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OLKARIA III FIELD DEVELOPMENT

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ABSTRACT

The Olkaria III geothermal project is the first private geothermal project in Kenya. The Power Purchase Agreement was awarded by Kenya Power and Lighting Company (KPLC) under a World Bank supervised international tender for the field and power plant development.

The field development is a combined effort of ORMAT and some of the leading geothermal engineering groups worldwide.

In parallel with the field development, ORMAT has constructed on a fast track, an "early generation" binary power plant using ORMAT® Energy Converters (OECs) which helped to meet the power demand, which was in short supply at the time in Kenya. It also enabled testing of old and new wells for a longer period of time and continuous updating of the field parameters during the conceptual design and detailed engineering phases of the project.

Phase I of the project has been completed. The plant is producing 12.5 MWE with an availability of 100% at a 96% load factor over the last 3 years. The field was fully developed to support an output of 64 MWE Gross (58 MWE Net) meeting KPLC's requirements for a nominated total net capacity of 48 MWE for the power plant (to be reached at the completion of Phase II).

1.0 INTRODUCTION

The worldwide geothermal energy potential is estimated as 60,000 MWE from nearly 40 countries, with some 8,100 MWE installed and operating worldwide. Estimates are that Kenya has the potential for near term development of over 500 MWE with an ultimate potential exceeding 2,000 MWE.

The Olkaria III geothermal power plant will bring significant development and economic benefits to Kenya, including infrastructure investment, national geothermal capacity and the creation of skilled jobs. The clean renewable geothermal energy contributes to sustainable resource development, thereby lessening Kenya's dependence on imported fuel and the vagaries of weather and climatic conditions.

The power project in rural areas contributes to the curbing of migration from these areas to the cities, by developing these areas and transferring professional skills to local operators. In addition, the local banking system, communication system, transportation, accounting offices, legal advisors and professional consultants are used.

2.0 THE PROJECT

OrPower 4 has secured the right to develop and operate the Olkaria III geothermal development concession within the Rift Valley in Kenya. This concession has an area of approximately 12.4 km^2 and encompasses the West Olkaria geothermal resource, which was first confirmed to exist with the drilling of exploration well OW-301 in 1983.

The Olkaria III area lies 3 km to the west of the 45 MWe Olkaria I ("Olkaria East") geothermal development area where the first 15 MWe unit came on line in June 1981. The third and final unit started operation in March 1985. Olkaria I is operated by the Kenya Electricity Generating Company Ltd. (KenGen), which is also currently developing the 2 x 32 MWe Olkaria II project ("Olkaria Northeast"). The Olkaria II lies immediately north of Olkaria I and extends to within 2 km of the northeast boundary of the Olkaria III concession.

In July 1996, with efforts to develop the current power generation potential of Kenya, the Government of Kenya (GOK) conducted an international tender for a contract to build, own and operate ("BOO") a geothermal power facility using existing local geothermal resources. This geothermal facility, Olkaria III, exists alongside two other geothermal facilities Olkaria I and Olkaria II (under advanced development).

In November 1998, the Olkaria III tender was awarded to ORMAT International, Inc. and ORMAT, through OrPower 4 as a special purpose company for the project, entered into a 20-year Power Purchase Agreement ("PPA") with Kenya Power and Lighting Company ("KPLC"), Kenya's sole electricity distributor. The Olkaria III project consists of two phases. Phase I, which is already complete, involved the construction of a 13.5 MWE plant. This Phase was constructed on a fast track to provide early generation and to assess the geothermal resource by providing a basis for a long-term flow test.

Phase II is the expansion to the full technically feasible capacity of the plant whereby under the PPA, OrPower 4 has to demonstrate that the wells can provide 120% of the nominated capacity over the life of the project.

3.0 THE DESIGN AND CONSTRUCTION OF PHASE II

The study, involving a 3-dimensional model of the Olkaria III field was a combined effort involving the leading geothermal groups including PB-Power of New Zealand, Orkustofnun of Iceland and GeothermEx of the USA. In addition, KenGen (the Kenya Electricity Generating Company Ltd.) have supplied a lot of information regarding the Olkaria III field and have contributed to the project in conducting well testing, data review and interpretation and other professional services. The study was conducted in parallel with drilling new wells in the field and the information gathered during drilling and testing of the wells was introduced to the field models and used as a tool for continuous calibration of the model. The result of the study was the decision on the power plant capacity target, which will be the basis for OrPower 4's obligation in the Power Purchase Agreement with the Government of Kenya.

4.0 WELLS DRILLED PRIOR TO ORMAT INVOLVEMENT

The development of Olkaria III geothermal field was started by KenGen in 1983 and nine wells were drilled to depths of 1900 to 2500 meters within the concession area by 1988. These are vertical wells, drilled with mud. The permeability of some of the wells is relatively low and they have a skin resistance as a result of using mud when drilling in the production zones. Only wells OW-301, OW-303A (now cemented) and OW-305 were clearly within the main productive reservoir. The other wells, which lie close to the concession borders, are significantly cooler than the more central wells and some have temperature inversions that show they are in outflow areas. Of these marginal wells, OW-302 and OW-401 have some useful discharge (well OW-302 is cycling) and connecting them to the power plant is in question.

In 1998, OrPower 4, a special purpose project company, initiated retesting of the producing wells OW-301, OW-302, OW-305 and OW-401 in order to study the present characteristics of the wells and changes in the productivity since the time they were drilled and tested. The test results (Table 1) were the basis of the design of the "early generation" plant and were used for the field analysis and building of the three dimensional numerical model.

5.0 CONCEPTUAL MODEL

The Olkaria III Concession area is located centrally within the West Olkaria area, which may be broadly defined as that area west of the Ol Olbutot Fracture Zone within the Greater Olkaria Geothermal Resource area. West Olkaria was the subject of a series of geoscientific exploration surveys, which were carried out during the late 1970s and early 1980s, and of an exploration-drilling program, which was carried out between 1983 and 1994. This exploration program was executed by the then Kenya Power Company (KPC).

During the first half of 1999, ORMAT assigned both the Kenya Electricity Generating Company Ltd. (KenGen – formerly KPC) and PB Power, GENZL Division, the tasks of developing a conceptual model and a development strategy for the Olkaria III Concession area.

Table 1. Flow test results.

Lip pipe (Inches)	Well No.	WHP (Bara)	Mass (t/hr)	Water (t/hr)	Steam (t/hr)	Enthalpy (kJ/kg)	Power (MWe)
8	OW-301	6.4	100.3	50.1	43.1	1647	4.8
6	OW-301	9.2	97.7	47.1	43.9	1597	4.9
5	OW-301	11.3	96.4	45.4	44.4	1612	4.9
5**	OW-301	(7.4)	(105.4)	(46.4)	(49.1)	(1665)	(5.3)
4*	OW-302	6.56	53.40	37.10	11.85	1108	1.32
3*	OW-302	7.79	39.05	26.16	9.65	1162	1.07
6	OW-305	(3.13)	(29.6)	(11.1)	(16.7)	(1830)	
5	OW-305	3.82	26.5	7.3	16.5	2121	
4	OW-305	5.66(4.94)	20.9(21.3)	7.4(5.0)	12.3(15.3)	1886(2149)	1.4
3	OW-305	9.4(8.73)	26.0(21.7)	7.6(5.8	16.9(14.7)	2013(2071	1.9(1.6)
6	OW-401	(4.59)	(76.7)	(53.1)	(17.3)	(1114)	
5	OW-401	4.67	62.7	46.4	10.9	1045	

Key: * 6” Lip pipe was used but flow was throttled back to equivalent of 3” and 4” Lip pipes

** Two single wellhead separators/silencers were used with two 5” Lip pipes. Otherwise only one either single or twin wellhead separator/silencer was used.

The resource conceptual models developed by these two groups, which were both based on the same data collected from the original KPC exploration program, were similar and identified a shallower (1500 - 800 masl) two-phase zone with good horizontal permeability, and centered in the eastern half of the Olkaria III Concession area. The temperatures in this zone were generally indicated to be in the 220 - 240°C range.

The models also postulated the existence of a deep high temperature reservoir, from which fluids upflow in the centre of the concession area to feed the shallower 2-phase system. The deep reservoir fluids, as indicated from samples from Well OW-305, are of neutral pH, sodium chloride type (530 ppm chloride) with very low gas content and with indicated temperature of around 320°C.

The system is predominantly bounded on the east by the two parallel north–south trending fracture zones – the Narasha Fracture zone, and the Olbutot Fracture zone. It is suggested that the zone between these two north-south fracture zones acts as a conduit at deeper levels for cooler north to south fluid flow. Wells such as OW-401, OW-202 and OW-203 indicate these cooler fluids at depth and certainly indicate the eastern limits to the West Olkaria reservoir.

No such physical boundary exists to the west, however production from the western exploration wells show extreme levels of non-condensable gases (predominantly CO_2), suggesting that production derived from wells drilled within the western half (west of Well OW-301) would probably be uneconomical (Table 2). The CO_2 concentrations measured during the initial production tests of the western exploration wells within the Olkaria III concession area were shown on Table 2.

Table 2. CO_2 concentrations of western wells.

Well	Date	Measured Enthalpy kJ/kg	Weight % CO_2 in steam (5 bara)
OW-301	21.4.99	1572	16
OW-304D	18.6.92	2212	43.9
OW-308	2.12.98	1800	64

Regional west to east, and north to south hydrological gradients drive the geothermal fluids to the east, and to a lesser extent to the south. The fluids in the shallow reservoir are high enthalpy and two-phase, which condense to hot liquid in the more distant outflow zones. The shallow reservoir pressure corresponds to a water table at about 1500 - 1700 masl or about 400 - 600 m depth. This significant level of “under-pressure” relative to the surface suggested high pressure losses will be incurred by liquid dominated, lower enthalpy fluids travelling up the well bore.

Figure 1 indicates the extent of the shallow reservoir and the top of the deep reservoir as postulated by the conceptual models.

The conceptual models indicate that temperatures at 200 masl (typical well depth of around 1800 m) range between 230 to 320°C with the highest temperatures occurring in well

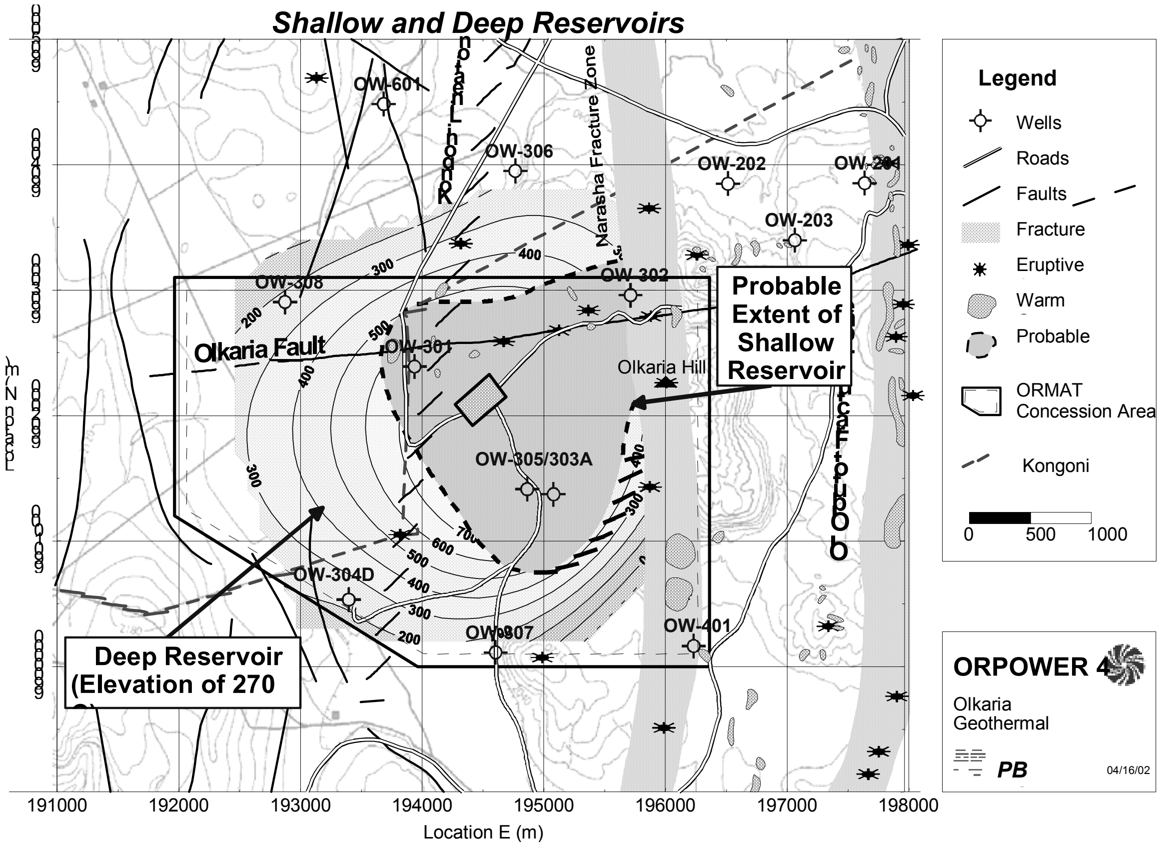

Figure 1. Shallow and deep reservoir.

OW-305 in the centre of the eastern half of the Concession area. The exploration wells in the Concession area (other than well OW-401) generally indicate increasing temperature with depth, with near isothermal conditions through the shallow reservoir zone (1500 - 800 masl) indicating good vertical permeability. However, the temperature gradients below this depth range are typically conductive, suggesting that the deeper zone permeability is not high.

Geothermal fluids from the deep, high temperature reservoir zone rise in the centre of the eastern half of the Concession area, through limited permeability, into the shallower reservoir, which has good vertical and horizontal permeability. The models suggested well two-phase high enthalpy production would be obtained from wells drilled into the zone centred on this postulated upflow.

Figure 2 presents a summary cross-section through the conceptual model.

6.0 DRILLING NEW WELLS

The first stage in the well drilling program was the drilling of five new wells as part of the field appraisal program as defined by the bid issued by KenGen, and then the completion of drilling to supply the power plant steam and brine requirement. The PPA contract with KenGen calls for field capacity capable of supplying 120% of plant requirements to allow for degradation of wells and well shutdown for maintenance. The drilling approach has been to drill from a low number of well pads in order to minimize the surface disturbance. Olkaria III is located within a national park and is home to many animals. One well on each pad is a vertical well and the other is directional with a target distance of at least 300 m to minimize interference. The drilling contractor was Nabors International of the USA.

Some of the early Olkaria III wells had severe skin damage, which was clearly the result of drilling with mud in the producing zones. The new well drilling program called for drilling with

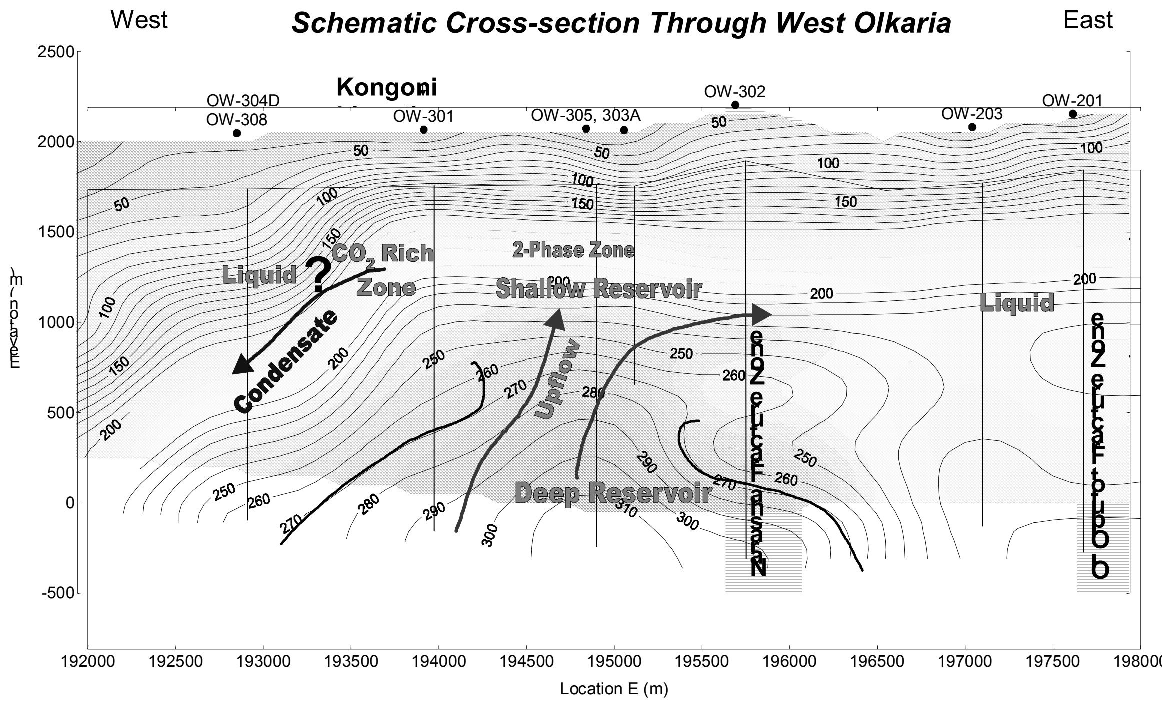

Figure 2. Schematic cross-section through west Olkaria.

air or aerated water only when arriving at the producing levels. The result was much higher permeability compared with the old wells. This factor, together with comprehensive modeling and analysis which was calibrated and updated in parallel with the drilling of more wells, results in high productivity figures compared to the old Olkaria III wells and those of Olkaria II.

During the period of February 2000 to March 2001, five exploration/production wells were drilled, completed, and tested, satisfying the primary Phase I objectives. In addition to these primary objectives, secondary objectives were to prove the extent of the identified shallow two-phase production zone; and to drill beyond this shallow zone to identify the postulated “deep reservoir”.

During the period March 2001 to March 2002, four additional wells were drilled, completed and tested, and two wells were commenced but not completed. See Figure 3 for well locations.

The production “success” rate of the wells was far in excess of expectations, thus allowing termination of the drilling operations in March 2002.

Each well was initially discharged vertically for a few hours to clear cuttings from the well-bore prior to diverting the flow through a horizontal discharge pipeline, a Russell James lip pressure pipe, and into an atmospheric cyclone separator/silencer fitted with a weirbox to allow monitoring of the separated water mass flows. In addition to the standard wellhead pressure (WHP), lip pressure, and weir box gauges, electronic transducers monitored each of these parameters, and the data was logged utilising a programmable data logger.

Each well discharge test program included an initial “fully open” discharge (i.e. no throttling) for a period ranging from 7 days to around a month, until stable and constant discharge conditions occurred. A range of discharge WHP’s were then tested, each for a period of around 5 to 7 days, allowing a well discharge characteristic to be plotted. A summary of the “production” discharge data produced from these tests is presented in Table 3.

The test of the wells has demonstrated 120% resource availability for a plant having a nominated net capacity of 48 MWE, meaning that the field developed is sufficient to support a plant of 64 MWE Gross or 58 MWE Net.

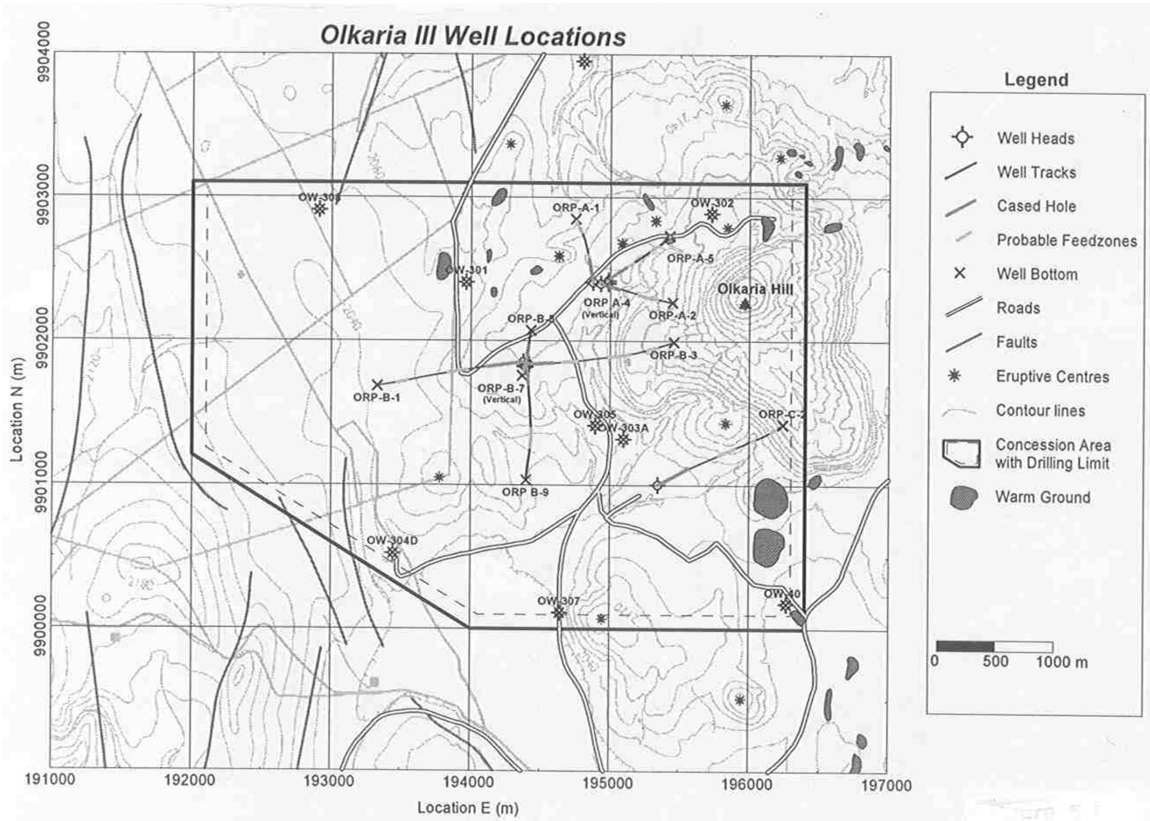

Figure 3. Olkaria III well locations.

Table 3. Olkaria III well production capacity data

Tested Available Steam / Water - Proven Indicative Capacity to Date - with 1st order NCG Correction - to 4 April 2002

Well	WHP (Bara)	Separation Press (bara)	Total Mass Flow (kg/s)	Steam Mass Flow (kg/s)	Water Mass Flow (kg/s)	Total Flow Enthalpy (kJ/kg)	NCG (Wt %)	Available Thermal Power Steam (MWt)	Available Thermal Power Water (MWt)	Total Available Thermal Power (MWt)	Nominal Generation Capacity Mwe
A-1	8.06	6.50	14.97	12.75	2.22	2475.00	2.26	34.30	1.60	35.90	5.27
A-2	9.68	6.50	76.42	22.37	54.05	1292.00	0.12	61.69	40.88	102.57	12.52
A4	9.91	6.50	26.55	21.71	4.84	2381.94	1.35	58.93	3.68	62.61	9.13
A5	10.78	6.50	54.92	29.18	25.74	1788.00	0.54	79.80	20.00	99.80	13.57
B-1	8.83	6.50	18.14	7.32	10.82	1521.00	10.21	18.17	8.00	26.16	3.36
B-3	9.03	6.50	15.59	12.15	3.44	2326.00	0.91	33.13	2.56	35.69	5.17
B-7	9.34	6.50	14.33	11.04	3.29	2283.40	7.70	28.17	2.47	30.63	4.42
B-9	9.69	6.50	31.41	21.94	9.47	2153.00	1.25	59.53	7.16	66.70	9.50
C-2	7.78	6.50	16.07	10.16	5.91	2013.00	0.67	27.77	4.23	32.00	4.50

7.0 INNOVATION AND INSPIRATION

For its commercialization and widespread use of air-cooled condensers in geothermal power plants and for its pioneering development of the first private geothermal project in Kenya, ORMAT was awarded the 2001 CTI World Climate Technology Award at a ceremony held on November 6, 2001 in Marrakech, Morocco.

The environmentally benign ORMAT geothermal technology with air-cooling enables the reinjection of all the geothermal fluid - thus further reducing emissions, consumption of water and enhancing geothermal resource sustainability (which both increases the viability of a project and provides a longer-term impact on climate change).

The Olkaria III project provides clean electricity to industry and households contributes to closing the supply gap in Kenya's electricity market and helps to develop rural areas by transferring skills and creating jobs.

It is to be hoped that this first private geothermal project in Kenya can serve as a model to promote the development of the extensive Kenyan and East African geothermal resources.

ORMAT has also accomplished a comprehensive Environmental Assessment of the Project to comply with strictest environmental standards, and yet to still construct the initial stage plant on a fast track.

8.0 ENVIRONMENTAL CONSIDERATIONS

The project complies with the "Geothermal Energy" section of the latest "Industrial Pollution Preventions and Abatement Handbook" published by the World Bank Environment Department in collaboration with the United Nations Industrial Development Organization and United Nations Environmental Program. All equipment is designed to minimize the environmental impact. The plant also complies with environmental requirements regarding the Air Quality, Liquid and Solid Wastes, Land Disturbance, Visual Aspects and Noise.

Water vapor and gases are dispersed so as to avoid concentrations at the ground level that are unacceptable to personal safety. Liquid drilling and wastes are pounded, and residuals of the liquid and solid wastes are treated and removed to site restoration. Drainage of the surface water is arranged to avoid the risk of erosion of the light volcanic soils. Spent geothermal water is injected into the ground with minimal disturbance to the geothermal reservoir.

With regard to land disturbance, well sites are fenced and pipelines are designed to allow the movement of animals across the area (including buried segments for above crossing and extreme high expansion loops for giraffe crossing). As far as practicable, visual changes to the landscape have been minimized to blend in with the background landscape.

9.0 CONCLUSION

The Olkaria III field development met all its planned goals as far as budget and timetable goes. The productivity of the wells and, as a result, the number of wells drilled to support the power plant was much better than planned. The causes for the good results are the field modeling, good well planning and well drilling. The successful field development is a combined effort by ORMAT and some of the leading engineering groups in the geothermal world: PB power of New Zealand, Orkostufnon of Iceland and GeothermEx of the USA, as well as the geothermal experts in various disciplines of KenGen of Kenya and the US drilling company Nabors.

The flow tests of the wells drilled, demonstrated a capacity to support of 64 MWE (Gross) and 58 MWE (Net) plant output meeting KPLC's requirement for a nominated net power plant capacity of 48 MWE.