

INTERACTION OF THE DEEP GEOTHERMAL SYSTEM AT SOUTHERN NEGROS GEOTHERMAL FIELD AND THE SHALLOW GROUNDWATER AQUIFER IN DUMAGUETE CITY

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ABSTRACT

Chemical and isotopic data indicate that significant quantity of mineralized thermal fluids are present downstream of the Palinpinon thermal areas that are migrating into the shallow groundwater aquifer. Water district wells located in Camanjac, 3 kms. east from the Palinpinon springs, are tapping fluids that are relatively enriched in Na+K, Cl+SO₄, B and Li concentrations. Fluids appear to be diluted towards the Sibulan area as waters become diluted to Ca+Mg-Cl+SO₄ type. Shallow water southeast from the Palinpinon springs is composed of typical Ca+Mg-HCO₃ groundwater. Isotopically, the shallow groundwater in Camanjac are relatively enriched in $\delta^{18}\text{O}$ and $\delta^2\text{H}$ while the wells southwest of the springs are relatively depleted. Slight variations in the stable isotope composition of the shallow groundwater was observed from 1999 to 2002, but the difference is not as distinct as the variations of the heavy isotopes in rainfall. Isotopic altitude gradient for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ are 0.28 and 2.1‰ per 100 meters change in elevation, respectively. These correspond to a calculated recharge elevation of at least 1000masl for the shallow groundwater. Relative age dating using Chlorofluorocarbon (CFC) reveals relative ages from 10 to older than 60 years old, which partly confirms with the previous Tritium age between 50 to 100 years old.

Numerical simulation models confirm the migration of the thermal fluids from Palinpinon to the groundwater wells in Camanjac, with no significant seasonal variation in isotope, Cl and SO₄ concentration indicating only minor dilution effect from precipitation. Drawdown in the deep geothermal reservoir have induced more than 500 meters of drawdown in the center of the resource but not enough to revert the naturally outflowing fluids into the Palinpinon thermal springs. Hence, there exists continuous natural migration of slightly mineralized geothermal

fluids into the shallow groundwater aquifer of Dumaguete City. Even though the chemical species of the groundwater fall within the Philippine Standard Drinking for Water, future expansion of the city's well fields should be diverted away from the path of the migrating diluted mineralized fluids to avert extraction of relatively Cl-rich waters.

1.0 INTRODUCTION

This study focuses on the relationship of the deep geothermal reservoir at SNGPF and the shallow groundwater system in Dumaguete City. A holistic approach was applied in the study by combining different scientific tools such as stable isotopes of ¹⁸O and ²H, hydro-geochemistry, tritium and Chlorofluorocarbon (CFC) tracers, and flow and transport numerical simulations. The project is a cooperation between PNOC-Energy Development Corporation (PNOC-EDC) and the International Atomic Energy Agency (IAEA) under the Co-ordinated Research Program (CRP) entitled "Isotope Response to the Dynamic Changes in Groundwater Systems due to Long-term Exploitation" (R/C 10729). Isotope and chemical analyses was done at the PNOC-EDC laboratory in Makati City, while the CFC and tritium analyses was conducted at the isotope laboratory of the IAEA in Vienna.

The study area covers the Okoy and Banica watersheds that include the SNGPF, Palinpinon, Sibulan, Dumaguete, Valencia and Banilad (Figure 1). Characterization of the shallow groundwater systems, which commenced in July 1999, included sampling of shallow groundwater sources for basic chemistry, trace metals and isotopic analyses. Repeat sampling followed in 1999, 2000 and 2001 and a high frequency sampling was conducted from December 2001 to July 2002. A total of 45 water sources were evaluated which include Metro Dumaguete

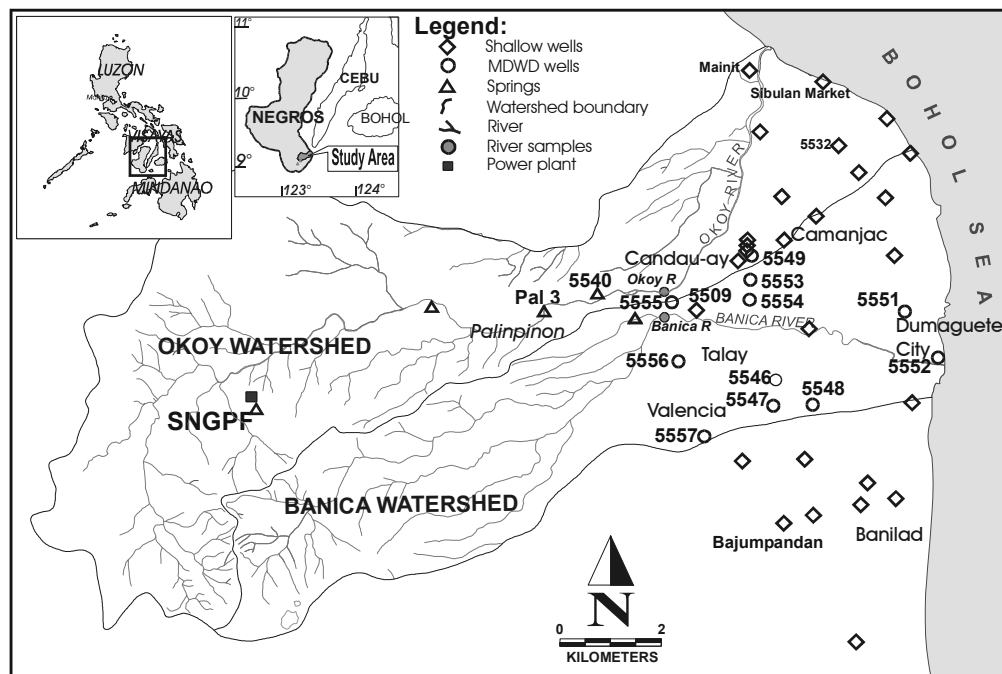


Figure 1. Location map of MDWD wells, shallow wells, springs and river systems.

Water District (MDWD) wells with an average depth of about 132 meters below ground level (mbgl), shallow wells with depths of <20 mbgl, cold springs, hot springs, warm springs and river systems. Samples for Chlorofluorocarbon (CFC) and Tritium dating were collected on June 2000.

Okoy and Banica watersheds cover an area of approximately 86 and 53 km², respectively. For this project only the lower watersheds were studied in detail since it is the area where the thermal hot springs and the shallow groundwater aquifer are located. The flow and transport of fluids are simulated from an elevation of around 350masl on the western boundary down to the shoreline on the eastern boundary. The northern and southern limits are the watershed boundaries of the two river systems.

2.0 OBJECTIVES

Independent studies on the effects of production from the geothermal and shallow groundwater systems have been conducted and established. It is the aim of this project to augment and combine the available data from the two systems to create a hydrogeological model that discusses their distinct individual characteristics yet focuses on how they interact in the subsurface. The objectives of the study are

- (a) to determine the baseline physical, chemical and isotopic characteristics of the deep geothermal and shallow groundwater systems;
- (b) to evaluate the dynamic changes in the deep geothermal and shallow groundwater systems due to long-term exploitation;
- (c) to ascertain any relationship between the deep geothermal system and the shallow groundwater system;
- and, (d) to determine the different shallow groundwater hydrogeological regimes through the use of numerical simulation techniques.

3.0 HYDROLOGY

Topographically, the Okoy and Banica river basins are bounded by very steep mountain terrain greater than 50%. Relatively small areas are gently sloping where part of the geothermal field was developed. The headwaters of the Okoy and Banica rivers is covered with thick forest both primary and secondary type while other areas are covered with thick grasses, coconut trees and shrubs. Soil development in highly elevated areas are minimal and ranges only from less than a meter to not more than 2 meters except in relatively flat areas where alluvial debris are deposited. The alluvium is normally consists of sandy silt and silty clay with pebble to boulder-size clasts.

The project area falls under the Type III climate of the PAGASA's Coronas Climate Classification, characterized by no very pronounced maximum rain period with dry season lasting from one to three months. February to May are relatively dry compared to the rainy season from June to January (Figure 2). Annual precipitation in Dumaguete City is 1216mm, which is relatively lesser than that in the SNGPF with an average annual precipitation of 2500mm. At Dumaguete city, ambient air temperature is coldest during the month of January with 25°C and warmest during May with 28°C. Relative humidity ranges from 76% in April and 81% in January.

Historical mean annual discharge data for the Okoy river system is estimated at 1544 mm while that of Banica river system is roughly 1488 mm. Hydrograph analyses indicate that pre-1984 baseflow averages 83% and decreased to about 66% from 1984-1988 (Geotechnica, 1994). Variations are attributed to the decreased rainfall events after 1984 resulting to the lowering of the groundwater hydraulic heads. Direct runoff are calculated at 948 mm/year for Okoy and 664mm/year for Banica watershed

Evapotranspiration for Okoy and Banica watersheds were estimated at 1211 and 1325 mm/year, respectively. Net recharge is then estimated to be 314 mm/year for Okoy and 322 mm/year for Banica watershed (SWECO, 2001).

4.0 HYDROGEOLOGY

The deep geothermal system at SNGPF is capped by a siliceous layer and an impermeable andesitic lava flow. Permeability in the reservoir is attributed to fracturing due to the presence of faults, but significant permeability is also present along lithologic contacts, primary or intraformational permeability among pervious volcanoclastics and along the chilled margins of andesitic dike intrusions (Hermoso and Mejorada, 1997). Meteoric recharge into the deep geothermal reservoir is limited in areas with intense fracturing, and the flow of the geothermal fluid is mainly towards the northeast and southwest as manifested by the presence of hot springs and altered grounds. A significant drawdown in the center of the geothermal reservoir at Puhagan of about 500m had been observed since the start of steam production in

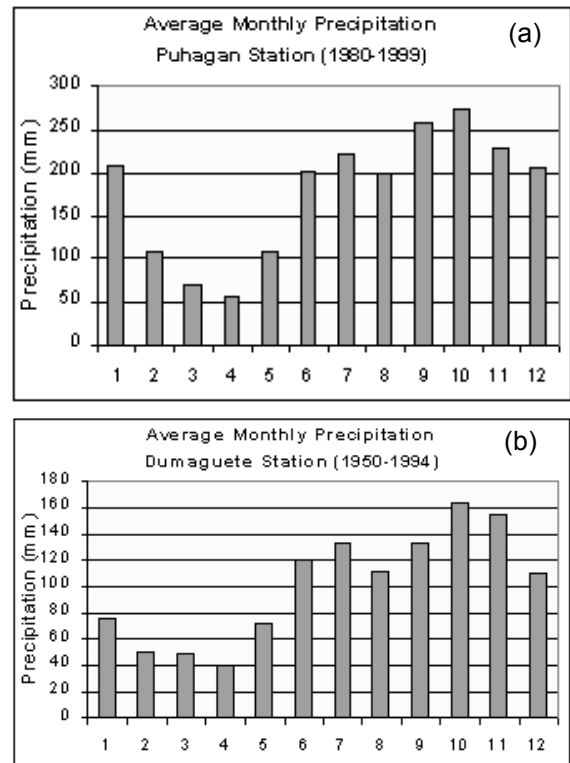


Figure 2. Monthly rainfall distribution at (a) Puhagan, (b) Dumaguete City.

1983, and this drawdown created a cone of depression that extended down to well N-1 where the water level declined from 100m above the surface in 1983 to about ground level in 1994.

At the Lower Okoy and Banica valley, the Quaternary Alluvium consists of highly permeable fine to coarse sand, gravel and boulder with occasional poorly permeable clay beds/lenses and marine sediments of limestones and corals. Figure 3 shows the simplified geologic map showing lithological distribution.

The uniformity of the chemical and isotopic characteristics of the shallow and deep wells suggests that there is only one aquifer in the alluvial plain with minor localized intercalations of fine layers of clay. However, Step Drawdown Tests (SDT) and Constant Discharge Tests (CDT) conducted in all local water district wells indicate that wells with depth range from 0 to 50 mbgl has higher hydraulic conductivity values ($25 \times 10^{-5} \text{m/s}$) relative to the deeper wells with depths from 50 to 150 mbgl ($5 \times 10^{-5} \text{m/s}$). Transmissivity values from 11 wells ranges from

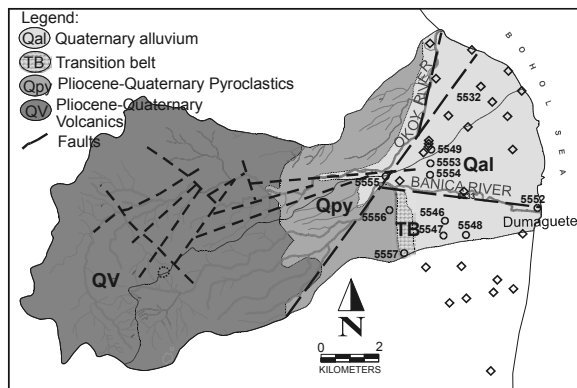


Figure 3. Simplified geologic map showing groundwater wells.

1.91 to $30.1 \times 10^{-3} \text{ m}^2/\text{s}$ (Sweco, 2001). The water level is less than two (2) mbgl near the coast and about 70 mbgl in the MDWD well 5555 area. The groundwater flow is generally perpendicular from the coast, except for a significant drawdown in the wells within the Candau-ay and Talay area of about 25m and 20m, respectively, since 1985. However, sporadic data since 1990 shows that the water level in all water district wells have not declined, suggesting that enough recharge is complementing the groundwater extraction of the water district and the local communities.

Wenner georesistivity survey determined a resistivity contrast of the volcanic deposits and the alluvial sediments near Valencia. The values show that the volcanic deposits have relatively low resistivity of less than 10 ohm-m than the alluvial sediments with about 30-50 ohm-m. Well data proves that the transition belt in the area is highly permeable.

5.0 RESERVOIR GEOCHEMISTRY

5.1 Geothermal System

Geothermal production since 1983 have caused major changes in the geothermal reservoir, namely: (a) reinjection returns, (b) pressure drawdown, (c) inflow of cool acid fluids, and (d) mineral deposition (Orizonte et al., 1999).

Reinjection (RI) returns were identified from the increase in Cl, decline in CO_2 and $\text{CO}_2/\text{H}_2\text{S}$ ratio, decline in Cl/Ca ratio and lowering of downhole temperatures and discharge enthalpies in the affected production wells. The RI fluid's rapid return, having a mean transit time of 5 to 18

days based on Iodine-131 (^{131}I) tracer, has resulted in severe thermal declines from 5°C to 30°C in most heavily affected wells (Urbino et al. 1986). The shift of injection to some 3 kilometers away from the production sector has gradually arrested the thermal declines, although no apparent recovery in temperature has been observed. Pressure drawdown of around 6 MPa at the production sector has enhanced reservoir boiling and expansion of the two-phase zone. This is evidenced by physico-chemical indications such as increase in CO_2 in the total discharge and increase in discharge enthalpy. Drilling and priority utilization of high enthalpy wells which tapped the expanded two-phase zone were undertaken to minimize the pressure decline. In addition, the reduced amount of waste brine produced by this strategy has helped lighten the constraint of the fields' limited reinjection capacity.

Cool acid inflow is a secondary type of recharge common among wells directed towards the high-gas upflow region. The sulfate-type acidity is derived from the oxidation of H_2S in shallow groundwater forming an acid- SO_4 perched aquifer (Seastres et al., 1995), where the resulting acid is induced downwards along faults into producing horizons. Thus, acidity is commonly associated among wells with high-enthalpy discharges and high gas contents.

Mineral deposition of silica (SiO_2), calcite (CaCO_3) and anhydrite (CaSO_4) as blockages in geothermal wells greatly reduces the capacity of the well. Silica reduced the observed reinjection capacity of the wells by as much as 50%. Calcite deposits, induced by boiling of fluids in the geothermal reservoir, were observed within the area of the flash point of the wellbore. Blockages of anhydrite were likewise observed in wells, normally just below the point of the acid-sulfate inflow (Orizonte et al, 1997).

5.2 Shallow Groundwater System

Water characteristics such as conductivity, salinity, temperature, basic chemistry and isotopic compositions were used to delineate the different types of fluids in the study area.

The conductivity, salinity and temperature profiles consistently delineate an anomaly within the warm springs in Palinpinon that appears to extend towards the northeast direction. Groundwater located southeast from the

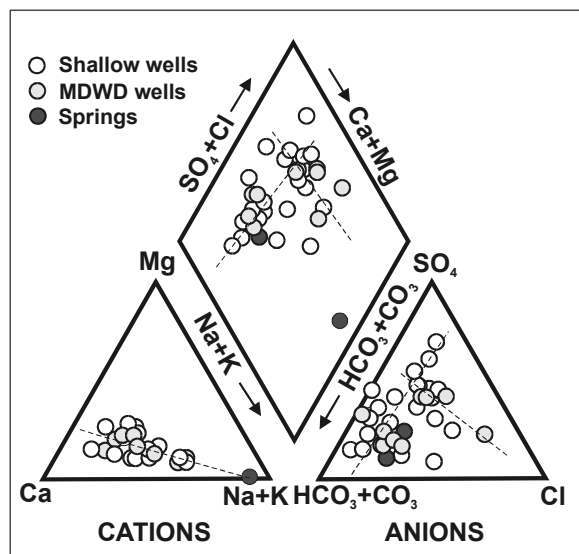


Figure 4a. Piper diagram of water sources showing dilution lines (Sept. 2000).

Palinpinon springs shows typical groundwater characteristics with less than $300\mu\text{S}/\text{cm}$ conductivity and temperature of 25°C .

The shallow groundwater in the area does not manifest a single homogeneous fluid but rather shows diverse composition. Water samples during September 1999 and September 2000, which falls within the rainy season, indicate a very distinct variation between the HCO_3 -rich, Cl-rich, Na+K-rich waters and those that are in between (Figure 4a). An apparent dilution line could be drawn from the cation ternary diagram with only two end products, but the anion diagram suggests three different water sources. One source is typical HCO_3 groundwater, the other source, which is relatively high in Cl concentration, is the diluted outflowing geothermal fluids. The third, which is enriched in SO_4 , is a mixture of outflowing geothermal fluids and steam condensate from the geothermal reservoir. The presence of steam explains why there are only two end products in the cation diagram, suggesting that the steam transports only CO_2 and H_2S gases into the aquifer and forms SO_4 compounds upon contact with the groundwater. The dilution is even more evident in Figure 4b during the dry season. High frequency sampling of selected water sources depict the same chemical trend with no significant seasonal variation.

The spatial distribution of the different types of water based on their chemical characteristics is

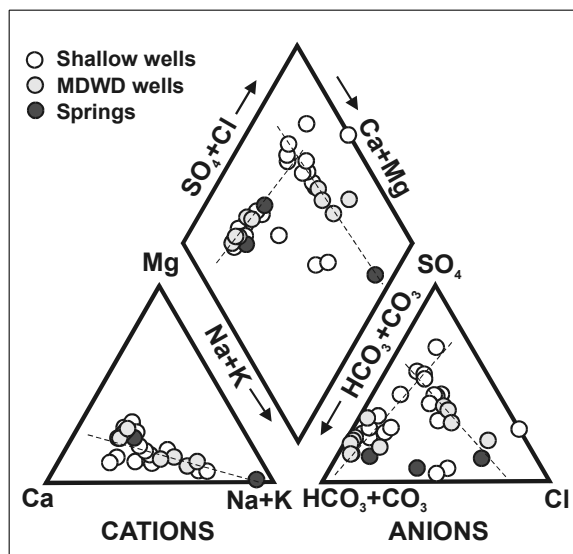


Figure 4b. Piper diagram of water sources showing the same dilution lines in Fig. 4a (Feb. 2001).

shown in Figure 5. Wells that are located about 3 km. east of the Palinpinon thermal springs are the **Na+K-Cl+SO₄** waters, northeast of these wells are the **Ca+Mg-Cl+SO₄** waters and the wells to the southeast are the typical **Ca+Mg-HCO₃+CO₃** groundwater.

Some significant chemical parameters like Cl, B, As and Li were intermittently monitored by the PNOC environmental group on the Metro Dumaguete wells from 1995 to present to determine specific chemical changes in the shallow groundwater system. No significant change was observed.

6.0 $\delta^{18}\text{O}$ AND $\delta^2\text{H}$ ISOTOPES, TRITIUM AND CFCs

6.1 Rainfall

Four stations are maintained and monitored by PNOC-EDC at SNGPF which are distributed at different locations and elevations within the geothermal field, namely: Ticala (350 masl), Puhagan (760 masl), Balas-balas (980 masl) and Nasuji (1100 masl). Samples from these stations are analyzed monthly for Cl and isotope composition. The $\delta^{18}\text{O}$ stable isotopic composition with time indicates the relative enrichment between 1993 and 1997, which is attributed probably to the migration of relatively enriched rainfall. The Local Meteoric Water Line (LMWL) was updated using available

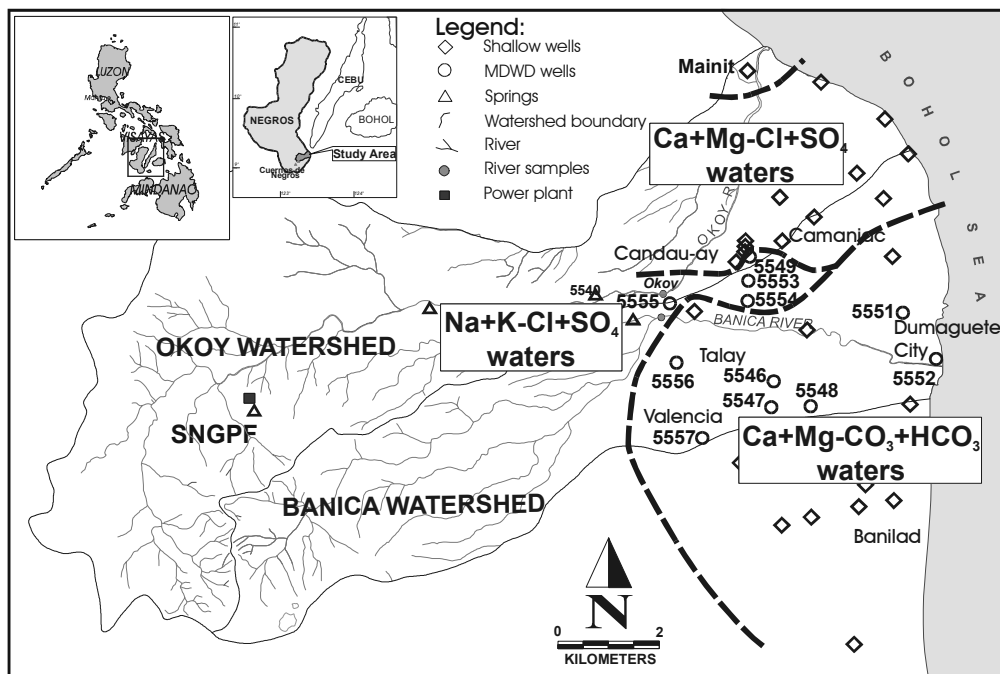


Figure 5. Spatial distribution of the different water types based on chemistry.

precipitation isotopic data from 1991 to 1997 (Figure 6). Excess deuterium was recalculated and reduced to 12.5 per mille from the previous value of 14 per mille (Gerardo et al., 1993) making the equation of the line $\delta^2\text{H} = 8 \delta^{18}\text{O} + 12.5$.

6.2 Wells and Springs

The shallow groundwaters plot within the trace of the LMWL. Plots of the warm springs depict an evaporation trend, which is most likely because the samples were obtained from hot springs emanating from the surface. Isotopic composition of the deep geothermal fluid prior to the commercial operation in 1983 are also plotted for reference.

Minor localized variation in heavy isotopes can also be observed among the groundwater wells, but not as distinct as that of rainfall. Wells located south of Banica river (5546, 5547, 5548, etc.) are relatively depleted in heavy isotopes (-48.3 per mille $\delta^{18}\text{O}$) while wells within the vicinity of well 5554 are relatively enriched (-46.7 per mille $\delta^{18}\text{O}$) as shown in Figure 7. Same dilution trends could be observed for the Sep. 1999, Feb. 2000 and Dec. 2001-Jul. 2002 isotope data. The variation in isotopic composition could be attributed possibly to: (1) inflow of isotopically enriched thermal waters

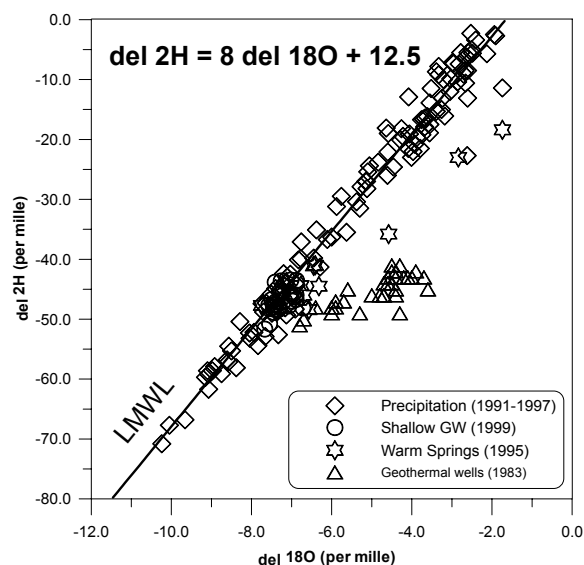


Figure 6. Isotope plots of LMWL, hot springs and geothermal wells and MDWD/shallow wells.

into wells to the northeast (2) inflow of isotopically depleted waters into wells 5546, 5547 and 5551 coming from higher elevations; (3) steam condensate addition in the Palinpinon thermal springs area.

High frequency sampling in Dec.2001-July 2002 indicate minor changes in the isotopic composition of selected representative wells

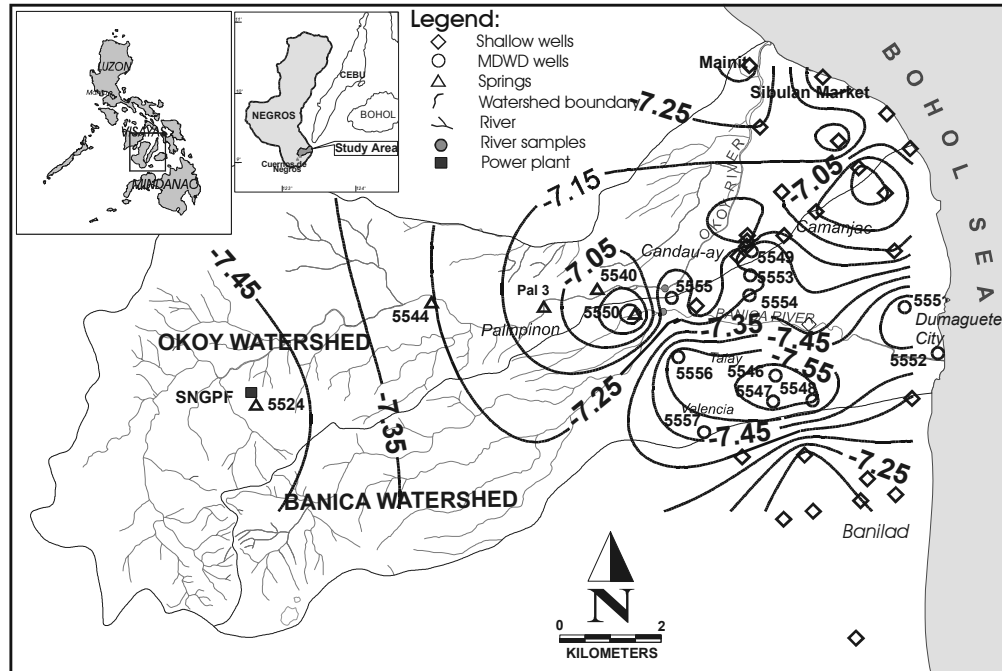


Figure 7. Iso-plot of $\delta^{18}\text{O}$ concentration (Feb. 2001).

which coincide with the local seasonal changes. There are no significant isotopic composition variations in the shallow groundwater based on available data from 1993 to 2002.

6.3 Isotopic Altitude Gradient

The weighted averages of the isotopic composition of rainwater at the four monitoring stations in Ticala, Puhagan, Balas-balas and Nasuji are defined by the equations $h = -347.3 \cdot \delta^{18}\text{O} - 1266$ and $h = -47.52 \cdot \delta^2\text{H} - 857.24$ with correlation coefficients of 0.90 and 0.82, respectively. The value of h represents the mean elevation of meteoric water recharge. Therefore, the average isotopic composition of rainfall at sea level are -3.65‰ $\delta^{18}\text{O}$ and -8.04‰ $\delta^2\text{H}$ corresponding to a decrease of 0.28‰ and 2.1‰ , respectively, for every 100 meters increase in elevation.

Calculations of elevations of recharge by Gerardo et al. (1993) from three sets of data (1991-1992) for each of the four monitoring stations projected the elevation of recharge for the geothermal system at 1000 masl. Recharge for the shallow groundwater system was likewise projected by Pascual (1993) from seven sets of data (1991-1992) for the four monitoring stations at 551-754 masl for the deep wells (>50-150 meters depth) and 242-495 masl for the shallow

wells (<50 meters depth). For this study, all available rainfall isotopic data with Deuterium excess of 10-14 was used in the calculation of the elevation of recharge which was calculated to be from 1000 to 1400 masl, which fall within the area of Nasuji and Sogongon at SNGPF, Mt. Talines, and the slopes of Cuernos de Negros volcano.

6.4 Tritium Concentrations

Tritium concentrations of geothermal wells and shallow groundwater wells for 1991 and 1993, respectively, reveal that waters in the geothermal system are mature (values are mostly less than one) while that of the shallow well 5546 is recent. Shallow wells 5530, 5504, and 5547 may be tapping water that are mixed with recent and much older waters. The relative ages of the shallow waters are about 10 years old while that of the MDWD wells ranges from 50 to 100 years old.

6.5 Chlorofluorocarbons (CFCs)

Five (5) groundwater production wells of MDWD and two (2) rivers (Okoy and Banica rivers) were sampled in Dumaguete City in June 2000 for CFC, stable isotope, tritium and chemistry analyses. Samples from six (6) geothermal production wells, the brine line 317 and a creek

Table 1. CFC data and interpretations

Water Source	CFC Conc.			Recharge Year			Apparent Ages			Remarks
	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
	(pmol/kg)						Years			
5547	0.11	ND	0.01	1961	<1940	<1970	39	>60	>30	CFC-free water, indicating water is at least 50 years old (or >60 yrs old?). Presence of CFC-11 and CFC-113 indicate contamination during sampling (both are hard to remove).
5546	0.29	0.09	0.01	1966	1960	< 1970	34	40	>30	Mixed waters. CFC-free water is ~94-95% and recent water is ~5-6%. Relative age of old water is ~40 years old while younger water is at least 30 years old
5554	0.66	0.13	0.02	1972	1964	1976	28	36	24	Mixed waters. CFC-free water is ~89% and recent component is ~11%. Old water is about 36 years old while younger water is about 24 years old. Relatively high CFC-11 concentration indicates possible contamination during sampling. Hence, high mixing ratio
5556	0.75	0.29	0.05	1972	1968	1979	28	32	21	Mixed waters. CFC-free water is ~77-80% and recent component is ~20-23%. Older water is about 32 years old and younger water is 21 years old. The presence of relatively high percentage of recent component implies not-so-distant recharge area.
5555	1.58	1.2	0.12	1981	1990	1986	19	10	14	Either relatively young water with recharge years between 1986-1990, or mixed waters. CFC free water is ~13-42% and recent component is ~58-87%. Slightly enriched ¹⁸ O suggests inflow of isotopically depleted water (or evaporated surface water)
Banica River	2.09	2.42	0.15	1992		1988	8		12	Slightly lower than the water which is in equilibrium with modern air, indicating discharge of groundwater into the river. Baseflow component of river discharge is about 28%.
Okoy River	2.24	1.26	0.18	1990	1994	1991	10	6	9	Slightly lower than the water which is in equilibrium with modern air, indicating discharge of groundwater into the river. Baseflow component of river discharge is about 5-19%.
UPE – creek	2.91	1.27	0.32	1989	1988	< 1970	11	12	>30	Why is this in equilibrium with modern air? My calculations show baseflow component of about 28%.
RI Rine 317	0.13	0.32	ND	1962	1970	< 1970	38	30	>30	Mixture of CFC-free water (77%) and recent water (23%) which is about 30 years old.. Among the recent water, younger water is about 6%.
PN22-WBR	c	0.1	c	< 1943	1961	< 1970	>57	39	>30	Basically old water with only about 7% recent component which is about 39 years old.
OK10D -WBR	c	0.1	c	< 1943	1961	< 1970	>57	39	>30	Basically old water with only about 7% recent component which is about 39 years old.

were also collected for the same analyses at the Southern Negros Geothermal Production Field (SNGPF). The CFC technique has not been used in the geothermal environment and this study is the first attempt to introduce the tool in the determination of recent recharge waters or injection returns. Analysis and interpretation was done in the IAEA laboratory by Dr. L. Han.

a. Shallow groundwater and surface water

Table 1 shows the determined CFC concentrations, the apparent ages of the young waters and the summary of the data interpretations. Among the 5 MDWD wells, well 5547 was the only well which is CFC-free. A trace of CFC-11 and CFC-113 was detected probably owing to contamination from air during sampling. This indicates that the water in the well is at least 60 years of age. Well 5555 proved to have the youngest groundwater with more than 50% of the water having a relative

age of only about 10 years. This could be attributed to nearby recharge and infiltration coming from the Okoy and Banica river systems.

Well 5546 has mixed types of waters, with about 95-96% CFC-free “old” water and 5-6% young waters of about 40 years old. Younger groundwater based on the CFC-11 data is at least 30 years of age. This could signify that about 6% of the water in the well infiltrates at lower elevation than the older 94% water.

Well 5554 has about 11% recent component with a recharge date of 1964, and contains 89% CFC-free groundwater. The relatively high CFC-11 concentration probably indicates contamination from air during sampling. Hence, the high calculated mixing ratio of 5.08.

The age of the groundwater appear increasing towards the southeast from 10 years old in well 5555 to more than 60 years old in well 5547.

This suggests higher recharge elevation for the aquifer in the Valencia area, hence longer residence times, while the aquifer within well 5555 is being recharged at lower elevations.

Both the Okoy and Banica rivers have CFC concentrations that are slightly lower than the water at equilibrium with modern air, and indicates baseflow for Banica river of about 11 to 28% based on the concentration ratios of CFC-11 and CFC-113, respectively. Baseflow component for the Okoy river could not be estimated due to sample contamination.

b. Geothermal wells

Difficulty owing to instrument contamination from other volatile substances was experienced in the analyses of samples from SNGPF. Steam condensate and weber water samples from PN22, OK10D and the RI line 317 were successfully analyzed. However, only the weber water sample gave conclusive results.

Weber samples from production wells PN22 and OK10D have CFC-12 concentration of 0.1 pmol/kg. This indicates that about 7% of the waters in both wells are young waters with recharge year of 1961 (39 years old) and 93% of the water is CFC-free (old waters). Both wells were identified to be receiving injection returns from a reinjection well TC3R. However, it could not be determine if the young waters in the two wells are injection returns or groundwater recharge, or both. The RI line 317 was detected to have a CFC-12 concentration of 0.12 pmol/kg, indicating that the geothermal waters being injected are a mixture of 77% CFC-free water and 33% 30-year old "young" water.

As this is the first introduction of the tool in a geothermal environment the use of the data and the interpretation must be approached with caution.

7.0 GEOTHERMAL SYSTEM OUTFLOW AND SHALLOW GROUNDWATER INTERFACE

The natural geothermal outflow is physically manifested in the form of warm springs in Palinpinon. The geothermal fluids are probably channeled through permeable east-trending faults and discharge to the surface near the contact of the volcanic terrain and the

Quaternary alluvium resulting to the relatively elevated Na, Li, B, Cl and SO₄ concentrations in wells 5549, 5553, 5554, and 5555. Minor amount of fluids flow along the Lower Okoy Fault towards Sibulan but these are already diluted with the shallow groundwater as evidenced by low values of Li and B concentrations. This trend suggests that the geothermal outflow from the Palinpinon mixes with meteoric water and flows towards the northeast. The apparent increase in the chemistry (Cl, Li, Na, SiO₂ and As) of the fluids at the Mainit well located 5 kilometers north of well 5554 suggests that slightly mineralized fluids are being channeled along the Lower Okoy Splay fault and appears in the Mainit well area (Figure 8).

The chemistry of fluids south of the Banica river does not show any indication of mixing with the geothermal fluids from the Palinpinon area.

At the lower Okoy and Banica watersheds, there has been no observed regional decline in groundwater levels. Only a localized cone of depression of about 25 meters was observed within the immediate vicinity of wells 5549, 5553 and 5554 and 20 meters in the area of wells 5546, 5547 and 5548 due to the extraction of the MDWD (SWECO, 2001). The localized cone of drawdown does not extend in the Palinpinon area.

Massive drawdown since the start of production at the Southern Negros Geothermal Field resulted to the lowering of the water levels of more than 500 meters, but this level appears to be leveling already as the geothermal field approach its steady state. The drawdown also affected the wells northeast from the geothermal field, where the water level of well N-1 declined from about 100 meters above surface (artesian) to ground level in the year 1994. No significant drawdown can be observed on the wells and springs that are located further to the east, which is indicated by the continuous presence of the thermal springs in Palinpinon.

8.0 NUMERICAL MODEL AND SIMULATION

8.1 The Model

Integrated groundwater data from chemistry, isotope and other physical properties imply that there are three types of waters in the lower Okoy

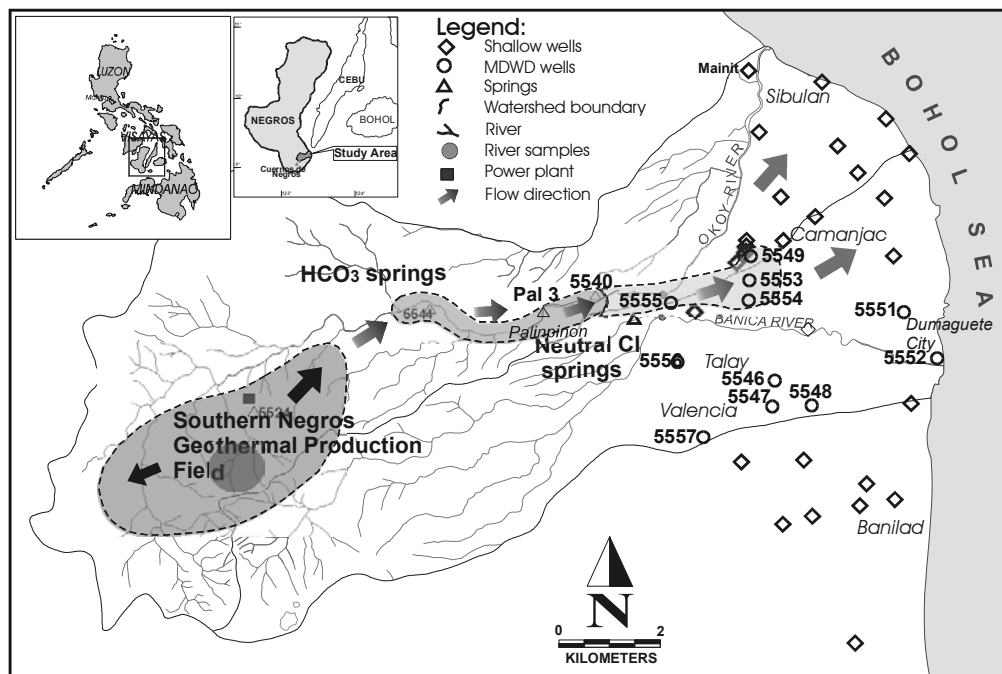


Figure 8. Migration of thermal fluids from the SNGPF to the Palinpinon area and towards the shallow groundwater aquifer.

and Banica watersheds. Groundwater south of Banica river are typical HCO_3 waters, while waters towards Sibulan are diluted waters coming from the well 5554 area. The mineralized waters from the thermal area in Palinpinon appear to influence the groundwater quality towards the northeast. Depth to groundwater near the shore is zero and elevates to around 70 masl within well 5555 and to around 130 masl near Valencia. The uniformity of the chemistry and isotopic composition, as well as the well log data, manifest a single unconfined aquifer with occasional lenses of clay. Well data, however, indicates that the upper 50 meters of the aquifer has higher permeability (25×10^{-5} m/s) and has lower permeability from 50 to 150 meters (5×10^{-5} m/s).

Influxes into the lower Okoy and Banica watersheds are recharge from precipitation, boundary influx coming from the upper aquifer, thermal water influx from the hot springs and river infiltration. Outfluxes are in the form of groundwater well discharges and flow to the sea (Figure 9)

8.2 Flow Simulation

Two-dimensional numerical flow model and simulation was restricted only to the lower Okoy

and Banica watersheds to simulate the migration of thermal waters from Palinpinon into the shallow groundwater aquifer. Modeling the lower watershed also reduces the uncertainty of the simulation results since there are limited available data in the upper watershed. Aquifer conductivity values were based on pumping tests, borehole log data and geology. Faults were also represented as cells of higher permeability. Conductivity values were assigned for the less permeable quaternary pyroclastics to the west (5×10^{-5} m/s), the alluvial aquifer at the middle (8×10^{-5} m/s) and the more permeable aquifer near the shore (18×10^{-5} m/s).

Initial heads were imported as the existing depth to groundwater table contour. River conductance was estimated based on the river bed permeability. Total porosity was estimated at 20% and the effective porosity at 10%, while the storativity was assigned at 0.01. Influx from the upper watershed is represented through wells at the entire eastern boundary.

Figure 10 presents the result of the flow simulation runs which matches the depth to groundwater calibration target. The conductivity data assigned are within the standard deviations of the actual aquifer values. Hence,

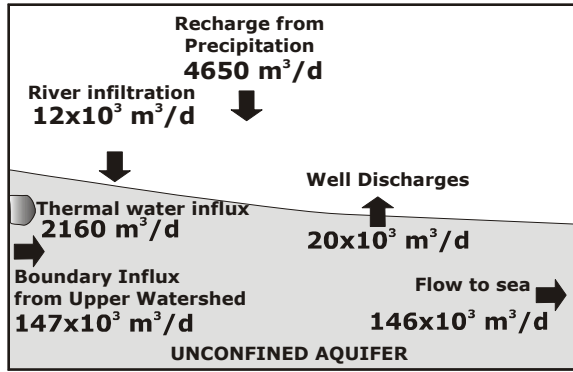


Figure 9. Flow model and groundwater influxes into the shallow groundwater aquifer.

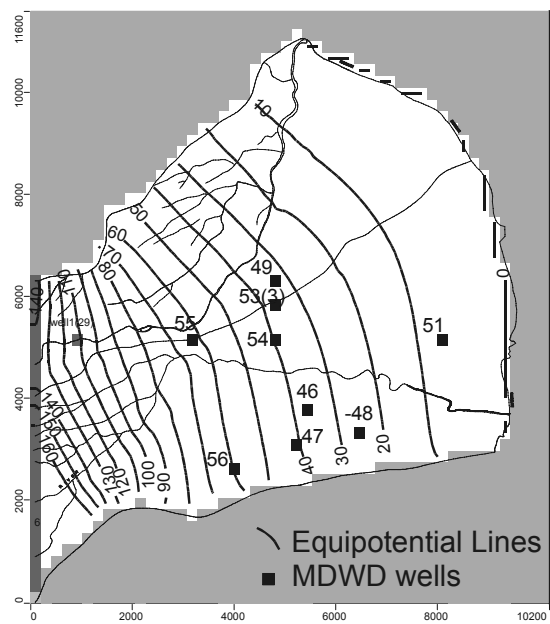


Figure 10. 2D groundwater equipotential contour map under steady state condition.

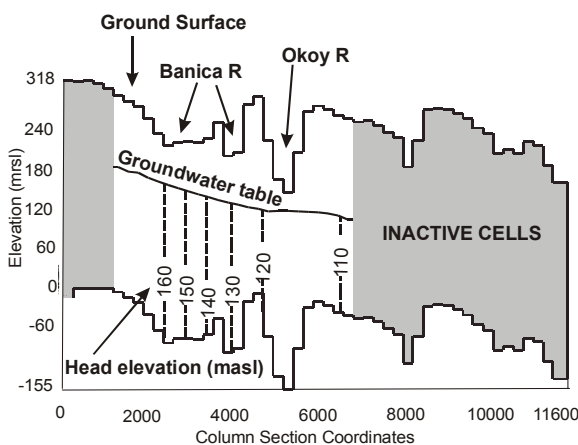


Figure 11. N-S cross section showing Okoy and Banica Rivers.

uncertainties are very minimal in the results obtained. The contour shows that the MDWD wells and the rivers have no influence on the groundwater flow, which is almost parallel to the coastline. The Banica river system is topographically elevated than the Okoy river system, and hence the higher water level at Banica. This also suggests that some Banica river water are flowing towards the Okoy river valley, as shown in a N-S cross section in Figure 11. This flow was also postulated by Sali Et al. in 1994 based on topographic differences.

The presence of higher permeable faults does not have an effect on the flow direction but on the relative flow velocity of the fluids. The presence of such structures is more manifested in volcanic areas than in alluvial aquifers.

9.0 CONCLUSIONS

The shallow groundwater in the Lower Okoy valley is grouped into three major water types: (1) **Na+K-Cl+SO₄ waters**, (2) **Ca+Mg-HCO₃+CO₃ waters** and (3) **Ca+Mg-Cl+SO₄ waters**. MDWD wells 5555, 5549, 5553 and 5554 produce diluted mineralized fluids with relatively elevated Cl, SO₄, Na, K, As, Li and B values. The second type are the wells located along and south of the Banica river which represent the typical shallow groundwaters. The third type are waters in wells located northeast from Palinpinon towards Sibulan. It should be noted, however, that the Cl and SO₄ concentration in the wells, though relatively enriched, are still within the limits of the Philippine drinking water standard.

Stable isotope compositions in years 1993, 1995, 1999, 2000 and 2002 and chemistry of MDWD wells and shallow wells shows minimal seasonal variation. However, rainfall isotope data from 1991 to 1997 reveal a relative depletion attributed to lesser amount of rainfall. An updated precipitation isotopic composition was used in recalculating the deuterium excess of 12.5, making the equation of the LMWL $\delta^2\text{H} = 8 \delta^{18}\text{O} + 12.5$. Recalculation of the isotope altitude gradient revealed a decrease in $\delta^{18}\text{O}$ and $\delta^2\text{H}$ of 0.28‰ and 2.1‰, respectively. The calculated elevation of recharge ranges from 1000 to 1400 masl.

Tritium concentrations of geothermal wells indicate mature waters (<1 TU) while that of the

shallow wells indicate more recent waters (1-5 TU). CFC data, on the other hand, suggests that the relative age of groundwater ranges from 10 years in well 5555 to more than 60 years in well 5546.

Geothermal fluids from the natural outflow in Palinpinon flows farther to the east as manifested in the chemistry of wells 5555, 5549, 5553 and 5554. Some of the mineralized fluids cross the contact of the volcanic terrane and the Quaternary alluvium, mixes with the groundwater and flows on the subsurface towards the northeast.

The mixing of mineralized geothermal fluids in the MDWD wells 5555, 5549, 5553 and 5554, possibly through Palinpinon Fault, is a natural occurrence extending from the geothermal outflow in Palinpinon. Further northeast the fluid transport is already governed by convection and dispersion.

Numerical simulation confirms the northeastward migration of relatively mineralized thermal fluids from the Palinpinon springs to the shallow groundwater aquifer.

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