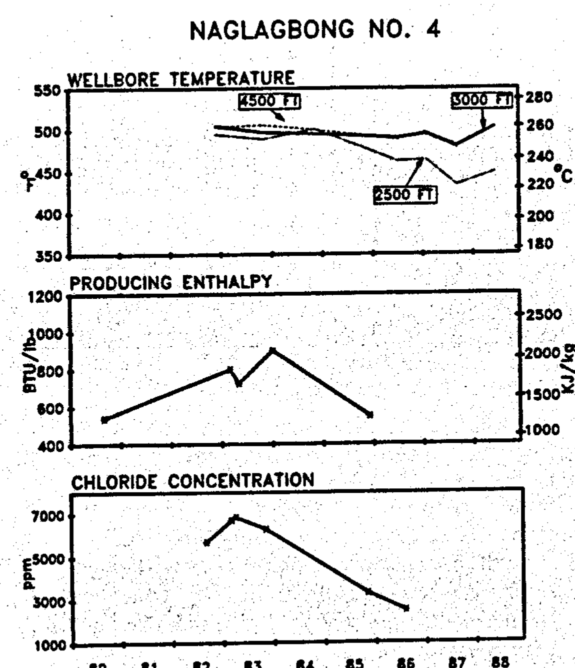


Figure 11.

Groundwater is not the only cool fluid to contend with in the reservoir. The Tiwi development plan was originally designed to minimize NPC's capital costs by extracting as much heat as possible (i.e., dual flash) and disposing of the spent brine via canal to the Lagonoy Gulf. In the 1970's, this was considered environmentally acceptable. Farmers in the area successfully use geothermal brine to irrigate rice crops, and surface disposal was then established practice at Larderello, Weirakei, Cerro Prieto and other fields with benign fluids.

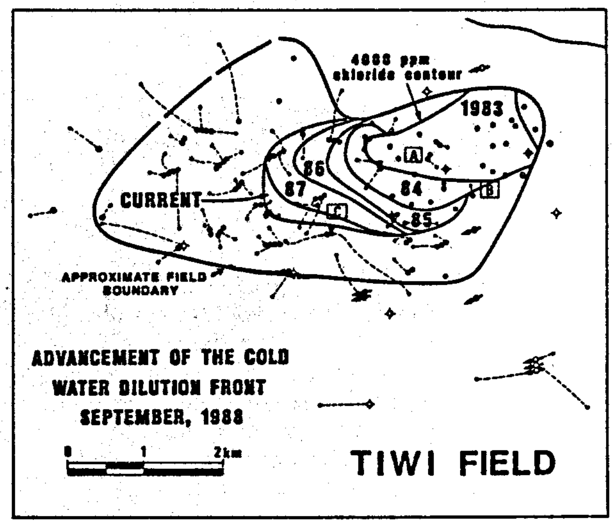


Figure 12.

Concerned about possible long-term impacts, NPC and PGI moved to re-inject brine in 1983. The first wells were located in a band of corrosive, non-commercial wells in the vicinity of Plants A and C *(Figure 13)*. These were favored by the economics of availability, minimal pumping and the possibility of increasing reserves through dilution or buffering of the corrosive fluids.

It was determined by 1985 that the infield injection program could not handle the brine rates needed, and was detrimental to the resource. The next alternative was a group of wells around the eastern end of the field known to be in communication with the reservoir. These were put in service in 1986, and are labelled "Edge Infield" on *Figure 13*. This group also could not handle sufficient injection, and several wells had to be removed from the program to avoid production damage. This led to drilling several dedicated injectors in the current "Outfield" program.

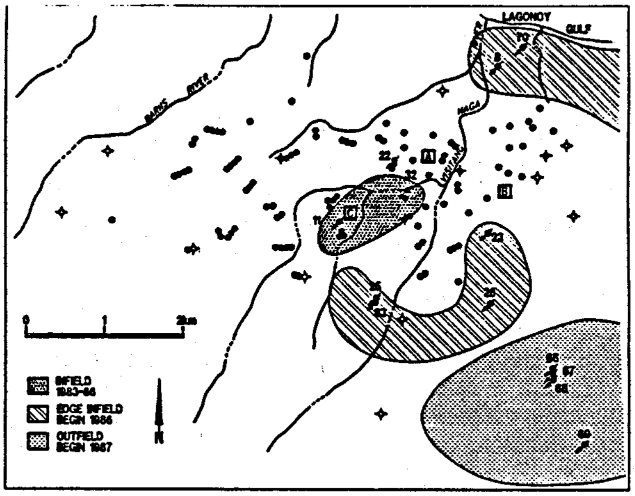


Figure 13. INJECTION PROGRAM AREAS

Drilling in the Kapipihan and Matalibong areas made up most of the production declines in Naglagbong. The focus of research in the latter area was on recompletion of wells to shut off cold water entries, and acid stimulation. Acid treatments were developed both to stimulate new completions and to remove scales. Acid jobs generally are done in conjunction with mechanical removal of wellbore scale. Several procedures using conventional and Unocal-proprietary methods were needed to optimize results in different areas. By 1986, these procedures were being used regularly. In 1987, they accounted for 20% of the steam supplied to the plants.

SYSTEM STABILIZATION 1987-1989

By 1987, the needs of NPC were changing, causing NPC and PGI to alter Tiwi's operating plan. Two principal differences from the early 1980's were an increased requirement for plant reliability and declining costs for alternative fossil fuel.

The reliability of geothermal power and its importance to the NPC grid were highlighted in the turbulent early months of the Aquino administration. Geothermal units were chosen on several occasions to anchor the system in the event of possible upset. Also, the transmission system connecting Tiwi central Luzon was recognized as a target by anti-government forces. These events increased the importance of avoiding unscheduled outages.

Complimentary as this attention may have been, it reduced the output of Tiwi in 1986 and 1987 below the steam supply limit for the first time since 1984. The monthly variation was exacerbated by several damaging typhoons, with results shown in *Figure 14.* The annual total output (*Figure 15*) has subsequently been in the range 1.8 - 2.0 TWh.

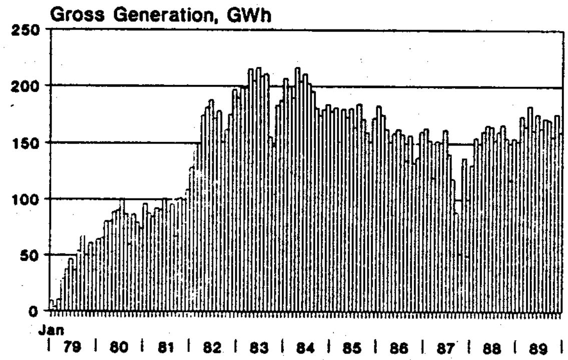


Figure 14. TIWI PROJECT MONTHLY OUTPUT

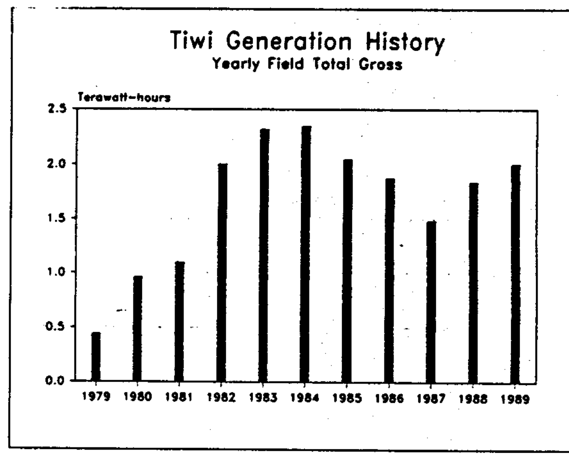


Figure 15.

The decline in world oil prices (*c.f., Figure 2*) allowed NPC to keep geothermal units off line for maintenance more economically and to emphasize steam conservation. This coincided with the payback of NPC's entire investment in the Tiwi project (*ELC, 1987*), an event which highlighted the attractiveness of geothermal power to a capital-limited utility.

These factors led to adoption of a schedule in which one unit is always held in reserve or being overhauled, with five units in continuous operation. In addition to facilitating plant maintenance, this program improves efficiency and generation. At a steam supply of 2680 T/h (5900kph) Tiwi could produce 240 MW with six units operating. With five units operating, reduced steam use for condensor gas extraction increased output to 250 MW. Reliability was further improved by the introduction in 1988 of particulate scrubbing equipment at PGI's final steam separation facilities.

OUTLOOK

The Tiwi reservoir continues to evolve in response to production, injection and influx. The production rate from the Naglagbong area is less than half of its initial value. The center of production is now the Kapipihan-Matalibong area, as can be seen in *Figure 16*. A number of wells in the Naglagbong area are now operated on a "huff and puff" cycle to counteract the effects of cold water. NPC is considering the replacement of gas ejectors on some units with compressors to save steam. Although Tiwi is stable, it is not static, and further changes can be expected in both steam field and powerplant operations. Tiwi now contributes about 10% of the electrical demand of Luzon, and is an essential element of the island's southern grid.

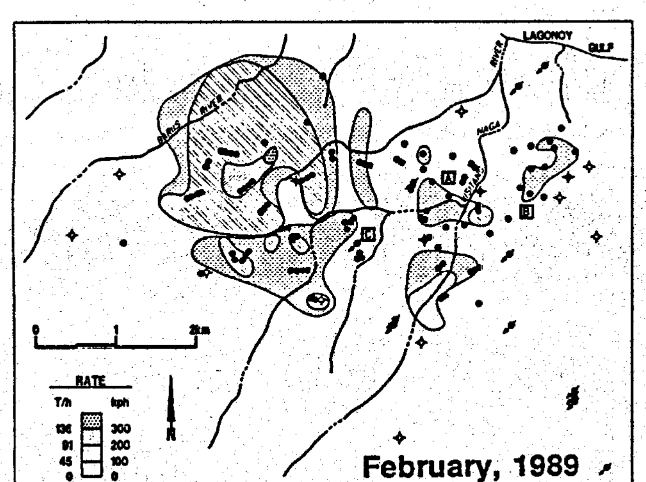


Figure 16. STEAM PRODUCTION RATES

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