The Kenya Power Company Limited
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Environmental Assessment

Final Report

North East Olkaria Power Development Project

Vol 2

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1. Introduction

This Environmental Assessment (EA) report has been prepared on behalf of Kenya Power Company (KPC) by Sinclair Knight and Partners Pty Ltd in association with RPS International Ltd (Kenya) and ESA Pty Ltd (Sydney).

KPC propose to develop a 64 MWe power station comprising two 32 MWe units, to extract geothermal energy available in the North East Olkaria geothermal area located approximately 80 km NW of Nairobi. At present KPC operate a 45 MWe power station at East Olkaria approximately 3 km SSE of the proposed power station site.

The EA has been conducted following World Bank guidelines for the preparation of EAs. It provides the following information:

- o a description of the local setting, the geothermal resource and the history of the development (**Section 2**);
- o a brief review of the requirements for power in Kenya and a justification of the need for the project (**Section 3**);
- o a review of the regulatory and legal requirements that the project will be affected by under Kenyan law (**Section 4**);
- o a description of the major elements of the development (**Section 5**);
- o a description of the existing environment under the categories, flora, soils, fauna, climate and meteorology, air quality, noise, water quality and water management and socio-economics (**Section 6**);
- o an assessment of impacts for each element of the environment and the recommendations for mitigating measures to ensure that impacts are maintained at an acceptable level (**Section 7**), and;
- o a summary of the major conclusions reached in the impact assessment section and the recommended mitigating measures and monitoring that should be undertaken (**Section 8**).

The major environmental issues that have been identified for the project are the way in which the project will interact with the Hell's Gate National Park, which encloses both power stations, the potential for adverse effects due to air emissions on the neighbouring flower farms located adjacent to the proposed power station, the interaction of the power station with Lake Naivasha, and the impact that the power station work force will have on the community infrastructure in the Naivasha area. It is concluded that all these matters can be satisfactorily managed by the project.

2. Local Setting and History of the Development Project

2.1 PREAMBLE

This section presents background information on the North East Olkaria Project. Included is a description of the project in a national and regional setting, a brief review of the history of the project and a review of the regional and local geology. It also presents a useful introduction to **Section 5**, which provides further background information on the geothermal resource and the infrastructure required to extract geothermal energy and generate electricity. The information is presented in the form of a review of existing sources of information, such as earlier geological studies and the feasibility report for the development. The section does not present original research or new interpretation of data and the reader seeking more details on these aspects should consult the literature cited in the various discussions. The reader should also be aware that this section introduces information that is discussed and analysed in much more detail elsewhere in the report.

2.2 LOCATION AND LOCAL SETTING

The location of the project area in a national setting is shown on **Figure 2.2.1**. **Figure 2.2.2** shows the project area in a regional setting.

The Olkaria geothermal resource is located on the southern side of Lake Naivasha. The resource presently supports an existing power station, which commenced construction in 1980. Stage 1, 15 Mwe, was commissioned in 1981, Stage 2, a further 15 MWe, was commissioned in 1982 and the final 15 MWe expansion was commissioned in 1985. Thus the present development stands at 45 MWe. The existing power station provides useful information for determining the effect that the proposed geothermal power station development will have on the environment. The environmental studies presented in this EA make extensive use of this information, thereby improving the level of confidence in the assessment of environmental effects that will result from the proposed development.

The presence of the existing power station also has consequences for cumulative effects, particularly for air pollution and socio-economics.

An important factor in the environmental studies has been the existence of the Hell's Gate National Park, which was established on 2 February 1984, several years after the present Olkaria power station was commissioned. The park encloses both the existing power station and the site for the proposed power station and much of the geothermal resource. This imposes constraints on the way in which the park and the power stations need to be managed. These matters are considered in **Section 7**, which discusses the interaction that is taking place between KPC and Kenya Wildlife Service (KWS) to ensure that conflicts do not arise.

Another important factor in the environmental studies is the question of Lake Naivasha, the southern shoreline of which is located approximately five kilometres from the site of

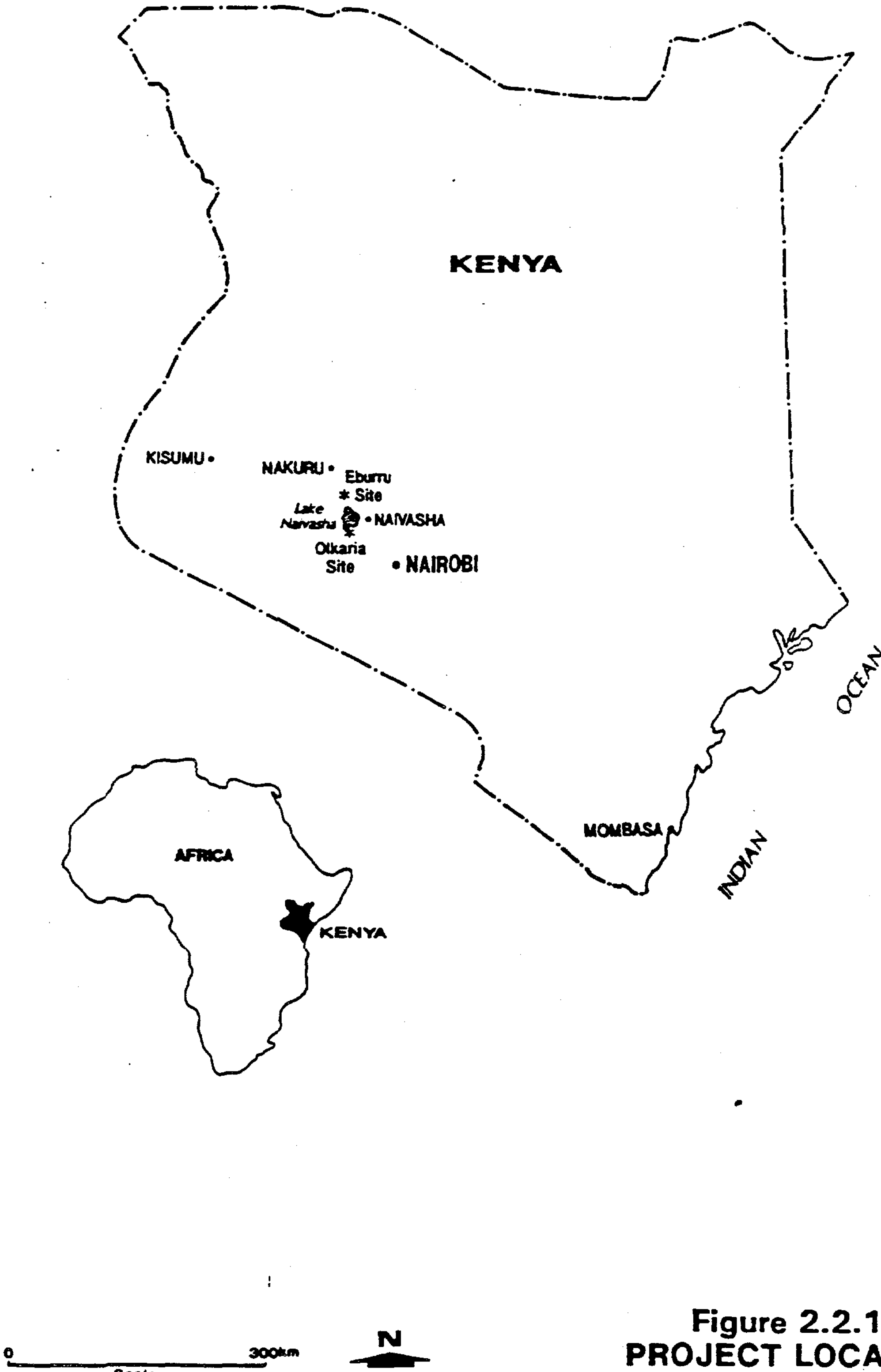


Figure 2.2.1
PROJECT LOCATION

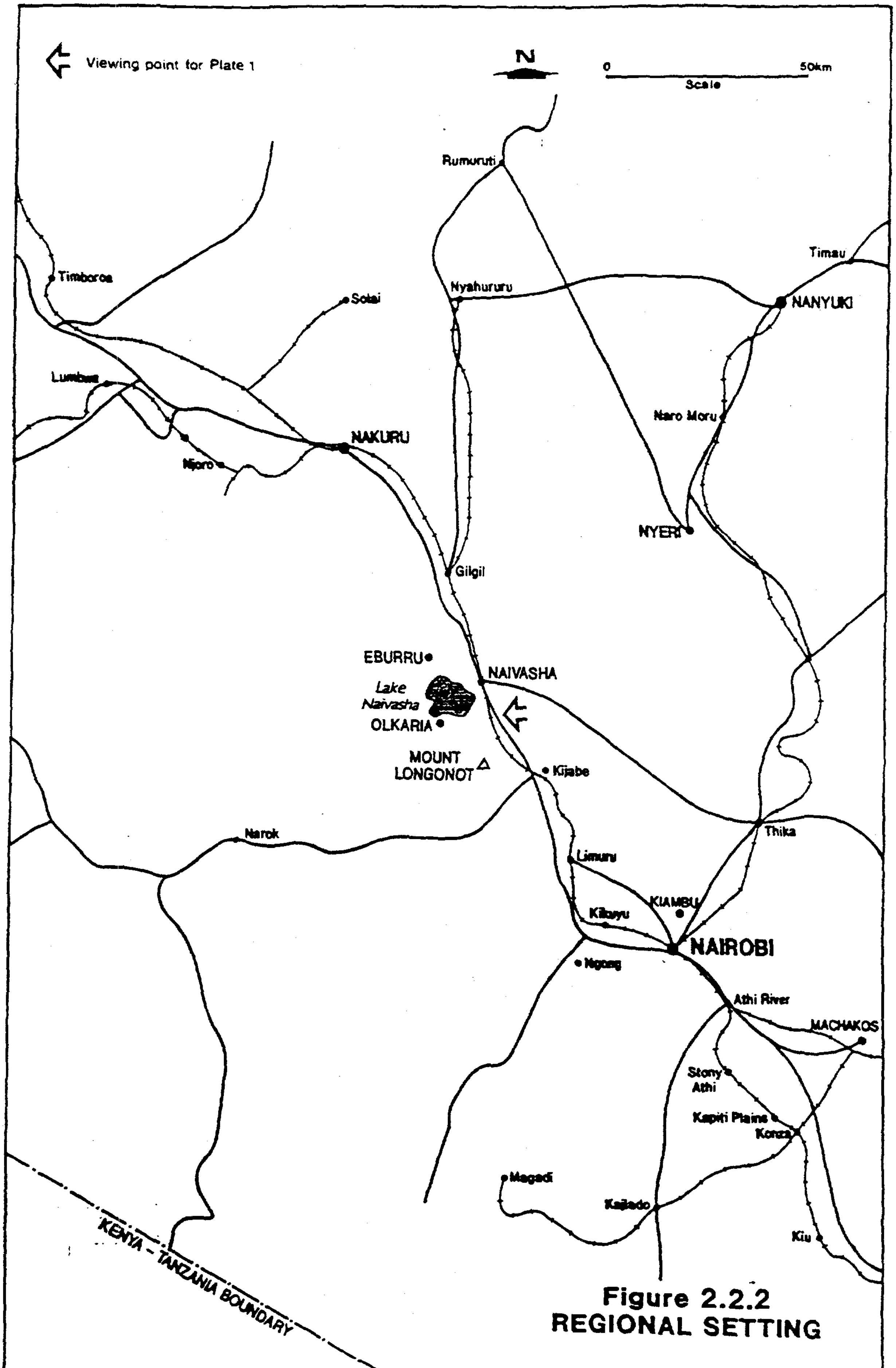


Figure 2.2.2
REGIONAL SETTING

the proposed power station. The lake, along with the geothermal resource are arguably, from an economic point of view, the two most important physical resources in the area. KPC at present makes use of lake water for make-up cooling water for the existing power station, for "domestic" purposes and for exploration and development drilling. KPC does not need to rely on the lake for the operation of the power station, nor for the exploration program. However, the use of lake water is presently the most economical method of providing water for the existing power station and for the expansion programs and thus KPC is a user of lake water (see further discussion on lake water usage in **Section 6**.)

Plates 1 to 12 are presented to assist the reader in appreciating the general surroundings including the terrain, the vegetation and the physical appearance of the existing power station, the well-field, the transmission lines and so on.

Plate 1 is a distant view towards the project area from the Trans Africa Highway on the lower part of its descent on Kikuyu Escarpment of the Rift Valley travelling towards Naivasha. The approximate viewing point and direction of viewing are shown in **Figure 2.2.2.** The plate shows the southern portion of Lake Naivasha (1), part of the Ol Njorowa Gorge (2) and Olkaria Hill (3) as they appear from this distant viewing point. Occasionally (not in this view) small plumes of condensing water vapour from the existing power station cooling towers, or gas ejectors, or wells under test, are visible as a very minor feature of the landscape viewed from this point. Generally these would not be noticed from the road. The existing power station is approximately 25 km southwest of this viewing point and is not visible because it lies behind some hills. Its approximate location is marked (4) on the plate. The proposed power station will also be obscured from view at this point.

Plate 2 shows the existing 45 MWe power station as viewed from the high ground approximately 1.5 km to the northwest (see **Figure 2.2.3**). Some of the cliffs of Ol Njorowa Gorge are visible in the background. This view is typical of dry, daytime conditions. No vapour plumes are visible under these conditions. Generally, in the early morning, or during days when the humidity is high, cloud-like plumes of condensing water vapour are visible from the cooling towers, the gas ejectors on the main power station building and from the separators at each well.

Plate 3 shows the site of the proposed power station viewed from approximately 500 m to the west-northwest of the existing power station cooling towers (see **Figure 2.2.3**). The photograph was taken under damp (humid conditions) and shows large plumes of condensing water vapour from the cooling towers ((1) on the left of the photograph) and from the gas ejectors ((2) in the centre). The peak of Mount Longonot (3) is visible in the background to the right. An interesting observation that can be made from the photograph is the much greater plume rise that the cooling tower plume undergoes compared with the plume from the gas ejectors. The proposed power station design provides for non-condensable gases (including hydrogen sulphide) to be emitted from the cooling towers. This should provide significantly better dispersal of the hydrogen sulphide emission than is the case with the existing disposal method. The existing disposal method through high-velocity gas ejectors on the eastern side of the main power station building allows the gas ejector plume to be grounded prematurely as the gas ejector plume is frequently trapped within the turbulent building-wake as the air flows across the building. The plate shows this occurring to the lower portion of the plume.

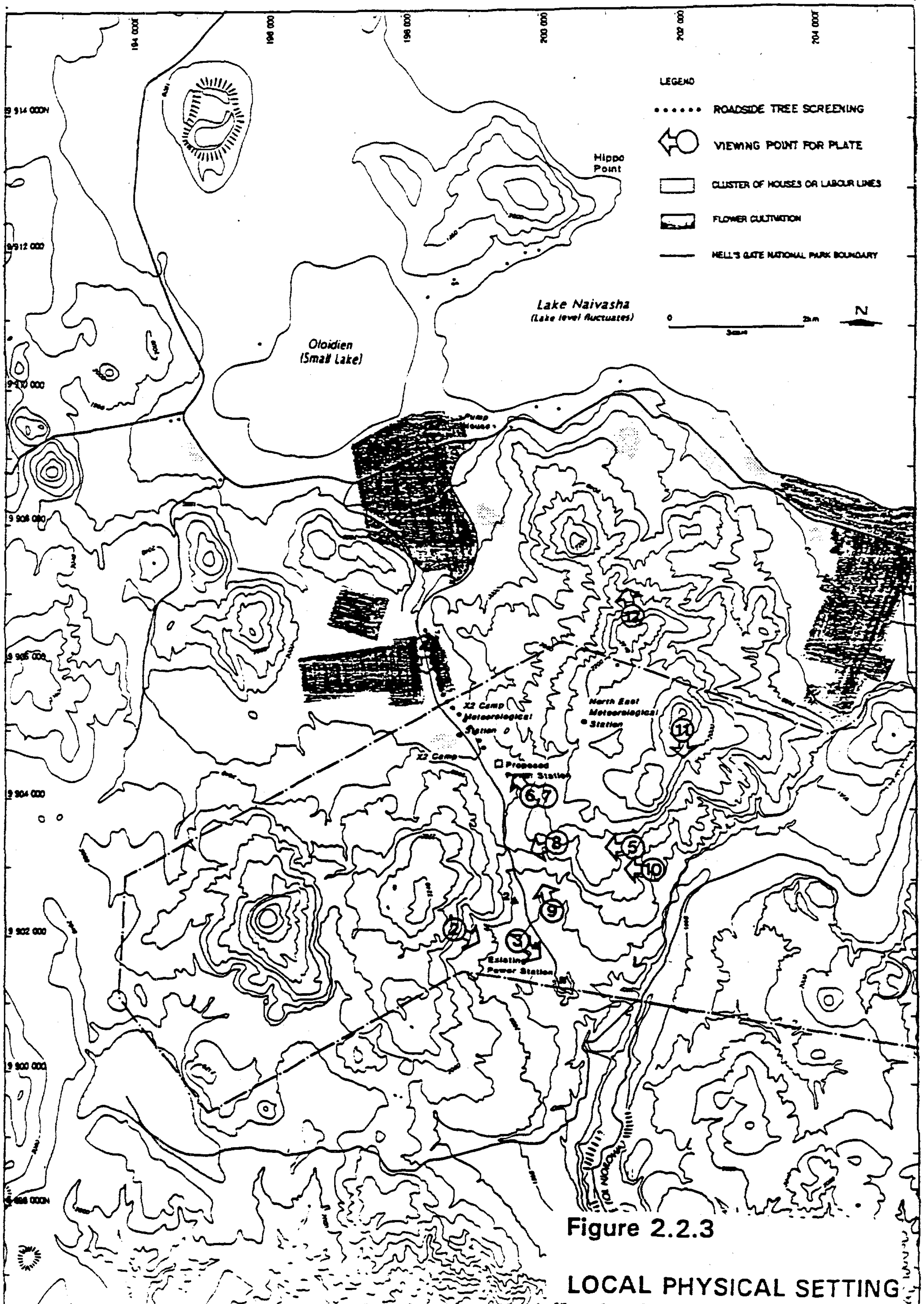


Figure 2.2.3

LOCAL PHYSICAL SETTING

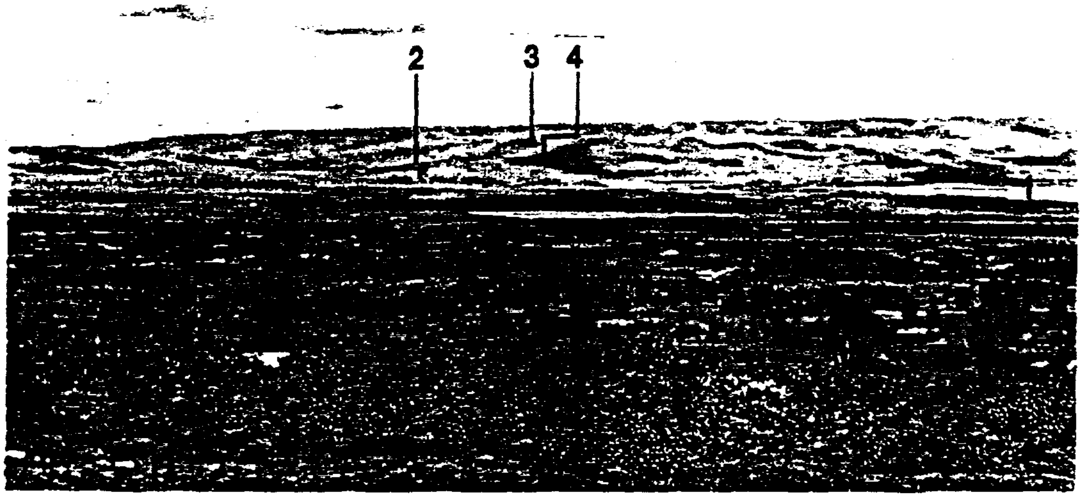


Plate 1 - The Olkaria Area from the Trans Africa Highway (see text for details).

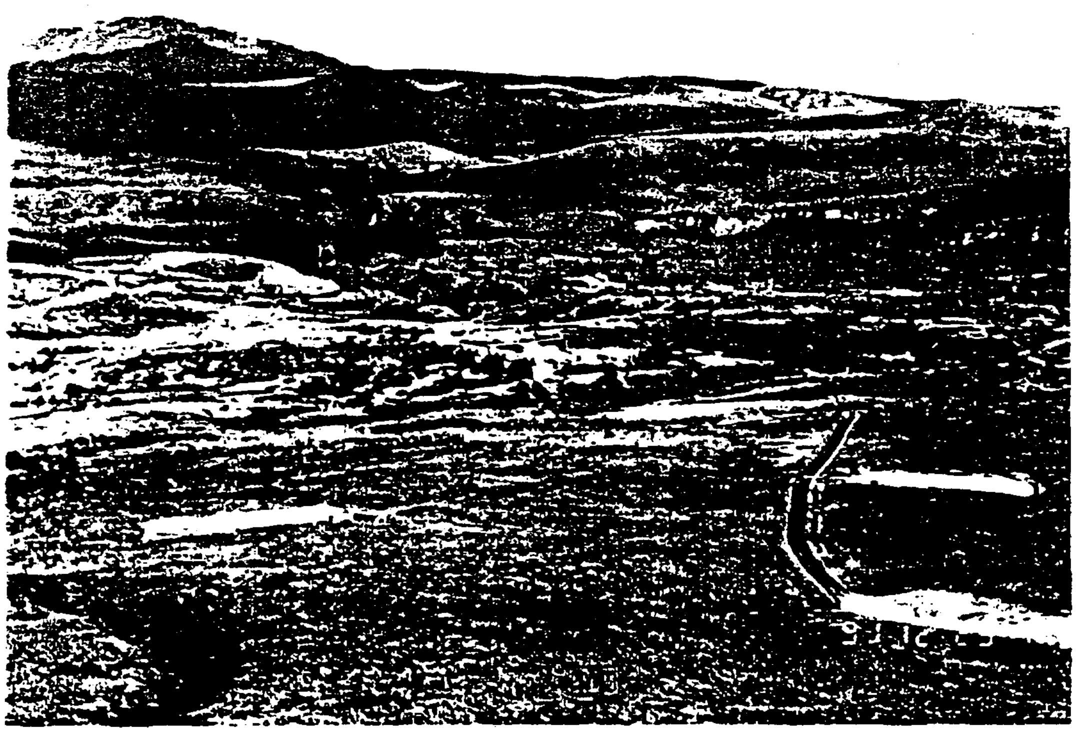


Plate 2 - The existing East Olkaria Power Station under dry conditions (see text for details).

Plate 3 - The existing East Olkaria Power Station show appearance of condensing water vapour plumes under cool humid conditions (see text for details).

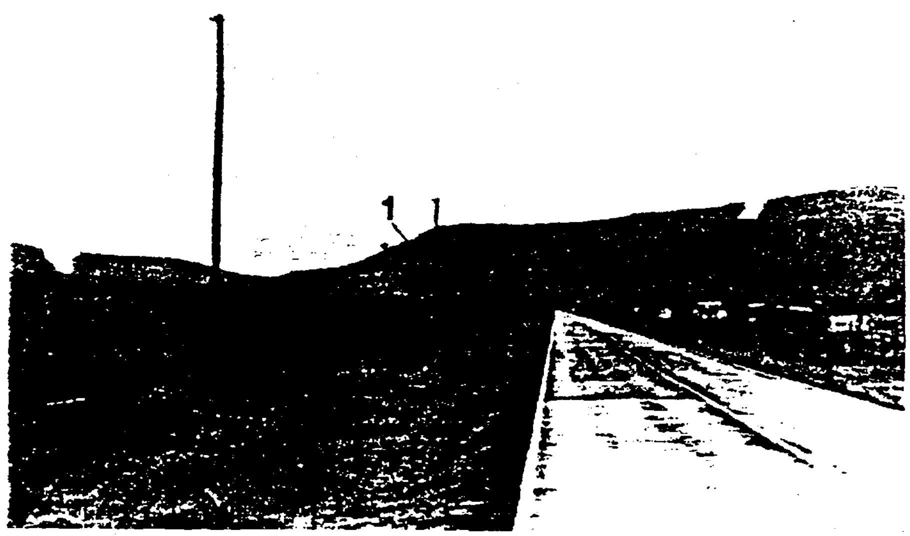


Plate 4 - Proposed North East Power Station site viewed from north (see text for details).

Plate 4 is taken from the road approaching the Olkaria Gate entrance to Hell's Gate National Park (see **Figure 2.2.3**). The viewing point is approximately one kilometre from the gate. It shows the site of the proposed power plant (1). The photograph was taken under cool humid conditions and plumes of condensing water vapour from Wells 710, 709 and 703 under test, are also a major feature of the plate. Tree planting on the eastern (left) side of the road will screen the power plant structures, but not the cooling towers plume, from the point.

Plate 5 shows a view of the top of the plume (1) of a well (Well 717) undergoing testing. The power-line pylon on the left of the photograph is part of the transmission line from the existing power station to the national grid. Large herbivores such as zebra and kongoni, although shy of human activity, appear to be unperturbed by the well testing operation despite the loud noise associated with the activity. The photograph was taken with a telephoto lens and the zebra shown in the plate would be approximately 200 m from the well. The zebra will sometimes walk and stand on the well pad of wells under test.

Plate 6 shows a view over the site of the proposed power station (1), which lies approximately 1.2 km to the north-northwest of the viewing point (see **Figure 2.2.3**). X2-Camp (2), the sealed power station access road (3), the (KWS) Olkaria Gate entrance to Hell's Gate National Park (4) and part of the Oserian flower farm cultivation (green area behind power station site) is also shown on the plate. **Plate 7** is from the same viewing point but taken with a longer focal length setting to show the more distant features more clearly. The same key applies to this plate as to **Plate 6**. The leafless state of the bushes in the foreground is due to an extensive fire, which burnt much of the vegetation in the area in early 1991.

Plate 8 shows a view from the east across the proposed power station well-field. It shows tanks used to store and feed Lake Naivasha water for drilling work required for well development (1), several drill pads (2) and Olkaria Hill in the background.

Plate 9 shows typical well-head infrastructure as used on the existing power station. It shows the separators (1) and associated high-pressure piping to take the steam from the well to the power station. The well-head is fenced with a cyclone wire fence which is just apparent in the photograph. The photograph also shows the appearance of the transmission line pylons (2). These are generally only "noticeable" when the viewing point highlights them against the horizon. The proposed power station will use two centrally located separators. Individual separators will not be required at each well-head. Piping will be coloured to blend better with the natural vegetation and the plumes of condensing water vapour will not be visible. Cyclone-wire mesh fencing will still be used.

Plate 10 shows a drill pad and drilling rig with Olkaria Hill in the background. The size of the pad is determined by the requirement for space to store equipment and to work during the drilling work. The completed well-head requires very much less space.

Plate 11 shows a view from high ground to the north of the power station looking south (see **Figure 2.2.3**). The existing power station is off the photograph to the right of the viewing point. Points of interest are Central Tower (1), which is on the southern boundary of Hell's Gate National Park, the Ol Njorowa Gorge (2) and Suswa Volcano to the left in the far distance (approximately 40 km from the viewing point). The

Plate 5 - Well under test (see text for details).

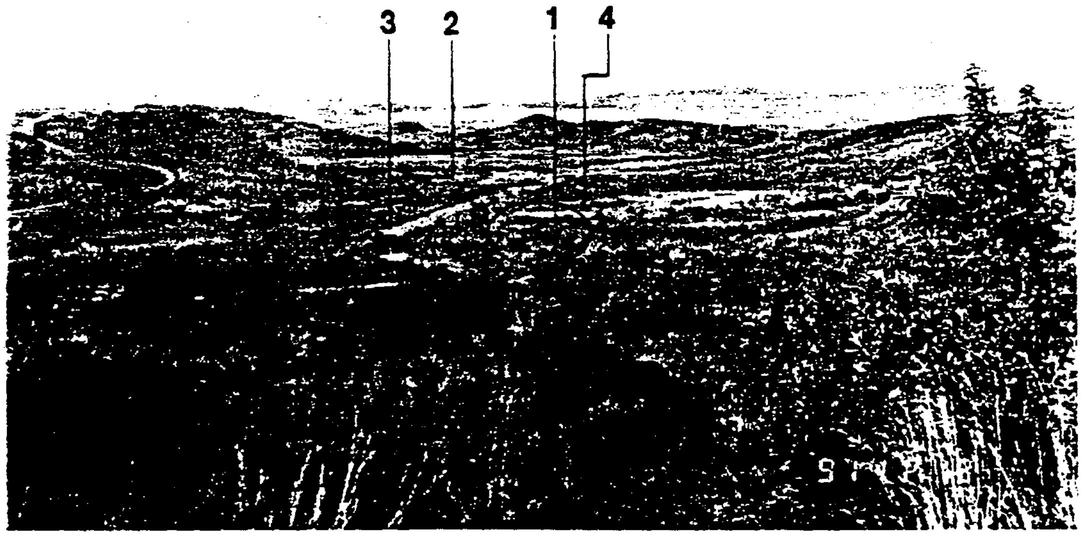


Plate 6 - General view of the proposed North East Power Station Site from the south-southeast (see text for details).

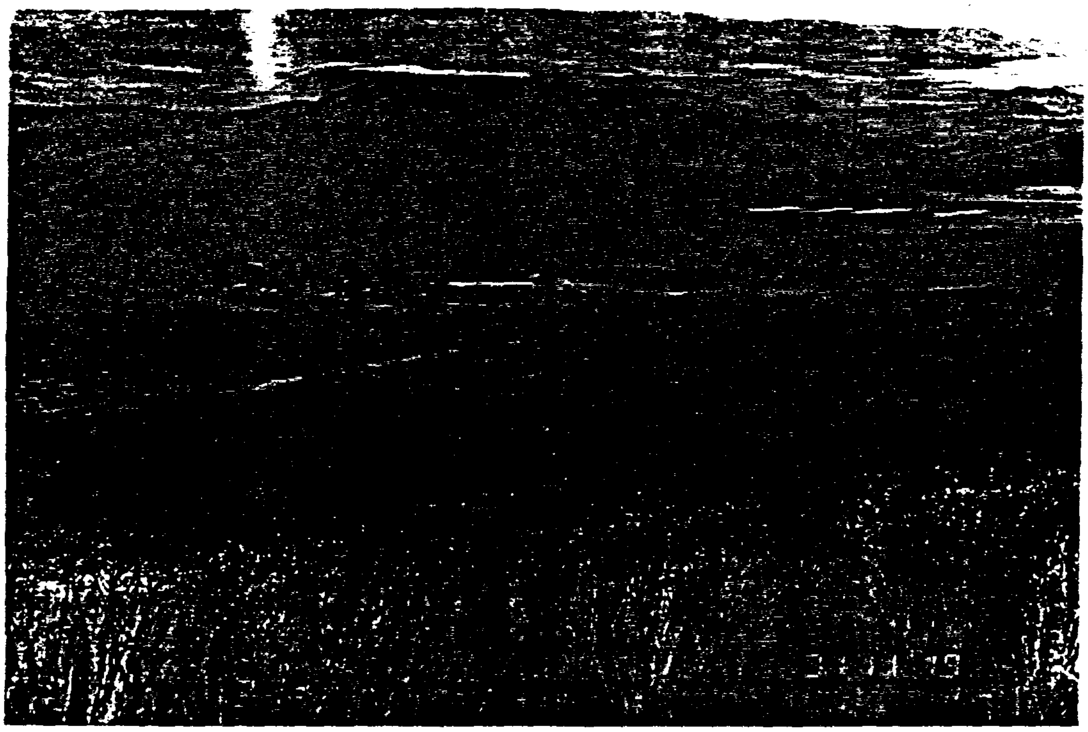


Plate 7 - More detailed view of proposed North East Power Station Site from the south-southeast (see text for details).

Plate 8 - View from the east across the proposed North East Power Station well-field, towards Olkaria Hill (see text for details).

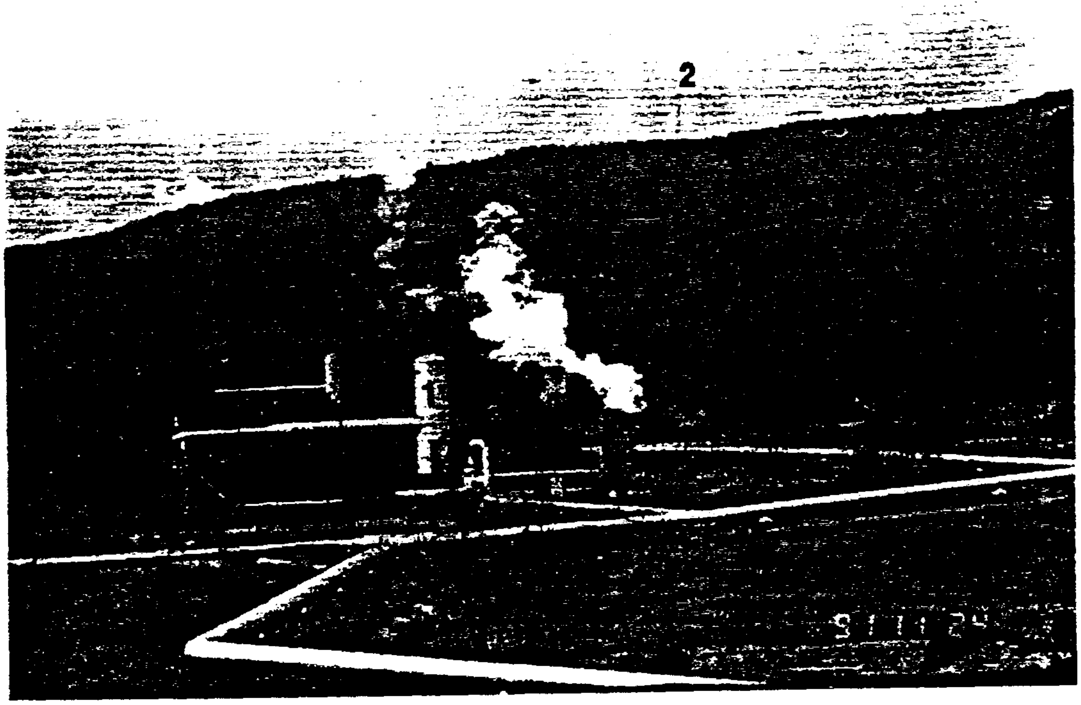


Plate 9 - Well-head facilities on existing East Olkaria Power Station well-field (see text for details).

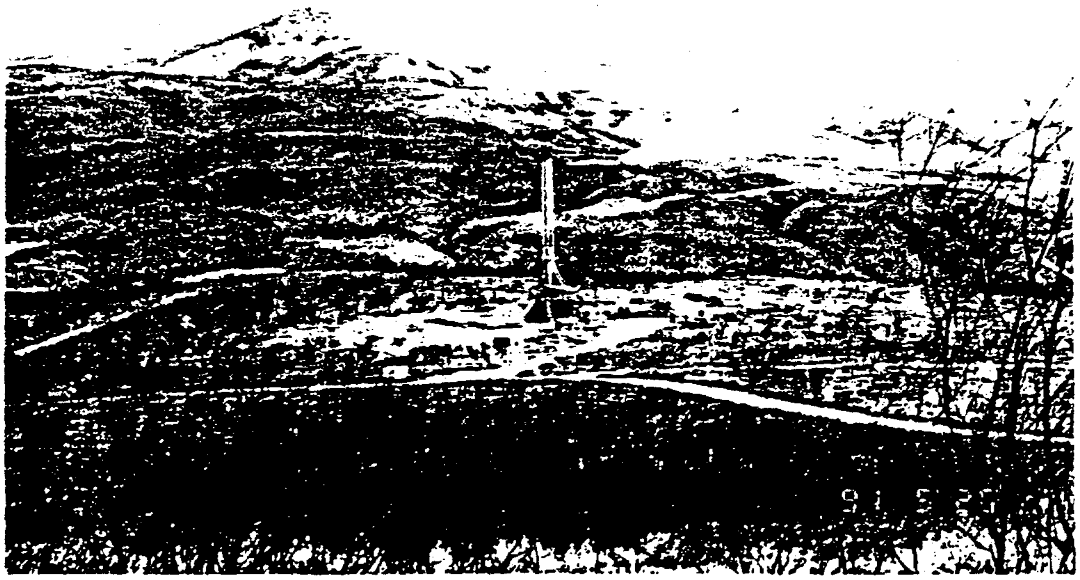


Plate 10 - Drilling on the North East well-field (see text for details).

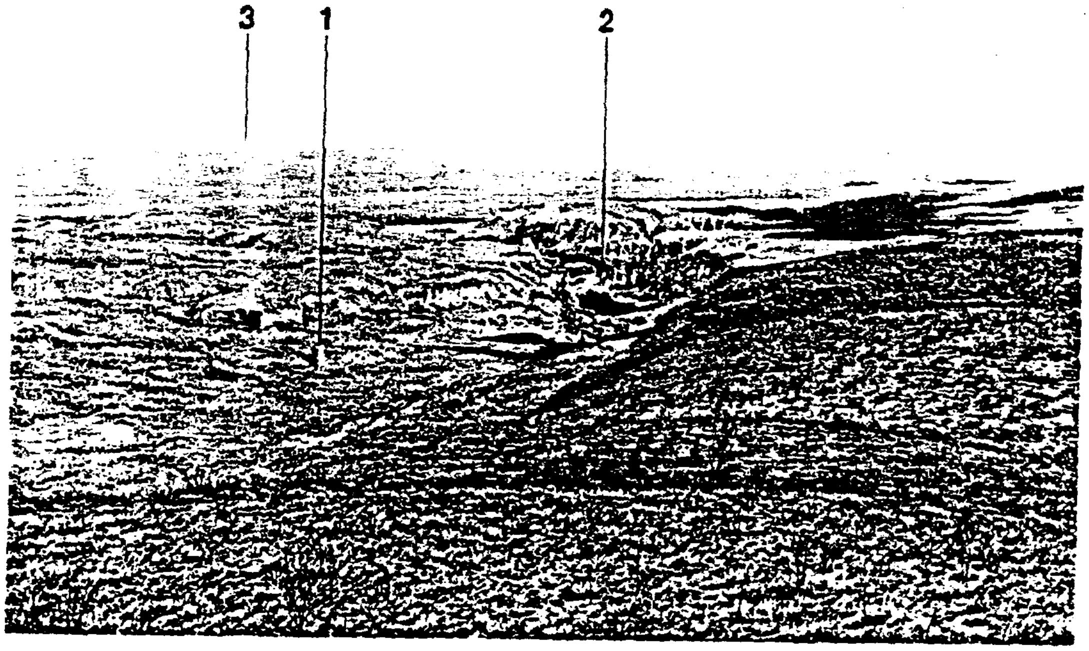


Plate 11 - Part of Ol Njorowa Gorge and Suswa Volcano (see text for details)

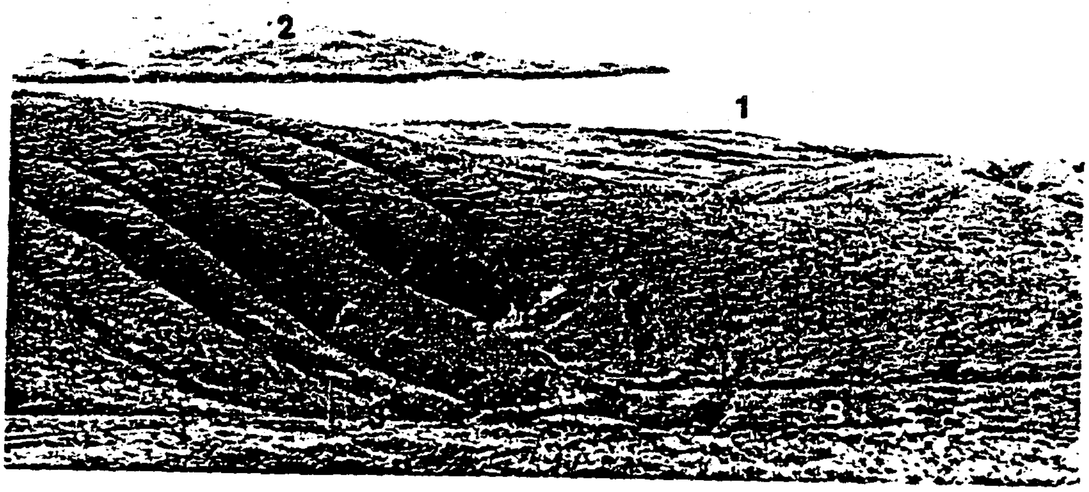


Plate 12 - Western part of Lake Naivasha looking over Hippo Point (see text for details).

proposed power station will not interfere with these spectacular views, which can be seen from the higher ground surrounding the existing and proposed power station sites.

Plate 12 is a view of the western third of Lake Naivasha from high ground, approximately 6 km north-northeast of the existing power station (see **Figure 2.2.3**). Points of interest are the KPC Lake View Housing complex (1), Hippo Point (2) and the power line pylon (3).

2.3 GEOLOGY OF THE AREA

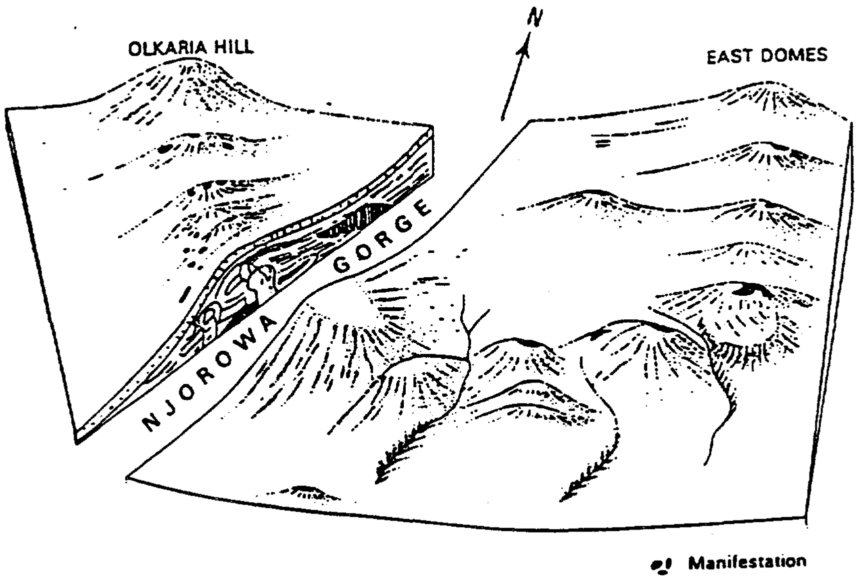
This description of the geology of the area has been prepared, for the most part, from a report prepared for the Ministry of Energy (Kenya) by **Clarke et al. (1990)**, from a paper by **Ogoso-Odongo (1986)** and from discussion with KPC geothermal scientists. The purpose of the description is to provide background information on the geological features of the area. It does not present original research or new interpretation of data.

Figure 2.3.1 (from **Clarke et al., 1990**) summarises the major surface features of the area and relates them to their geological origins. The rocks and structures throughout the area have been created within the past four million years. **Table 2.3.1** (derived from information presented in **Clarke et al. (1990)**) summarises the episodes that resulted in the creation of the major features.

The Olkaria Volcanic Complex (see **Figure 2.3.1**) is a multicentred volcanic field comprising at least 80 small centres covering an area of approximately 240 km^2. This may be contrasted with the Longonot Volcano, which has a single large distinct volcanic centre. The composition of the surface rocks in the Olkaria Complex is comendite, or peralkaline rhyolite. Most of the surface features comprise steep sided domes formed from lava and/or pyroclastic rock, or thick lava flows. **Figure 2.3.2** shows the locations of the major domes and lava flows. In some cases the domes have coalesced and present themselves on the surface as arc-like ridges, or large hills rather than discrete domes (see Ol Orugo Hills and hills in the Gorge Farm area in **Figure 2.3.2**). The domes enclose an approximately circular depression which is obscured in part by the presence of the Ololbutot ridge (formed approximately 130 to 230 years ago) and the Gorge Farm hills. The enclosed depression has been cut by the Ol Njorowa Gorge which was formed by outflowing water from Lake Naivasha (see **Figure 2.3.2**). The existing geothermal power station is located in the approximate centre of the depression. (see **Figure 2.3.2**)

Details of the subsurface geology are known from over 30 geothermal wells, ranging in depth from 1000 to 2500 m. These show that subsurface rocks comprise at least 2600 m of subaerially erupted rhyolitic, trachytic and basaltic lava, and associated pyroclastic rocks.

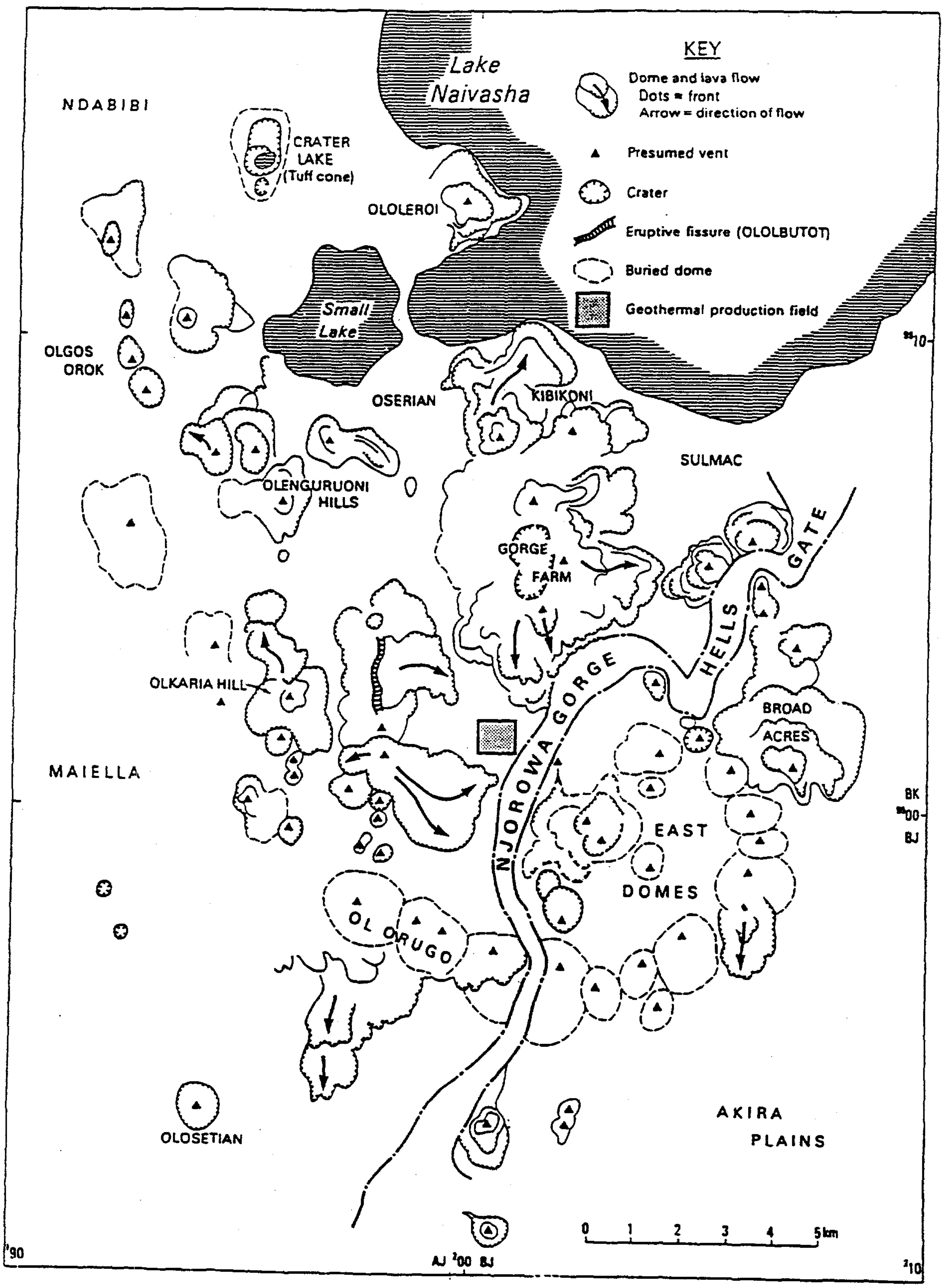
The period of formation of the complex is estimated from samples taken at a depth of 1000 m near Olkaria Hill to be 0.45 million years. The younger Olkaria events are estimated to be 9150 $\pm$110 years old, events that gave rise to the ring domes are estimated to be 3280 $\pm$120 years old and, as noted earlier, the Olubutot lava flow is estimated to be 180 $\pm$50 years old (**Clarke et al., 1990**).



(From Clarke 1990)

Figure 2.3.1

MAJOR SURFACE FEATURES



(From Clarke 1990)

Figure 2.3.2

LOCATION OF DOMES AND LAVA FLOWS

2.4 THE GEOTHERMAL RESOURCE

The Olkaria geothermal field has been under investigation for approximately thirty years. Two wells drilled in 1956 encountered hot conditions which established the presence of a potential resource.

The geothermal energy is extracted by drilling into the steam zone and transporting the steam, water and non condensable gases, by high pressure pipeline to the power station turbines. This section briefly reviews information that is known about the steamfield. This is described in **Section 5** of the feasibility study (**Ewbank Preece Limited, 1989**). It is also considered in some detail by **Clarke et al. (1990)**. Material presented below draws on these two reports.

The geothermal field is associated with the Olkaria Volcanic Centre. From the arrangement of fumaroles and other geological information it is inferred that the field occupies an approximately circular area of 50 to 80 km^2. The northeast sector which is the resource that would be exploited by the North East Olkaria Power Station, occupies an area of approximately 12 km^2, within which a production field occupying 5 km^2 would be developed. It is expected that a further 3 to 4 km^2 could be added to the production area following further study. The total area would then be 8 to 9 km^2. The distribution of wells is shown in **Figure 2.4.1**, which also shows the area of the field. Over the 30 year life of the power station there will be approximately 55 wells, 30 to the east of the road and 25 to the west. These are referred to as the east and west sectors respectively. The wells will be spaced at approximately 325 m giving an average density of approximately eleven wells per square kilometre, each producing on average 3.25 MWe initially. Thus for a 64 MWe power station approximately twenty wells will be required, ten in each sector. In practice each sector will require approximately 14 wells and during the 30 year life of the project approximately seven to ten replacement wells will be required (per sector).

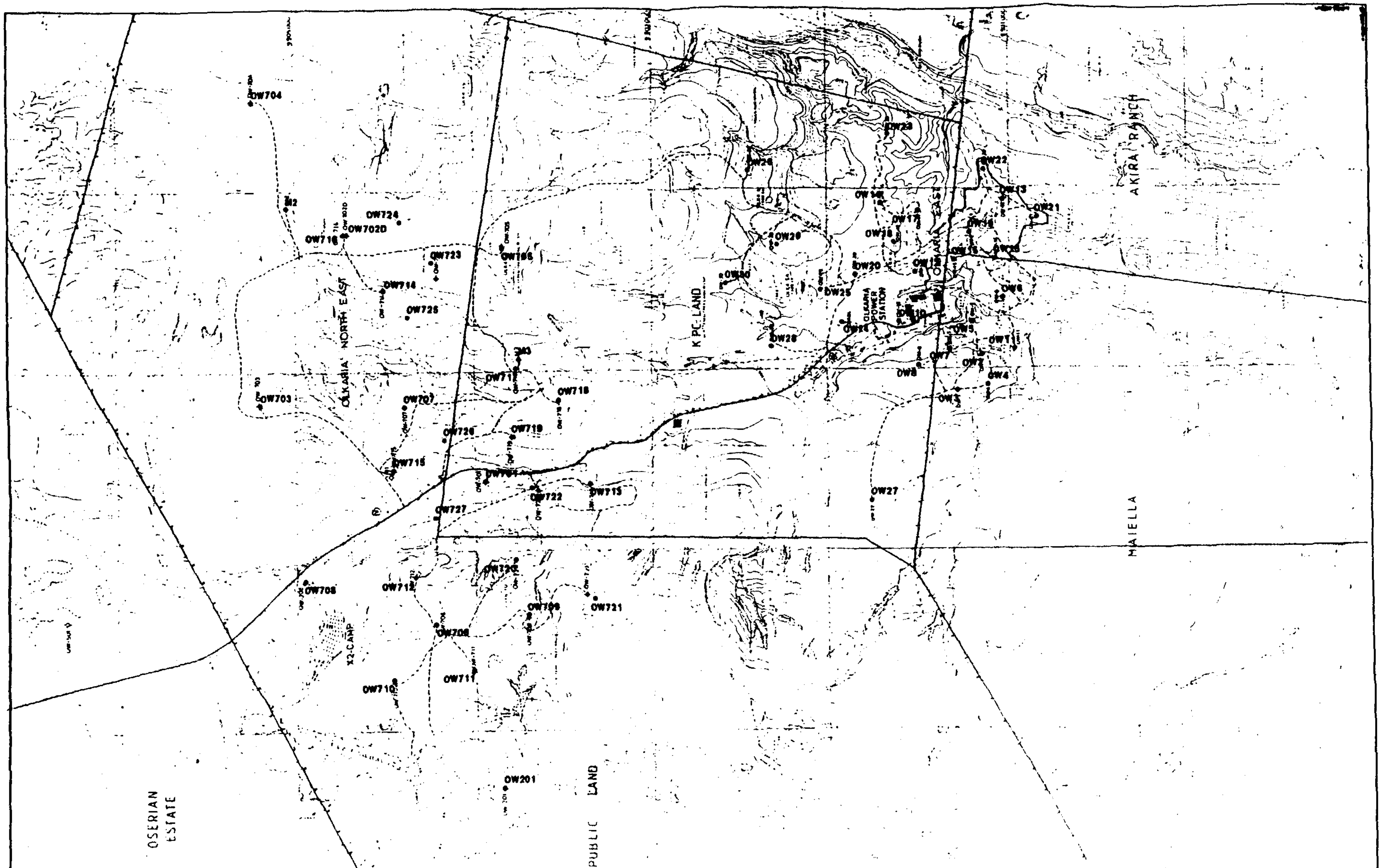


Figure 2.4.1
LOCATION OF WELLS AND STEAM GATHERING SYSTEM

TABLE 2.3.1 - SUMMARY OF MAJOR GEOLOGICAL ACTIVITY, ASSOCIATED FEATURES AND AGES OF FEATURES (Source: Clarke et al., 1990)

Episode	Activity	Associated features	Age range
V4	Late Quaternary to Recent Salic Volcanoes	MAJOR CENTRES OR COMPLEXES Longonot Volcanic Group Eburru Volcanic Group Olkaria Volcanic Group MINOR CENTRES Elementeita Volcanic Group Ndabibi Volcanic Group Akira Volcanic Group	0.4-0 Million years
D4	Extensive minor faulting of the Rift floor		0.8-0.4 Million years
V3	Quaternary flood lavas of the Rift floor	Mt Margaret formation (Mt) Gilgil Trachyte Formations (Trg) Kijabe Hill Formation (Kb)	1.65-0.9 Million years
D3	Renewed faulting of the Rift margins		1.7 Million years
V2	Early Quaternary flood trachytes	Limuru Trachyte Formation (Tr) Karati and Ol Mogogo Basalt Formation (Trb)	2.0-1.8 Million years
D2	Formation of steep faults (narrowing of Graben)		3-2 Million years
V1	Pliocene ash flows	Kinangop Tuff Formation (Tk) Mau Tuff Formation (Tkm)	3.7-3.4 Million years
D1	Major faulting of the Eastern Rift margin		4-3 Million years

3. Need for the Project

3.1 KENYA POWER REQUIREMENTS

The feasibility study forecasts the peak demand and annual power requirements to 2006, using the Acres International National Power Development Plan prepared in 1985. The Acres Plan forecasts have been updated by commencing the base year using actual figures for peak demand and electrical energy consumption for 1987. Assuming growth rates which correspond to the Acres higher growth rates forecasts to 1990, the median growth rate forecasts to 2006, have been used. Selection of the higher growth rate estimates to 1990 is justified by the fact that the first two years of the Acres' forecasts were 2.1% lower than the actual growth rate. However, it was considered that in the longer term the median growth forecasts were likely to be the more accurate. Table 3.1.1 summarises the forecast demand for electrical energy and the peak demand.

TABLE 3.1.1 - SUMMARY OF ALTERNATIVE LOAD FORECASTS

Year	Median forecast		Lower forecast		Higher forecast	
	Energy GWh	Peak demand MW	Energy GWh	Peak demand MW	Energy GWh	Peak demand MW
91/92	3483	589	3328	563	3542	599
92/93	3662	620	3477	589	3780	640
93/94	3852	653	3634	616	4033	684
94/95	4051	687	3797	644	4303	730
95/96	4261	724	3968	674	4591	780
96/97	4484	762	4147	705	4899	833
97/98	4718	803	4333	738	5227	890
98/99	4970	846	4528	771	5577	949
99/2000	5242	893	4732	806	5951	1014
2000/2001	5528	942	4945	843	6350	1082
2001/2002	5829	9949	5168	881	6775	1155
2002/2003	6142	1049	5400	922	7229	1235
2003/2004	6464	1105	5643	965	7714	1319
2004/2005	6801	1163	5897	1008	8230	1407
2005/2006	7157	1225	6163	1055	8782	1503

Source: **Ewbank Preece Limited, (1989)**

Table 3.1.2 summarises the peak power capacity of the power generation system for hydro, thermal, gas turbines and geothermal within the country for the period 1990/91 to 1994/95 and also lists the projected demand assuming median forecasts.

TABLE 3.1.2 - DEPENDABLE POWER GENERATION CAPACITY AND ENERGY BALANCE PROJECTIONS

Source	91/92		92/93		93/94		94/95	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Hydro	417.6	1984.0	460.4	2118.0	417.6	2118.0	460.4	2118.0
Thermal	96.5	623.4	96.5	623.4	96.5	623.4	96.5	623.4
Gas turbines	42.0	291.3	42.0	291.3	42.0	291.3	42.0	208.3
Geothermal	43.2	352.6	43.2	352.6	43.2	352.6	43.2	352.6
Total	**599.3**	**3251.3**	**642.1**	**3385.3**	**599.3**	**3385.3**	**630.1**	**3302.3**
Expected peak demand	589.0	3483.0	620.0	3663.0	653.0	3853.0	687.0	4052.0
Surplus/Deficit	**+10.3**	**-231.7**	**+22.1**	**-277.7**	**-53.7**	**-467.7**	**-56.9**	**-749.7**

Source: **Ewbank Preece Limited (1989)**

The apparent anomaly whereby the power generation system can meet the projected peak load in 1991/92 and 1992/93 but not the projected annual energy requirement arises because the peak load figures take no account of equipment availability, which is affected by breakdowns and scheduled maintenance.

If no new generating capacity is developed, the feasibility study analysis identifies a significant capacity shortfall in the early 1990s, of 33 GWh in 1992/93, assuming average rainfall in the hydro-electric power generating areas. The shortfall is estimated to increase to 216 GWh in 1994/95. This indicates an urgent requirement for additional generating capacity.

3.2 KENYAN GEOTHERMAL RESOURCES

Kenya has a number of geothermal areas, which have been identified as a result of joint Kenyan Government and United Nations Development Program (UNDP) scientific surveys. The major prospects are at Olkaria, Eburru and Bogoria. As a result of a 1972 review, the Olkaria prospect was given top priority and this has led to the development of the existing 45 MWe power station at Olkaria. Further drilling and well testing in the North East Olkaria field (north of the existing power station) have demonstrated the existence of a steamfield capable of supporting a 60 MWe power station for a period of at least 30 years. None of the other geothermal prospects have been drilled and tested to the same extent as the North East Olkaria prospect.

3.3 DISCUSSION OF ALTERNATIVES

Kenya's power needs and methods of meeting these needs are discussed at length in the **Acres (1987)** national power development plan and the feasibility study (**Ewbank Preece**

Limited 1989). Some apsects of these reviews have been discussed above.

There are of course alternative approaches to meeting the demand for power identified in Table 3.1.2 and these are discussed in the feasibility report (**Ewbank Preece Limited 1989**) and the national power development plan (Acres 1987).

Alternatives are to leave the demand for power unmet, to import the power (from Uganda), to meet the requirements by the development of hydro projects, or to develop coal-fired, oil-fired or gas turbine power plants. Apparent alternatives, such as wind and solar power, cannot presently be considered as practical alternatives in meeting energy requirements of this magnitude. A final approach is to meet the demand by energy conservation or demand management. Energy conservation could produce some savings, but these would not significantly affect the overall conclusions of the **Acres (1987)** or **Ewbank Preece Limited's (1989)** reports. Demand management is simply a method of not meeting demand (for example by shedding load from prioritised "non-essential" loads at times of high power demand). Since unmet demand in Kenya is valued at 79.4 USc/kWh (**Ewbank Preece Limited** 1989). This is substantially higher than the cost of providing the power. A no-development option would seriously affect the growth in GDP.

Thus the analysis to justify the development of the North East Olkaria resource needs to show that the North East Olkaria project is a logical step in meeting the growth in Kenya's power requirements at this period in the development of the generation network. To do this it is necessary to note that for efficient utilisation of a geothermal field it is necessary to operate the power plant at a continuous steady load (that is as a base load power plant), when this is able to be done then geothermal power is the lowest cost option by a substantial margin. The requirement for this base load generation capacity in the Kenyan requirements for power has been established. It is this component of the demand that the North East Olkaria project is seeking to meet.

Agreements are in place with Uganda to import 30 MW continuous power from the Owen Falls hydropower plant. However, for base case studies this import has not been considered as firm or dependable capacity.

Alternatives for base load generation capacity have been reviewed by **Ewbank Preece Limited (1989)**. They review the relative costs of various base-load plant options and conclude the following:

1. Gas-turbines are not economic for base load operation.

2. Coal-fired plants are more economical than oil-fired plants for base load generation.

3. The geothermal option is more economical than coal-fired generation at load factors above 60 to 65 per cent.

4. For higher load factors geothermal plant is by far the most economical option.

It will still be necessary to develop gas or oil-fired power plants to meet peaking loads particularly in dry years when power generation by hydro plants will be reduced.

Undeveloped hydroelectric resources in Kenya total over 1400 MW of capacity and 6000 GWh/y of average energy. The most promising hydroelectric project is the Miriu project on the Sondu River with a unit cost of average energy of $US 0.030/kWh. The remaining projects all have estimated unit cost in the range $US 0.050 and $US 0.058/kWh. The Miriu project is recommended for development in 1997/98. These can be compared with the cost of $US 0.039/kWh for a 2 x 32 MW power plant at North East Olkaria generating 472 GWh (that is 84 per cent plant load factor). This cost reduces with increasing plant load factor. From the above it is clear that geothermal power will be an important component in any plan to meet increasing power demand in Kenya, in particular the base-load component of this demand.

A least-cost generation expansion plan has been developed in the **Acres (1987)** report. The recommended generation plan is summarised in **Table 3.3-1**.

The table shows that 2 by 32 MW North East Olkaria units should be on line by mid-1994.

Given the present position on the urgent requirements for additional generation capacity and accepting that the requirement for power should be met, the only practical alternative is a thermal station. Geothermal power is significantly cheaper than either coal-fired or fuel-oil-fired stations and does not involve importation of the source of energy. Thus geothermal power is the preferred option and of these the North East Olkaria field is the only field proven at this stage to be capable of supplying sufficient capacity and energy to satisfy the projected demand.

TABLE 3.3-1 - RECOMMENDED GENERATION EXPANSION PLAN

Fiscal Year	Generation additions			
	Hydro	Geothermal	LS Diesel	MS Diesel
1990-1991	Turkwel			
1991-1992				
1992-1993				
1993-1994				90
1994-1995		2 x 30.7		
1995-1996				60
1996-1997		1 x 52.8		
1997-1998	Mi[illegible]u			
1998-1999		1 x 52.8		
1999-2000			1 x 50	
2000-2001			1 x 50	
2001-2002		1 x 52.8		
2002-2003	Oldorko		1 x 50	
2003-2004	Gitaru 3	1 x 52.8		
2004-2005			2 x 50	
2005-2006				
2006-2007			2 x 50	
2007-2008		1 x 52.8		
2008-2009			2 x 50	
2009-2010		1 x 52.8		
Total	204 MW	431 MW	450 MW	150 MW

Source: Acres (1987)

4. Conduct of the Environmental Assessment and Regulatory and Legal Requirements Affecting Geothermal Development

4.1 HISTORY OF LAND TENURE

The project is located on Public Land in the Naivasha Division of the Nakuru District of the Rift Valley Province. The land on which the proposed power station is to be built is public land which was gazetted as a National Park on 2 February 1984. KPC have operated the existing Olkaria Power station and exploration and development work for future power station developments since 1981.

4.2 WORLD BANK REQUIREMENTS AND IMPLEMENTATION OF REQUIREMENTS

4.2.1 Requirements

The requirements of the World Bank for EAs are outlined in Operational Directive 4.00, Annex A: Environmental Assessment, September, 1989. Annex A outlines Bank policy and nprocedures regarding EAs, and related types of environmental analysis, of Bank investment lending operations. OD 4.00 was replaced in October 1991 by OD 4.01, however this was after the commencement of the EA study.

The purpose of an EA is to ensure that the development options under consideration are environmentally sound and sustainable; and that any environmental consequences are recognised early in the project and taken into account in project design.

Several kinds of environment analyses and reports are required by the Bank, depending upon the nature of the project. Project specific EAs are used to analyse investment projects, the detail and sophistication of the analysis being commensurate with the expected impacts. The proposed geothermal development has apparently been classified by Bank environmental screening as "Category A", because the project may have 'diverse and significant environmental impacts'. A Category A classification requires a complete EA, which would normally cover:

- o Existing environmental baseline conditions;
- o Potential environmental impacts, both direct and indirect;
- o Systematic environmental comparison of alternatives;
- o Preventive, mitigating and compensating measures, generally in the form of an action plan;
- o Environmental management and training; and

- Monitoring.

As environmental issues generally involve national, regional and local government agencies, and cover a broad range of responsibilities, coordination of EA activities with all interested groups is regarded by the World Bank as crucial. The Bank suggests that this is best achieved through inter-agency meetings at key points in the EA process.

The Bank also expects the borrower to take the views of affected government groups and local non-governmental organisations into account in project design and implementation, and in particular in the preparation of EAs. This is important in order to understand both the nature and extent of any social or environmental impact, and the acceptability of proposed mitigation measures.

The Bank believes that a successful EA will also foster a strengthening of the environmental capability and understanding in the agencies concerned. Projects with major potential impacts normally require the establishment or strengthening of in-house environmental groups, both on-site and in the implementing agency or Ministry. Involvement of these units throughout the EA process:

- Ensures that the agency's/Ministry's knowledge and perspective are taken into account in the EA;
- Provides on-job training for the staff, and;
- Provides continuity for the implementation of the EA's recommendations.

The Bank's requirements as outlined above are being implemented within this EA through the scope of work, the establishment of a Study Review Committee, and liaison with government and non-government organisations. These are outlined in the following sections. The establishment of a staff training program is also discussed.

4.2.2 Implementation of Requirements

Meetings

During the inception phase of this project, contact was established with relevant government and non-government organisations. Letters of introduction were provided by KPC, and most authorities were visited by the Project Manager. In all cases the scope and duration of the project were outlined, and where relevant, available information was sought. The relevant authorities contacted were:

- National Environment Secretariat, Ministry of Environment and Natural Resources;
- Forestry Department, Ministry of Environment and Natural Resources;
- Kenya Wildlife Service;
- Ministry of Tourism and Wildlife;
- National Water Conservation and Pipeline Corporation;

- Ministry of Water Development in Nairobi, Naivasha and Nakuru;
- Nakuru District Administration;
- Ministry of Lands, Housing and Urban Planning;
- Fisheries Department, Ministry of Regional Development;
- Permanent Presidential Commission on Soil Conservation and Afforestation;
- Ministry of Energy;
- Ministry of Agriculture;
- Ministry of Health;
- Ministry of Labour, and;
- Kenya Energy Non-Government Organisations (KENGO).

Review Committee
A Review Committee was established, to oversee the study and to provide input into the study process and conclusions. The committee comprised permanent and part-time members. The permanent members were:

- Kenya Power Company (Chair);
- National Environment Secretariat;
- Nakuru District Administration (District Officer, Environment);
- Kenya Wildlife Service;
- Ministry of Water Development, and;
- KENGO.

The permanent members of the committee had their initial meeting on November 13, at Electricity House, Nairobi. The development project and the scope of the environmental impact assessment were explained by the Consultant and discussed.

Liaison with all groups listed above was maintained during the course of the study.

4.3 REVIEW OF RELEVANT ACTS AND ENVIRONMENTAL REGULATIONS

4.3.1 Kenya Statutory Requirements

Environmental impact assessment as a regulated process is in its early days in Kenya, despite the adoption of the Environmental Management Policy in 1979, and the introduction of a system of Environmental Impact Reports to cover all major governmental and private projects. In 1972 the National Environment Secretariat (within the Ministry of Environment and Natural Resources) was established to coordinate environmental activities within the country. It is responsible for the coordination and application of environmental management policy. However, the absence of legal instruments to facilitate the implementation of the policy means that the Environmental Impact Reporting process is not carried out effectively. Despite attempts since 1979 to review existing legislation as it relates to the environment, and proposed changes to provide a legal framework for the reporting process, the appropriate statutory provisions have yet to be developed. Environmental control of geothermal development within Kenya is therefore subject to the requirements of both specific legislative instruments that relate to different aspects of the environment, and to the Common Law.

In Kenya, maintenance and enhancement of the environment can and has been achieved through both political and legislative means. In the political approach, it is the combined effort of both Government and non-government organisations that creates a political awareness of issues, both through the media and through dialogue between the groups. The legal approach places an obligation, according to the existing laws of the country, on developers to take specified actions to prevent undue effects on the environment of an area. The political and legal control over environmental impact works interactively in Kenya, providing some degree of compensation over weaknesses which may exist in the environmental laws. Ministers responsible for the implementation of legislation are often given the power to make regulations controlling certain specified actions. Development aspects not mentioned specifically within the legislation, may be covered in regulations under powers granted within the act.

The legislative environmental controls relevant to the proposed geothermal developments are outlined below.

The Geothermal Resources Act

All unextracted geothermal resources are generally vested in the Government, subject to any rights vested in other persons. The power to licence a geothermal development is vested in the Minister administering the Act, and anyone so authorised is entitled to undertake actions in connection with the survey and investigation of such areas. The rights of the licensee also include the right to reclaim and utilise any water. However, land owner rights in regard to entry, drilling and well testing exist, and the licensee is liable for damages and injury which may result from these activities. Compensation to the land owner or occupier is required. The licensee is also subject to conditions relating to safety or any other conditions which are imposed by the Minister.

Any authority for exploration granted by the Minister can be revoked under certain conditions, namely if other bores, or geothermal resources are being affected detrimentally, or in the public interest. The Minister may make regulations under the Act, to further safeguard environmental implications of the development activity.

The Water Act

Water is an important component in any geothermal development, and the provisions of the Water Act apply in many ways to the development and operation of the geothermal resource.

Water in Kenya is owned by the Government, subject to any right of the user, legally acquired. The control and right to use water is exercised by the Minister administering the

Act, and such use can only be acquired under the provisions of the Act. The Minister is also vested with the duty to promote investigations, conserve and properly use water throughout Kenya.

Water permits may be acquired for a range of purposes, including the provision and employment of water for the development of power. The permit for proposed abstraction and storage, or other purposes, is subject to the approval of the Water Apportionment Board. The Board may set the conditions of the permit, namely the quantity of water granted and the time for abstraction, and may vary the conditions of the permit. The conditions of the permit must be adhered to, and at the termination of the permit, the Board may require the permit holder to remove all works erected in connection with the licence.

Easements can be granted over land for the purposes of water development and reticulation. Compensation for the use of the land, or for damages incurred due to the operation of the works within the easement, are determined by the Water Apportionment Board.

The construction of certain wells requires a permit and notice of intention of any well is required, as well as data on the quantity and level of water struck.

Pollution of groundwater is required to be controlled by sealing off any contaminated water and other methods as prescribed. Miscellaneous sections of the Act pertinent to environmental matters deal with the striking of an aquifer in the course of mining operations, prohibit the release of water without a permit, and specify penalties for polluting water used for human consumption.

The Wildlife (Management and Conservation) Act

The Act deals with areas declared as National Parks, under the Act. The proposed development area at NE Olkaria lies within Hell's Gate National Park and certain actions and obligations exist for land users (such as KPC) within that area.

If geothermal development was defined as mining (no definition exists under this Act), the consent of the Minister administering the Act would be required for any activities in connection with that development.

The Act controls activities within the park, which may lead to the disturbance of animals. Unauthorised entry, residence, burning, damage to objects of scientific interest, introduction of plants and animals and damage to structures is prohibited.

The Minister is able to make regulations as necessary for the well being of the park and its wildlife.

The Forest Act

The Act refers to areas defined as 'Forest Areas' or 'Central Forests'. Neither the proposed NE Olkaria development, nor the Eburru prospect are within a gazetted Forest Area. However, the Eburru Forest (which is a gazetted Forest Area) lies adjacent to the Eburru prospect.

The Forest Act specifically forbids certain activities within conservation areas. These include cutting and burning, access at certain times, building of certain types of structures and roads, cultivation, grazing, taking of animals and the collection of honey, without appropriate authority. Geothermal exploration and development in a gazetted forest area would therefore require authorisation from the Minister administering the Act.

The Act also prohibits activities such as cutting and burning on unalienated public lands not specified as Forest Areas or Central Forests. The Minister can make regulations to control development activities within all such areas.

The Agriculture Act
Legislative control over soil conservation and land development are mainly controlled within this Act, and many of the provisions can be generally applied beyond those lands suitable for agriculture.

The Minister administering the Act, after concurrence with the Central Agricultural Board and consultation with the District Agricultural Committee, can impose land conservation orders on lands to control cultivation, grazing and clearing. These controls may be necessary to protect the land against soil erosion, to protect fertility, and to maintain catchments. Local authorities are generally empowered to administer these sections of the Act, and the District Agricultural Committee is entitled to make regulations relating to these controls.

Agricultural (Basic Land Usage) Rules are prescribed under the Act, whereby vegetation clearing in steep slope areas or adjacent to watercourses, without authorisation, is controlled.

Land Acquisition Act
It is possible, under the provisions of this Act, for land to be acquired or granted access to for the purposes of geothermal exploration and/or development. Acquisition or access must be shown to be in the public benefit, and compensation must be provided to the land owners whose land is acquired or damaged.

The Factories Act
Environmental health and safety requirements within a functioning geothermal power facility are regulated by this Act. A power station is considered to be a factory within the meaning of the Act, and must be registered with the Chief Inspector of Factories. The Act requires that work areas be of an appropriate standard, well ventilated, with suitable lighting. Sanitary areas and drinking and washing areas should be provided, and safety provisions are described in the Act.

Of specific relevance to geothermal power plants are the requirements in this Act for the maintenance of air quality to protect the health of employees.

The Public Roads and Roads of Access Act
The use of public roads and the rights and obligations associated with construction and use of roads of access by geothermal exploration, construction and maintenance vehicles, are outlined in this Act. Public roads shall be absolutely dedicated to the public. Roads of access, however, can be provided across private land, but there exists the opportunity for objection to the proposed road by the landowner. Once established, the road of access must be maintained by the applicant.

The Public Health Act

This Act contains directives regarding regulation of activities that affect human health. There exist provisions within the Act to deal, in a general way, with water, air and noise quality as they pertain to human health. An environmental nuisance is defined, and includes the emission from premises of waste waters, gases, smoke which could be regarded as injurious to health. The owner and/or occupier of premises responsible for such nuisances are liable to prosecution under the Act.

Chiefs' Authority Act

This Act contains little of direct relevance to geothermal development. However, it empowers Chiefs to issue orders in relation to the following matters, which may have some relevance to geothermal development:

- to prevent the pollution of water in any stream, watercourse or water-hole, and prevent the obstruction of any stream or watercourse;
- to regulate the cutting of timber and the wasteful destruction of trees;
- to prohibit any act that might cause damage to any public road or to any work constructed or maintained for the benefit of the community;
- controlling grass fires, and;
- regulating the use of artificial water supplies constructed from public funds.

The Chiefs' Authority Act also provides for the Minister to authorise any Chief to issue orders for work or services for the conservation of natural resources.

Local Government Act

The Local Government Act is concerned with a wide range of matters that affect the day to day activities of individuals and organisations. To this extent the Act has provisions that will affect geothermal development. However the sections which have the most direct relevance are Sections 145, 146, 147 and 163.

- Section 145 is concerned with the miscellaneous powers of local authorities. Subsection (w) empowers a local authority to take measures that may be necessary or desirable for the preservation or protection of wildlife, and provide amenities for the observation of wildlife.
- Section 146, Subsection (d) empowers a local authority, with the consent of the Minister, to make grants for the establishment and maintenance of game parks and other related facilities.
- Section 147, Subsection (d) controls the cutting of timber and the destruction of trees and shrubs.

- Section 163, Subsection (e) empowers municipal councils, town councils and urban councils to control or prohibit all businesses, factories and workshops which by reason of smoke, fumes, chemicals, gases, dust, smell, noise or vibration or other cause may be a source of danger, discomfort or annoyance to the neighbourhood and to prescribe the conditions subject to which business, factories and workshops shall be carried on.

Other relevant legislation to geothermal development includes:

- The Antiquities and Monuments Act, whereby such structures as are known, or are unearthed by exploration, are protected, and;

- The Lakes and Rivers Act, whereby dredging in a lake or river must be licensed, and the licensing procedure governed by regulations.

5. Description of the Development Project

5.1 PREAMBLE

This section presents background information on the North East Olkaria Project. The geology of the area and the geothermal resource have been described in **Section 2**.

The project is described in the feasibility study prepared by **Ewbank Preece Limited (1989)**. The study is comprehensive, but because well-drilling and testing were not complete at the time of its preparation, it does not include details on pipeline routes, nor does it include firm details on the proposed methods for disposal of geothermal brine and other waste fluids, except to note that these will be re-injected.

This section summarises information from the feasibility study to provide a description of the project for the purposes of determining its interactions with the environment. It provides a brief overview of the way in which a geothermal power station is developed, including a description of each phase of the project. It then provides specific information for the North East Olkaria Project, describing the steam gathering system, the power generation system and other facilities including offices, fencing, workshops, roads, sewerage and provisions for fire fighting.

5.2 THE WELLS AND STEAM GATHERING SYSTEM

5.2.1 Wells

The well-field has been drilled and to date 27 production wells have been tested. The location of wells, including those in the East Olkaria field is shown on **Figure 2.4.1**. Well depths range from 1744 m to 2497 m below the surface; that is down to 425 m above sea-level to 341 m below sea-level. Fluid in-flow to the wells generally occurs in three zones, 1200 to 1500 m above sea-level, 500 to 800 m above sea-level and 45 m below sea-level to 300 m above sea-level. The heights below the local surface will of course depend on the elevation of the well site. **Table 5.2.1** lists all wells and provides data on the well elevation, drilled depth, inflow zones (feeder zones) and steam flow rate expressed in kg/s and potential electrical power in MWe.

Wells in the field have been drilled vertically. Typically the drilling process involves the preparation of a rectangular flat area of ground up to approximately 140 m by 60 m. This area is required to accommodate the drill and associated equipment, including drill pipes. At Olkaria all drilling has been vertical. As drilling takes place, fines from the drill-head are flushed out with lake water, frequently mixed with detergent to assist in collection of the fines. The detergent used must be capable of withstanding high temperature and is usually alkyl benzene sulphonate. Bentonite drilling mud is often used. This is essentially an inert material, but can smother plants and does not support plant growth and in this respect is similar to a hard compacted surface. Waste water from drilling in the North East field has in the later period of drilling been channelled by

TABLE 5.2.1 - SUMMARY OF NORTH EAST OLKARIA WELL DATA

Well Number	Elevation (m-asl)	Depth of well (m)	Total water (t/h)	Total steam (t/h)	Total mass (t/h)	Electrical power potential (MWe)
OW-701	2012.9	1803.5	84.9	-	153.0	4.0
OW-702	2169.6	1744.0	-	-	-	-
OW-703	2169.6	1885.9	23.9	14.1	41.2	-
OW-704	2175.6	2005.7	-	-	-	-
OW-705	2154.9	2003.0	39.7	18.6	63.4	2.5
OW-706	2098.1	2100.0	28.1	36.8	82.4	4.0
OW-707	2053.1	1797.0	75.5	28.3	113.1	3.1
OW-708	1980.7	1802.0	43.7	21.8	71.1	2.4
OW-709	2123.2	1896.0	30.5	76.9	113.6	8.5
OW-710	2069.5	1799.6	32.8	22.6	62.3	2.5
OW-711	2105.2	1804.0	13.9	14.3	29.6	1.6
OW-712	2081.5	2015.0	11.7	-	37.0	2.6
OW-713	2036.6	1798.0	13.3	-	31.9	1.9
OW-714	2155.9	2497.0	85.8	-	172.0	7.1
OW-715	2010.8	2003.0	36.2	-	77.2	3.9
OW-716	2169.4	2291.0	7.4	49.6	-	4.5
OW-717	2097.6	2103.0	-	-	-	-
OW-718	2072.5	1899.0	-	-	-	-
OW-719	2044.2	2211.0	105.0	38.2	155.6	4.2
OW-720	2087.8	2175.0	3.6	-	20.7	1.8
OW-721	2162.8	2204.9	40.1	-	82.3	4.0
OW-722	2021	-	-	-	-	-
OW-723	2164.9	2205.3	-	-	-	-
OW-724	2176.7	2205.5	-	-	-	-
OW-725	2137.4	2197.5	-	-	-	-
OW-726	2026.8	2206.6	-	-	-	-
OW-727	018.8	2203.0	-	-	-	-

pipe and open channel to a conditioning pond[1] located close to the site of the proposed power station. After conditioning, it is gravity fed to a re-injection well near X2-Camp. It is understood that open channels are no longer used.

Open channels are not an acceptable method of disposing of drilling effluent or separator water in the Olkaria environment as the flowing water often causes deep erosion channels and under cool conditions when the relative humidity is high presents an unsightly flow of steaming water. In addition, detergent foam is formed which also detracts from the aesthetic values that KWS promotes as the attraction of the National Park.

As the well is drilled it is cased with a steel liner. Typically, the first 40 m has a diameter of 0.6 m, from 40 to 300 m the diameter is 0.44 m, from 300 m to 700 m the diameter is 0.31 m and from 700 to 1800 m the diameter is 0.22 m. The liner is cemented to the surrounding soil and rock using Class-A cement. The liner in the section of the hole in which steam is encountered is slotted to allow ingress of steam into the well. Once the well is completed, it is fitted with a valve and tested. The surrounding cleared land around the well can then undergo final rehabilitation with the naturally occurring grasses trees and shrubs. The area of land required around the completed well is a square area approximately 20 m by 20 m.

5.2.2 Separator Stations

At the existing East Olkaria Power Station, steam and water are separated at the well head. This results in a visible cloud-like white plume of condensing steam at each well. The size of the plumes depend on the prevailing relative humidity and dispersion conditions. Water is then either piped, or flows in concrete-lined open drains to an infiltration point a few hundred metres to the south of the existing power station where it is disposed of by seepage into the ground. Late changes to the design of the steam collection system have resulted in the necessity to operate 15 separator stations rather than the two originally envisaged and shown in **Figure 5.2.1**. This will change the appearance of the steam field so that during cool moist weather, small white plumes of condensing water vapour will be visible around each separator station. Under hot dry conditions these plumes will be very short and probably not visible. The visibility of the plumes on cool moist days will emphasise the existence of the separator stations, however the power station is not located in an area where the plumes would have a significant impact on the landscape. Further, the natural fumaroles have a rather similar effect on the landscape. The overall effect is expected to be similar to that from the existing power station. It is probable that most visitors to the park will consider the appearance of the plumes on the landscape as a point of interest rather than a negative impact. Some will inevitably consider the plumes as a detraction from the scenic value of the area, but this number is expected to be small because the landscape has already been extensively modified, and visitors will not be expecting to see a pristine wilderness area. The gorge area, which is the most scenically attractive area of the park will not be affected.

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[1] The conditioning pond allows suspended solids to settle and the water to cool. During cooling dissolved silica will precipitate from the water. The removal of the silica is an important part of the conditioning process as precipitation in pipes will cause blockages.

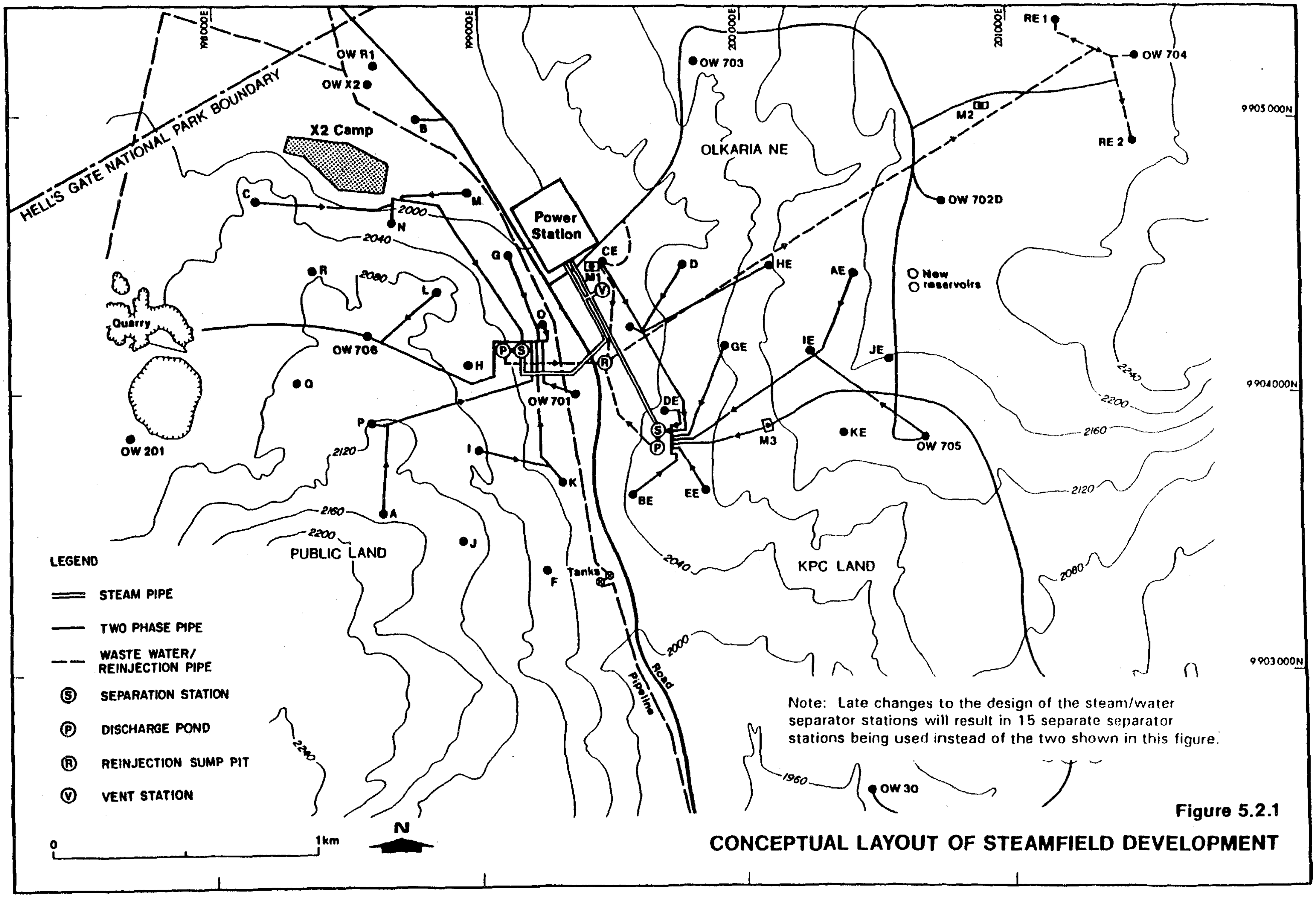


Figure 5.2.1

CONCEPTUAL LAYOUT OF STEAMFIELD DEVELOPMENT

5.2.3 Pipeline Routes and Service Roads

Pipeline routes are shown in Figure 5.2.1. Pipes will comprise a core of high pressure steel with thermal insulation. The outside temperature of these pipes is well below the level at which burning may occur if they are touched. The colour of the external cladding will be brown/green to reduce visual impacts. Pipelines which cross roads, will be encased in concrete culverts approximately 1.5 m diameter. Although the well-field is not in an area of the park that is densely populated by animals, following advice from the fauna consultant, several additional crossing points will be provided to allow grazing animals greater freedom of movement within the well field to minimise the interruption of daily migration routes.

The layout of service roads is also shown on Figure 5.2.1. All roads will be bitumen sealed to minimise dust generation, erosion and to provide all weather access to well-heads. In locations where slopes and soil types require, run-off will be collected in concrete lined drains and channelled to low slope areas where water energy will be dissipated before disposal to infiltration areas.

5.3 POWER GENERATION

5.3.1 Power Station Siting

Engineering considerations which influence the location of the power station are as follows:

- the requirement that it be located in proximity to the wells and at an elevation which causes minimal loss of energy in transporting steam and water from the wells to different altitudes;
- the availability of a large (6-10 ha) reasonably flat area for the power station, cooling towers, separator stations and retention ponds; and
- reasonable accessibility.

Environmental factors that influence site selection are:

- the site should maintain an adequate buffer zone between residential areas (and other sensitive areas) and the power station so that noise and air pollution are maintained at acceptable levels in sensitive areas;
- the site should not affect important archaeological sites;
- the site should not affect the habitats of rare or endangered animal or plant species; and
- the site should minimise the disturbance to existing land-uses, for example the grazing of wild animals.

Two sites were considered in the feasibility study. These were selected on the basis of engineering considerations and on the basis of a preliminary review of environmental factors. The sites were selected prior to the commencement of the detailed environmental studies which are presented in this EA. The two sites are shown in **Figure 5.3.1**. Site A is located on the northeast side of the bitumen road leading from the existing power station to Naivasha. It is at an elevation of approximately 2000 m. Site B is located 1.8 km further to the east at an elevation of approximately 2175 m. Site B is more remote from disturbed areas and would be better suited to minimise visual impacts and would, because of its elevation, be better suited to the dispersion of hydrogen sulphide emissions. However, it would introduce a further disturbance into an area of the park that is presently relatively undisturbed compared with Site A, which is near X2-Camp (where some KPC power station workers are currently housed) and close to the existing power station access road.

In summary, the feasibility study concluded that Sites A and B were equally suitable and that no technical or environmental factors favoured one site over the other. However, this present study favours Site A, because, although it will have a significant visual impact, which will be partly ameliorated by bunding and tree planting, it will minimise the disturbance to presently undisturbed areas of Hell's Gate National Park. In addition, the advantage that Site B would have for the dispersion of hydrogen sulphide would not outweigh the advantages to the Hell's Gate National Park of keeping development to already disturbed areas.

5.3.2 Power Station

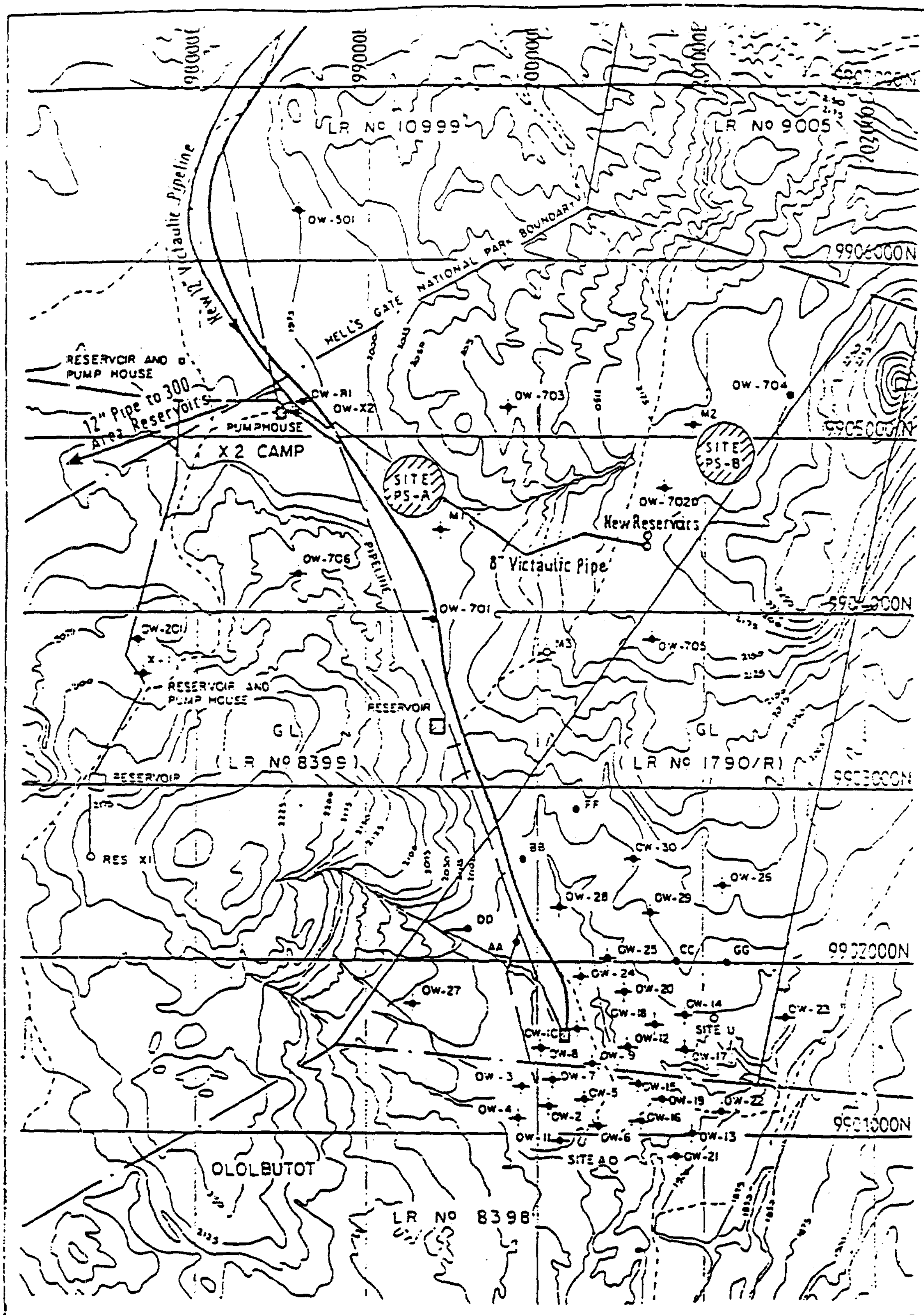
This section has been prepared from information provided in the feasibility study (**Ewbank Preece Limited, 1989**).

The proposed layout of the power station is shown in **Figure 5.3.2**. The main structures include the building housing the two turbines and two 32 kWe generators, pumps and condensers; and the two banks of three cooling towers, located on the eastern side of the power station building. The 132 kV substation will be located on the western side of the building. **Figure 5.3.3** shows an east-west cross-sectional view of the power station. **Figure 5.3.4** is a schematic diagram showing the basic operation of the power station. The basic process by which the power station operates is to use high pressure steam from the well-field to drive two turbines which in turn drive two 32 MWe generators. The following sections describe various aspects of the operations focussing on the provision of information relevant to environmental issues.

5.3.3 Handling of Waste Water by Reinjection

Steam, liquid water and geo gas are collected from the wells and piped under pressure through pipes on the surface to two central separator stations, where the liquid water will be separated from the steam and geo gas. Approximately 99.9 per cent removal of the liquid water will be achieved in the separator.

From the two central separators, the waste water will flow to conditioning ponds with a storage capacity of 3000 m^3 where the water will cool to approximately 40 C. (The conditioning process involves cooling and precipitation of some of the dissolved silica,



ALTERNATIVE SITES FOR NORTH EAST OLKARIA DEVELOPMENT

OLKARIA N.E. FEASIBILITY STUDY

Figure 5.3.1

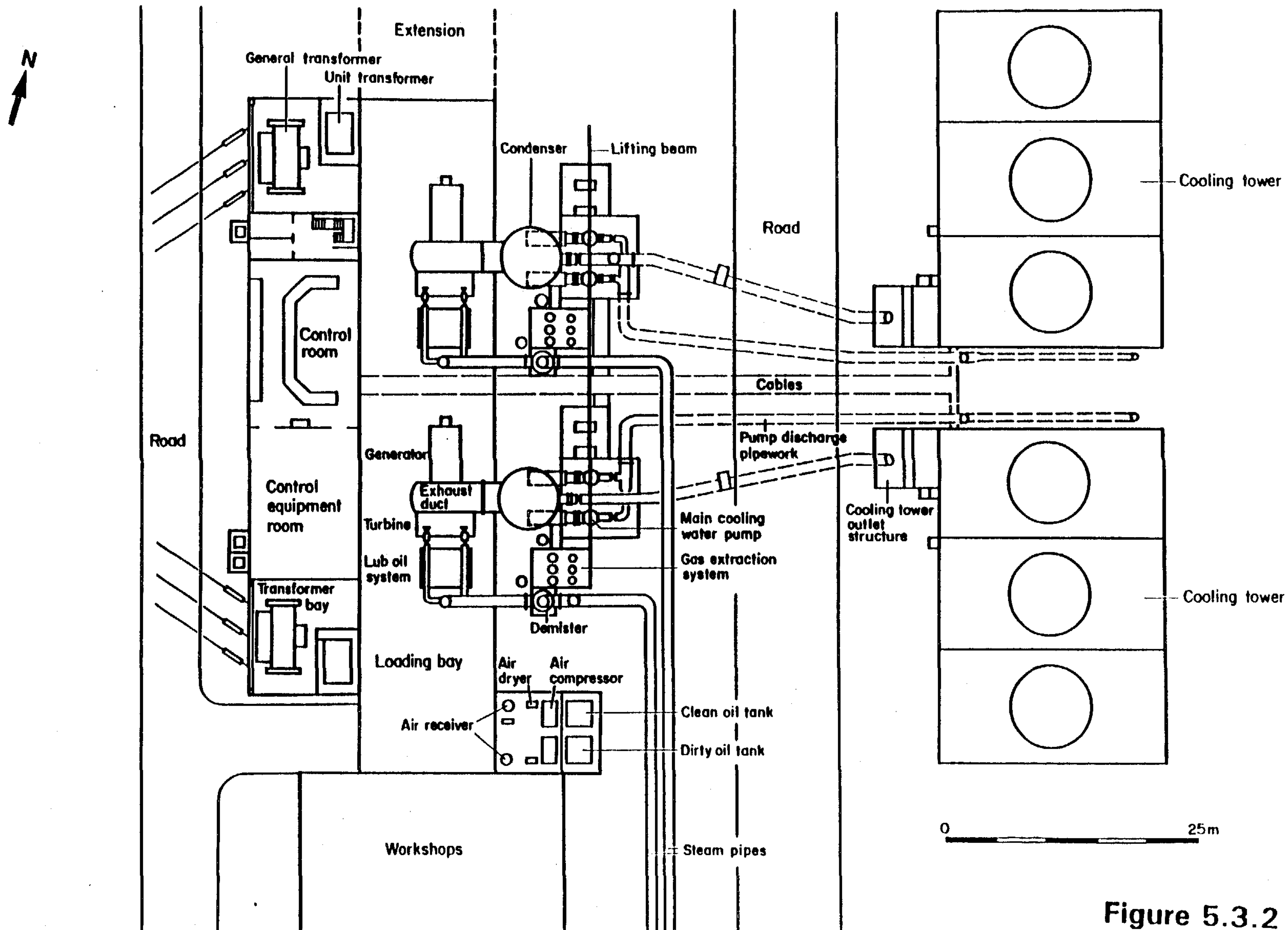


Figure 5.3.2

POWER STATION LAYOUT

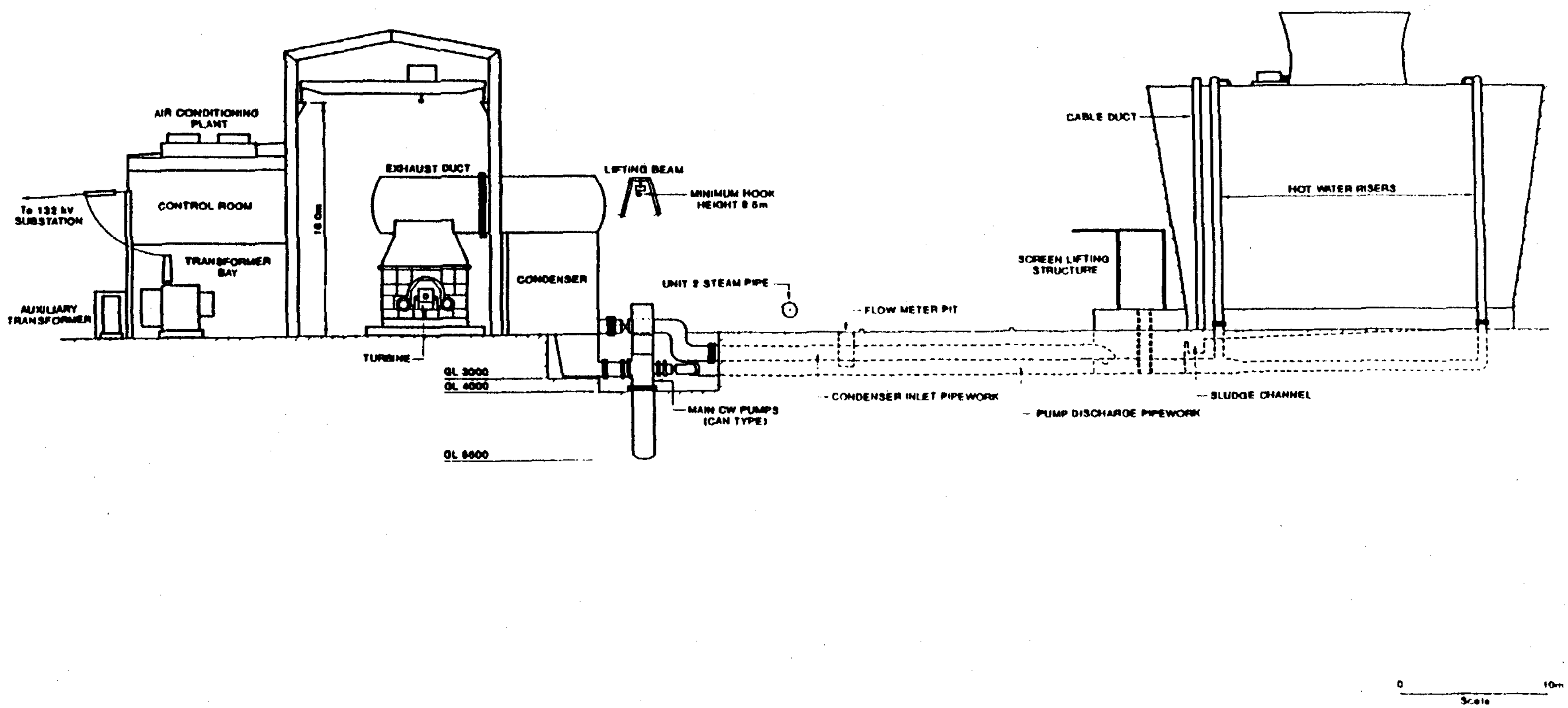
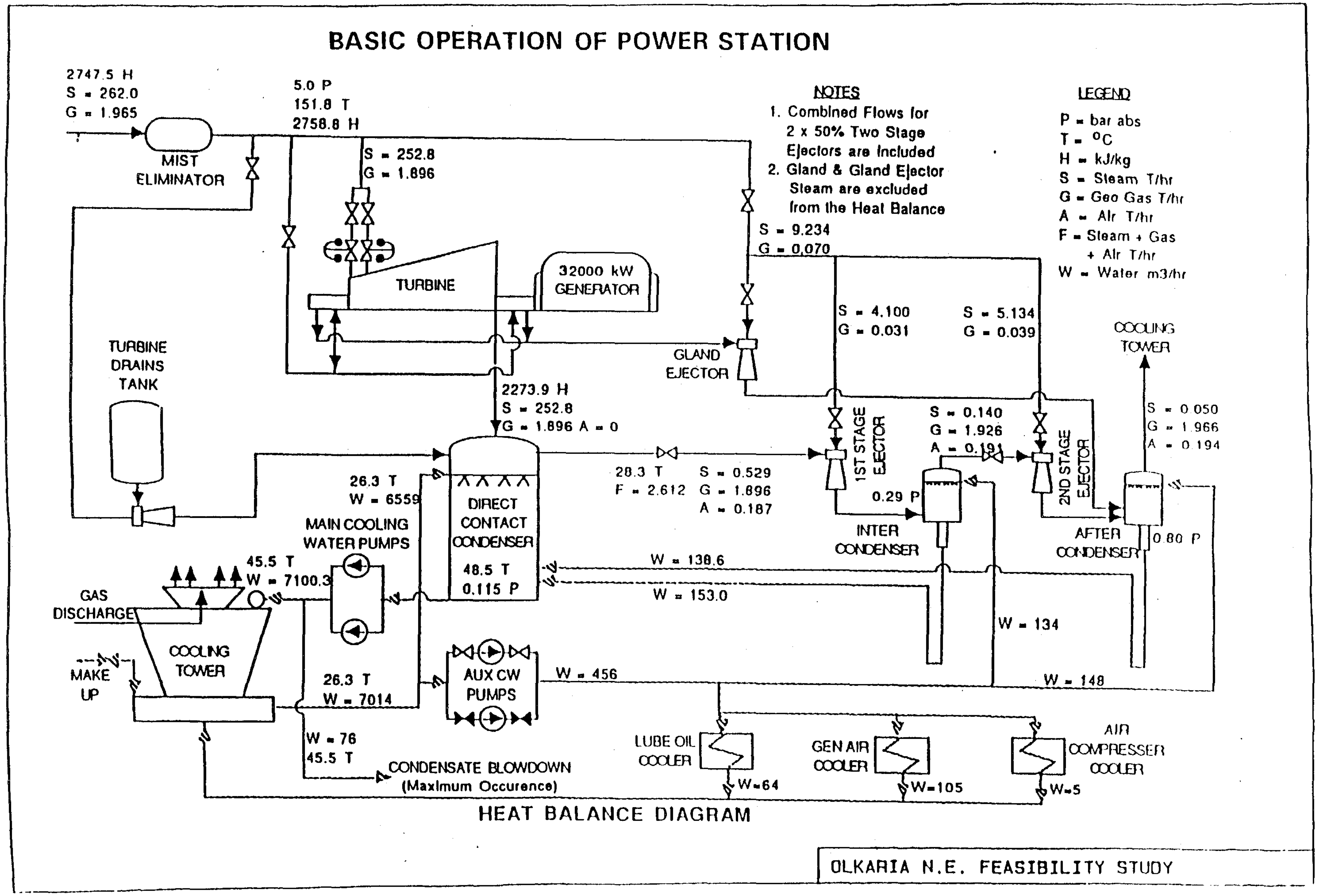


Figure 5.3.3
POWER STATION ELEVATION



HEAT BALANCE DIAGRAM

Figure 5.3.4

which has the potential to form a scale in pipe-work and wells, which will be subsequently used to dispose of the water to the re-injection well). The ponds will be fitted with reinforced concrete baffles to insure uniform retention time for the water and will be lined with butyl rubber sheets (protected with paving slabs), to prevent infiltration of water. The precipitated amorphous silica would need to be removed from the ponds periodically. This is relatively inert and could be buried. The pond area would be fenced to control access and to prevent animals from using the water as a regular source of drinking water. Birds are unlikely to use the ponds as the brine would still be too hot. However, while the water is not suitable for drinking (largely because of it high fluoride content), it is suggested that the ponds be made available as a recreational resource for KPC staff and/or visitors.

After conditioning, water would be piped under gravity to a separate sump pit beside the main road (see **Figure 2.4.1**) where blowdown water from the cooling towers would be added. Blowdown water would be taken from the cooling tower basins via a simple level control valve at each cooling tower basin. A 10 000 m^3 overflow pond, giving approximately 12 hours holding capacity at the initial enthalpy of 1500 kJ/kg, will be constructed for use in case of pump failure. The pond would normally be empty and would be 100 m by 50 m by 2 m deep and lined with butyl rubber to form an impervious seal. The rubber would be covered with paving slabs to provide protection from mechanical disturbance and from ultraviolet radiation. Security fencing would also be required.

High-lift pumps and a single line would be used to transfer the waste water from the sump to a point near OW-704 where the line would split into two separate lines which would go to the two re-injection wells RE1 and RE2 (see **Figure 2.4.1**). Safety valves would be provided on each re-injection line to protect against the re-injection wells becoming over-pressurised.

Both liquid water from the well field and blowdown water from the cooling towers is to be disposed of in the re-injection wells. The total volume of water that will need to be disposed of will depend on the enthalpy of the well-field, which is estimated to initially be 1500 kJ/kg and is expected to rise to 2100 kJ/kg after about three years (that is as time progresses, it is estimated that there will be less water per unit energy). The volume of blowdown cooling water will also depend on the relative humidity as this will affect the rate of evaporation from the cooling tower.

The feasibility study (**Ewbank Preece Limited, 1989**) estimates that excess blowdown will not exceed 177 t/h and a conservative design average would be 152 t/h. In summary the estimated amounts of water to be disposed of are as follows:

	Enthalpy - kJ/kg	
	1500	2100
Water from separators	698	212 (t/h)
Water from cooling tower condensate	152	152 (t/h)
TOTAL	**850**	**364 (t/h)**

Tests of OW-704 for its capacity to accept re-injection water showed an injectivity of 12.5 t/h/bar for the first 100 t and thereafter 24 t/h/bar. Well tests up to 110 t/h have been undertaken. It is theoretically feasible for the well to accept 850 t/h (Ewbank **Preece Limited**, 1989). It is accepted by the EA team that re-injection of excess water is the most environmentally desirable disposal method. Further, the disposal of excess water from the power station is a critical aspect of the design.

It is considered essential by the EA team that the feasibility of re-injection of 850 t/h over an extended period be demonstrated before it can be considered that the project based on the re-injection of waste water is environmentally acceptable.

5.3.4 Disposal of Geo Gas

At atmospheric pressure the total amount of geo gas is between 100 to 180 mmoles of gas per kg of steam (**Ewbank Preece Limited, 1989**). Geo gas contains a variable mixture of gases comprising primarily carbon dioxide (91-96 per cent by volume), hydrogen sulphide (1.2-4.9 per cent by volume), hydrogen (0.7-3.3 per cent by volume) with the remainder being methane and nitrogen. These gases are not condensable at the temperatures and pressure encountered in any phase of the process and are referred to as non-condensable gases. As the steam is used to work in driving the turbines, its temperature falls and condensation takes place so the percentage of non-condensable gas increases. Finally the non-condensable gas will be disposed of by discharging it into the cooling tower fans for dispersal into the atmosphere. The toxic fraction is hydrogen sulphide which is ultimately oxidised to sulphate and removed from the atmosphere by dry and wet deposition processes. The impacts of hydrogen sulphide prior to its oxidation and removal are discussed in detail in **Section 7.4**.

The total geo gas emission in the cooling towers for a 32 MWe power station is estimated to be 1.966 t/h (**Ewbank Preece Limited**, 1989, see also **Figure 5.3-4**) and most of this is of course carbon dioxide, which apart from being a "green house" gas is a "harmless" component of the atmosphere, present at a concentration of approximately 0.03 per cent.

An estimate of the "maximum" hydrogen sulphide emission rate can be made by assuming that 4.9 per cent of the geo gas is hydrogen sulphide (molecular weight 34 kg/kmole) and the remainder 95.1 per cent is carbon dioxide (molecular weight 44 kg/kmole). The average molecular weight of the geo gas will be 43.51 kg/kmole. Therefore for a 32 MWe power station emitting 1.966 t/h of geo gas, the volume emitted per hour at STP will be 1012.1 Nm^3. Since 4.9 per cent of this would be hydrogen sulphide the volume of hydrogen sulphide emitted per hour would be 49.595 Nm^3, and the mass of hydrogen sulphide discharged per hour from a 32 MWe unit is 75.278 kg/h (or 20.911 g/s). In practice the hydrogen sulphide emission should be the average over all wells weighted in accordance with the volume of steam provided by each well. At this stage not all the data from all wells in the North East well-field have been collected, but the average hydrogen sulphide concentration in the geo gas is expected to be between 2 and 3 per cent rather than the 4.9 per cent which is the average concentration for the most hydrogen sulphide rich well. From data presented in the feasibility study (**Ewbank Preece Limited, 1989**) this is OW-701.

5.3.5 Cooling Towers

Six cooling towers will be located on the eastern side of the power station building aligned parallel to the road and arranged in two banks of three (see **Figure 5.3.2**). **Figure** 5.3.3 shows a cross-sectional view of the cooling tower structure. The overall height of the towers will be 20 m above grade and they will be of the forced draft design. The major function of the cooling towers is to provide a heat exchange system for the turbine condensers on the low pressure side of the turbine. The cooling water and condensed steam are then pumped to the cooling towers where the hot water is allowed to flow/trickle over an open lattice structure losing heat by evaporation (approximately 80 per cent) and simple heat transfer (approximately 20 per cent) to a stream of air drawn through the tower by a fan.

Although water is lost from the towers by evaporation and from small droplets (cooling tower drift) of water that are caught by the wind and settle out in the area surrounding the cooling towers, there is an excess of water due to the continual addition of condensed steam. Acid gases (mainly carbon dioxide and hydrogen sulphide) in the well steam can cause the cooling system water to become acid over time. Alkaline material will be added to the cooling (blowdown) water to maintain it in a mildly alkaline state, (pH 8.5-9) using caustic soda, prior to being added to the separation water for re-injection. Preliminary estimates indicate that 150 t per year of caustic soda will be required to maintain the pH of recirculating water in the cooling towers at an appropriate level and a further 4.3 t per year will be required to adjust the pH prior to mixing with separation water.

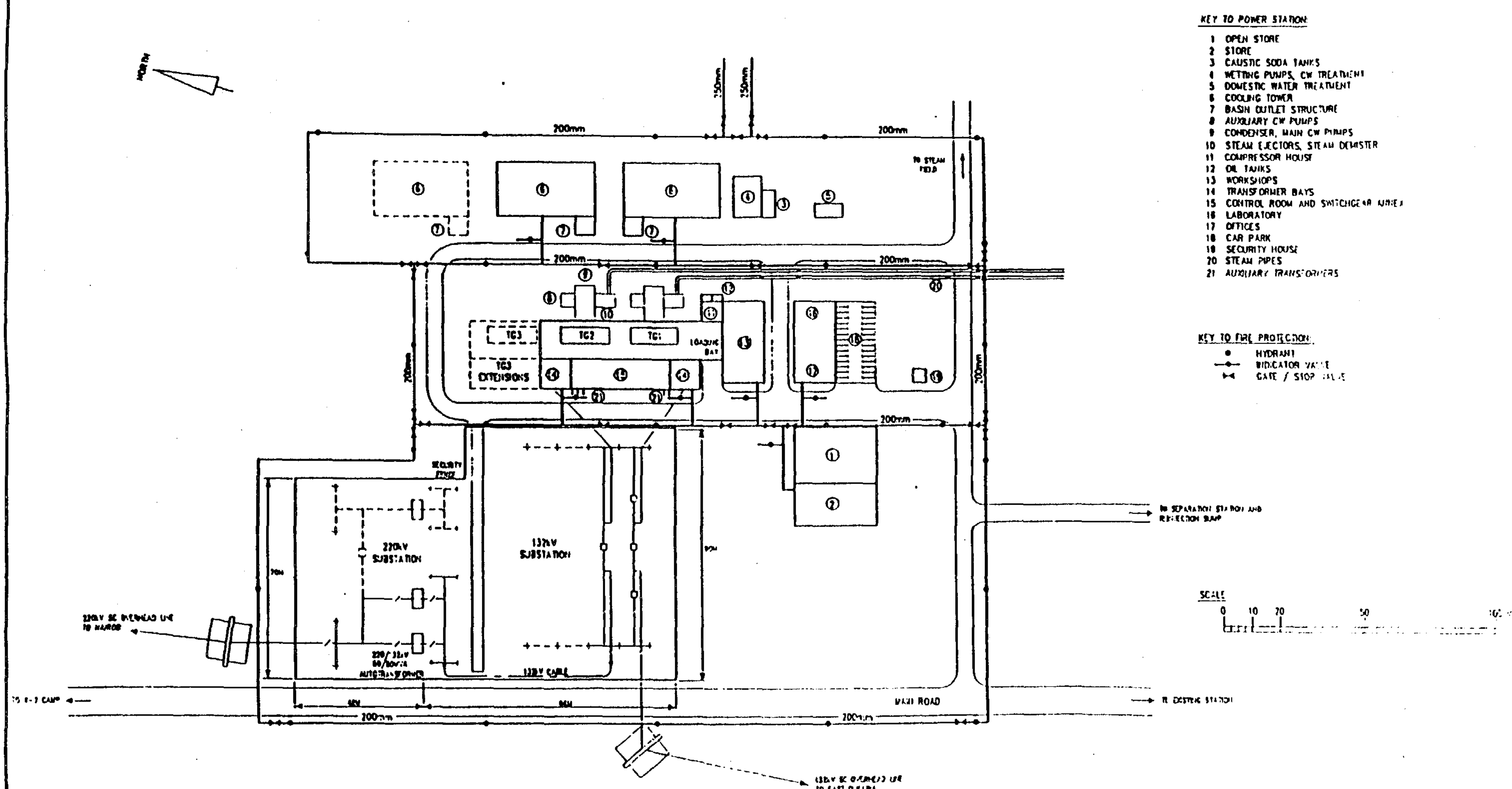
The feasibility study foreshadows the use of biocides/algaecides, probably sodium hypochlorite, which would be applied on a shock basis. With deep re-injection of excess water there would be no environmental problems with the addition of these materials.

The rate at which blowdown water will have to be disposed of will depend on the enthalpy of the steam (that is the amount of heat per unit mass of steam), the level at which the power station is operated and atmospheric conditions, which will determine evaporative losses. The maximum rate at which water will need to be disposed of from the cooling tower will be 76 t/h per 32 MWe unit (that is 152 t/h for the 64 MWe power station) and the water temperature will be 45.5 °C. This will occur during periods of high relative humidity and low steam enthalpy from the steam-field. Typically evaporative losses from the cooling tower will be 7100.3 t/h per 32 MWe unit (that is 14 200.6 t/h for the 64 MWe power station). This water is primarily condensed steam from the well-field.

5.3.6 Associated Facilities

Figure 5.3.5 shows the layout of the power station and associated facilities.

Workshops
Workshops will be located at the southern end of the turbine house.



Layout of Power Station and Facilities

Figure 5.3.5

OLKARIA N F FEASIBILITY STUDY

Administration Building
Offices and a laboratory are to be included in a separate administration building to be located on the southern side of the power station. Car parking for up to 30 vehicles will be provided.

Fire fighting
Fire fighting pumps will be located in a separate section of the cooling water treatment building. Engineering details of the hydrant locations, gate stop valve and the fire-water reticulation system are provided in the feasibility study (**Ewbank Preece Limited, 1989**). Approximately 27 hydrants will be provided and these will be served by a 200 mm reticulation pipe surrounding the cooling towers; the turbine, generator, main office, stores, workshops and car park; and the switch yard. Water supply will be by two 250 mm pipe from the lake-water tanks on the high ground (approximately 100 m above the power station) to the east of the power station near grid reference 200 000 m E and 990 5000 m N, see **Figure 5.3.1**. The system will be able to supply 7500 litres per minute for four hours.

Stores
The stores building and outdoor storage area will be located at the southern end of the switch yard, which in turn will be located on the western side of the power station building.

Fencing
The existing East Olkaria Power Station and well-field was originally enclosed by a cyclone wire fence approximately 2 m high. Make-up wells now exist beyond the fence perimeter. In addition, the East Olkaria Power Station well-heads are also individually fenced. In contrast, the recommended practice for North East Olkaria is that no perimeter fence should be built. Each well should still be individually fenced and the central works plus conditioning ponds should also be fenced as a single unit. The primary reason for this is minimise the interference to wildlife and to enable wildlife to move more freely between individually fenced areas. This practice will reduce the amount of habitat converted from wildlife use to electricity production. The resultant grazing should also reduce the amount of dead organic matter which forms a fire risk. The proposal is less expensive than the existing arrangement at East Olkaria and will also confer environmental benefits.

Sewerage
Sewage would be treated in a septic tank system with solids being removed as required by the Naivasha Council.

5.3.7 Power Transmission Lines

Figure 5.3.6 shows the route of existing power transmission lines (33 kV and 132 kV lines) in the area and the route of the proposed single circuit 132 kV line between the existing East Olkaria Power Station and the 220 kV line, which is proposed to be constructed between the Northeast Olkaria power station and Nairobi North.

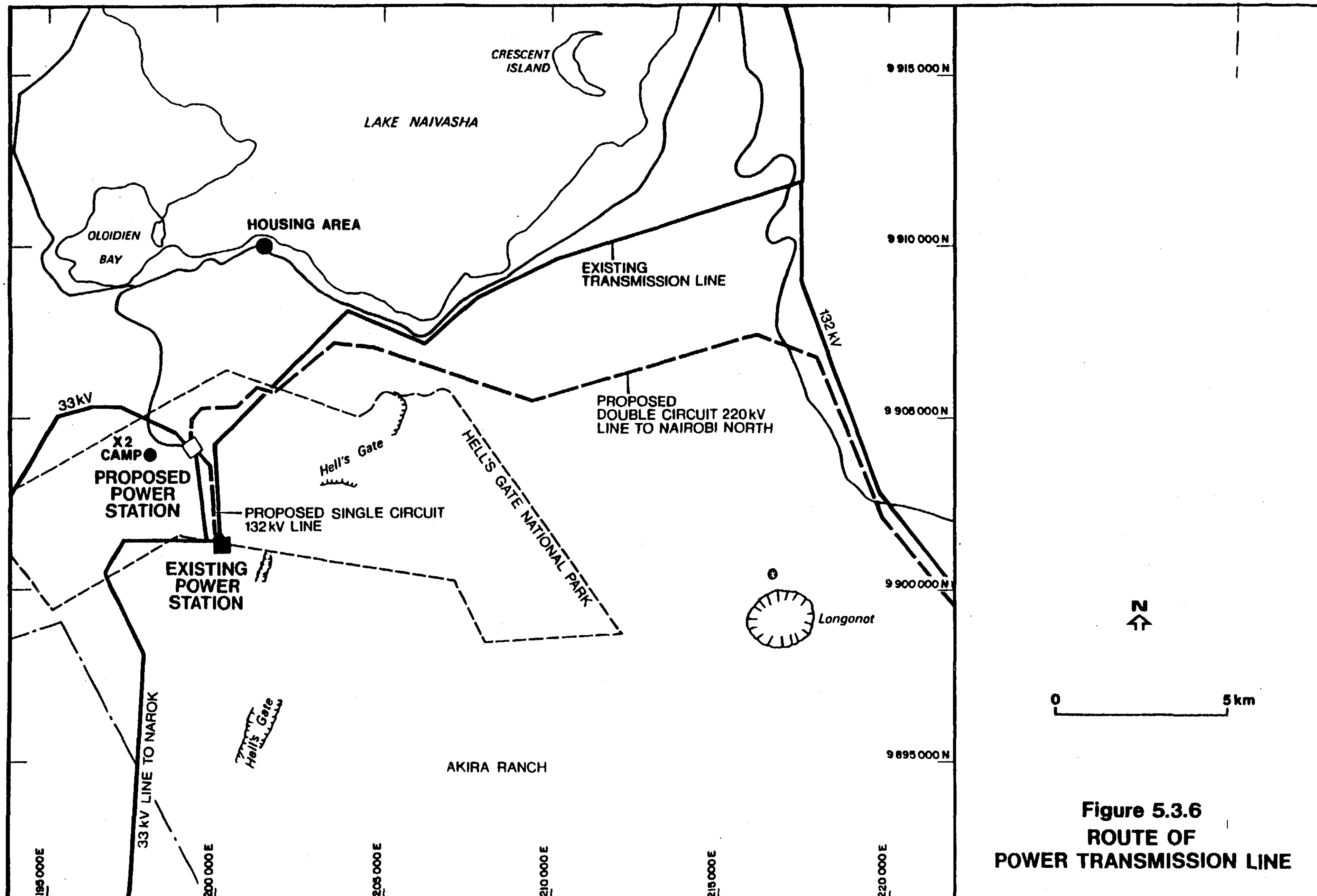


Figure 5.3.6
ROUTE OF POWER TRANSMISSION LINE

6. Existing Environment

6.1 LANDUSE SYSTEMS

The North East Olkaria geothermal field is located on the area shown in **Figure 2.4.1**. In 1982 the Hell's Gate National Park was gazetted. The boundaries of the park are shown on **Figure 2.4.1**. It now completely encloses both the existing power station and its associated geothermal field and the proposed power station site and the supporting geothermal area. The extent of this can be ascertained by looking at the locations of the 700 series wells shown on **Figure 2.4.1**.

Thus the power station area, the geothermal field and the National Park must co-exist in a multiple land use arrangement. The power station requires land for the physical components of the power station, which include the turbine building, cooling towers, offices, workshops, stores, car parking areas, roads, well pads and separators, pipelines and drains. Land is also required as a buffer zone for safety, security and to allow adequate area for the dispersal of odours, which while not necessarily harmful, affect the suitability of land for certain uses.

To the north of the proposed power station site the land is used for flower cultivation, vegetable growing, residential purposes and tourist developments. To the west and south and east (beyond the boundaries of the Hell's Gate National Park) land is used mainly for ranching.

The principal potential interference that the power station will have on these lands is by means of noise pollution and air pollution. Water pollution also has the potential to affect certain areas. However, the physical presence of the power station and the disturbance to the land required for power station development will have local impacts. The areas potentially affected will be discussed in **Section 7**. This section of the report is concerned with describing existing conditions.

6.2 FLORA

Introduction

This section describes the existing flora of North East Olkaria area. Ecological checklists from the area are presented in **Appendix 6.2.1**. The checklists used with Figure 6.2.1 show the distribution of plant species over the project area.

The Olkaria area is representative of some of the vegetation types found in arid areas of Kenya, falling in Ecoclimatic Zone 5. This characteristic vegetation is unique in that it develops in volcanic soil of recent origin. The bushland and bushed grassland is also a characteristic vegetation type found in other areas of the Rift Valley, in some parts of Nakuru district, Baringo district and also some parts of Laikipia district. The presence of steam vents creates some unique features in soil and geological formations which dictate the type of vegetation that develops in association with this phenomenon. Notably, several species of pteridophytes and orchids which would normally be lacking in this ecoclimatic zone are associated with the steam vents. Several are epiphytic plants on woody plants, occurring near the steam vents, where humidity is high.Throughout the areas in the Rift Valley that are outlets for underground steam, Fimbristylis exilis is a key species of sedge which signifies steam presence. This plant seems to tolerate high temperatures by forming masses of mart from dried older leaves that surround the young growing shoots, protecting them from excessive temperature exposure. Other species unique to this area include Ophioglossum rubellum, Dissotis senegambiensis, Dicranopteris linearis, Lycopodium cernuum, Pleopeltis macrocarpa, all pteridophytes not normally expected from ecozone five. Of special significance are orchid species, Cyrtorchis arcuata, Angraecum humile, Ansellia gigantea and Pteroglossaspis ruwenzoriensis. Orchids are unique plant species. They are highly valued by florists due to their beautiful flowers and therefore tend to be over-exploited. Some species are threatened with extinction.

Another unique habitat of this region, which has species not normally associated with Ecozone 5, is the gorges and luggas which are drainage areas. Species peculiar to this region, occurring only in these localities, include Teclea simplicifolia, a tree associated with montane forests in Kenya, Schefflera volkensii, Juniperus procera the pencil cedar, Dovylais abyssinica, Fiscus spp. Olea europaea ssp. africana - the African Olive.

All of these species are normally found in higher rainfall areas of Kenya, and under the prevailing climatic conditions at Olkaria, the gorges and luggas exhibit a totally different species composition uncharacteristic of this ecoclimatic zone.

The aerial photographs available were interpreted to produce a mosaic of the plant associations of the area. About six main vegetation types emerged with well delineated boundaries. Tarconanthus - Acacia dominated associations were found to be common, along with various combinations of Hyparrhernia, Digitaria and Themeda, as well as Cymbopogon as the major grasses.

6.2.1 The Plant Associations

Following aerial photo interpretation, a vegetation mosaic has emerged with distinct plant associations indicated in Figure 6.2.1. The classification is as follows:

(i)	Bushland	- B
(ii)	Bushed Shrubland	- C
(iii)	Bushed Grassland	- D
(iv)	Shrubbed Grassland	- E
(v)	Grassland	- G
(vi)	Rock outcrop	- R
(vii)	Barren land	- Z

These communities tend to gradually merge into one another with boundaries either dictated by change in topography, soil type and distinct drainage patterns and rock structure. Ground reconnaissance has revealed the following associations in the vegetation communities:

(i) Bushland (B)

Tarconanthus camphoratus - Acacia dreponolobium: This association while having these two species as dominants in the shrub layer also has varying combinations of grass and other herbaceous species, including Setaria sphacelata, Eragrostis cilianensis, with Chloris gayana appearing in more open patches. Themeda triandra, a fire tolerant grass is in small

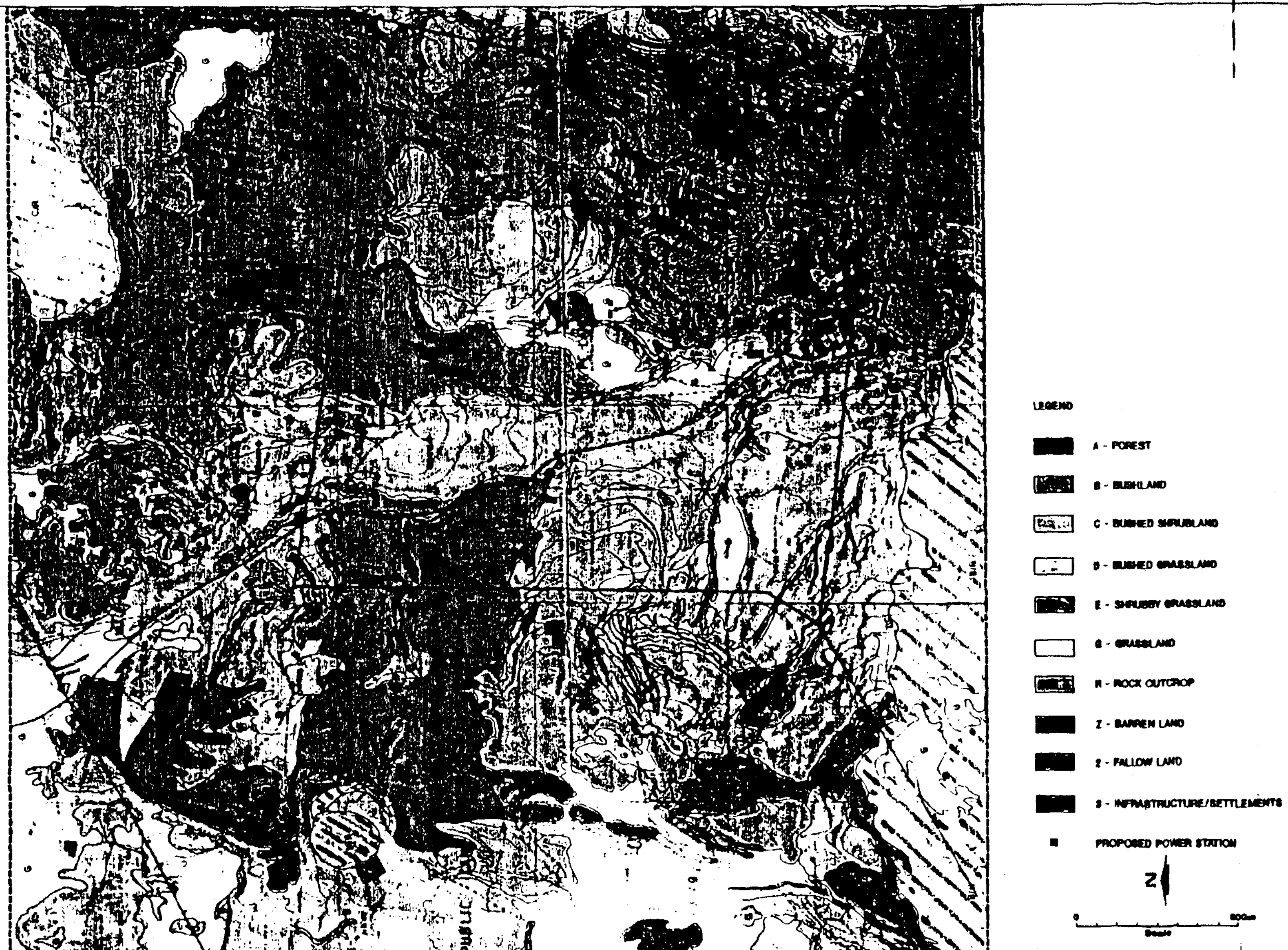


Figure 6.2.1
DISTRIBUTION OF VEGETATION – OLKARIA

quantities in this association. The species of forbs include Commelina, Cassia mimosoides, Tephrosia, Polygala, Zornia apiculata with Tribulus in more open spaces. This association is well represented in North East Olkaria where it occurs on lower slopes between open grasslands and hill tops.

(ii) Bushed Shrubland (C)

Acacia drepanolobium - Tarconanthus camphoratus: This association is characterised by rather shallow soil with stunted growth of these two species. A. drepanolobium tends to dominate, with scanty undergrowth of the herbaceous layer. A clear association of shrubs appears in clumps in the community. Patches of Setaria sphacelata appear towards the slopey ground in this association. More open spaces are occupied by annuals such as Aristida and Eragrostis cilianensis along with Tragus berteronianus.

(iii) Bushed Grassland (D)

Tarconanthus camphoratus - Acacia drepanolobium - Digitaria - Cymbopogon association: This is fairly well spread in the area covering substantial portions of the North East. Grasses dominating the landscape include Digitaria macroblephara, Cymbopogon caesius, Setaria sphacelata and Themeda triandra. Cyperus appears where there are signs of disturbance while Cynodon occurs in pockets of locally high raised ground as 'islands' which wildlife tend to frequent.

Setaria sphacelata is more predominant towards the sloping, more or less rocky ground with shallower soils, whereas Digitaria is more common in areas with deeper soils in this association. Chloris gayana is widely spread in this association, but tends to be suppressed in dominance. Herbaceous species include Striga, Cassia mimosoides, Cycnium, Indigofera, Hibiscus, Salvia, Tephrosia, Hypoestes, Pentanisia, Monsonia longipes, Euphorbia inaequilatera, among others.

(iv) Shrub Grassland (E)

Tarconanthus - Acacia - Cymbopogon - Themeda - Setaria association: This type of association tends to be characterised by tall Tarconanthus camphoratus shrubs, sometimes growing to tall trees. The landscape shows conspicuous Cymbopogon caesius and Themeda triandra as dominant grasses, with Setaria sphacelata in patches but in significantly noticeable distribution. This type of association allows little growth of forbs, but in patches of overgrazing, Zornia apiculata, Indigofera, Ocimum, Achyranthes aspera, Cleome monophylla, Heliotriopium, Chenopodium, are common, among several others.

(v) Grassland (G)

Digitaria abyssinica - Cyperus - Cynodon association: This tends to occur in low lying areas, or depressions with impeded drainage. Digitaria and the sedge Cyperus tend to occur in almost equal proportions from the centre of the association towards the periphery. Where drainage improves, Cynodon tends to outcompete the other two and dominate. At the edges, patches of forbs and Eragrostis appear as this association tends to merge with the bushland, with the ecotone supporting such species as Chenopodium, Polygala sphenoptera, Sporobolus, Portulaca, Vernonia, among others. In sections where drainage tends to be well channelised, Cynodon predominates, with occasional Geranium, Sonchus asper with Solanum nigrum in more mesic sites.

(vi) Rock Outcrops (R)

This is characterised by fairly sparse cover of shrubs of Tarconanthus and Acacia, where some soil allows plant establishment. It tends to be confined to hill tops and towards steep slopes. More often, Fimbristylis exilis predominates, as well as some Setaria sphacellata, Eragrostis cilianensis, a creeping form of Cynium, Cassia, Zornia, scattered Themeda triandra, and some Cyperus.

The steeper slopes of this association tend to contain patches of Cymbopogon and Setaria with Ficus, Teclea simplicifolia, Asparagus, Rhus natalensis, Maerua and Osyris at cliff edges, Carissa, Psiadia, with Digitaria macroblephara in patches between the rocks where some soil has collected. Cussonia spicata, Cordia sinensis, Euphorbia nyikae, Senecio, Aloe, Sansevieria, are some of the main species also found in steeper sides of the rocky terrain. Where some soil pockets appear, Chloris gayana, Themeda triandra, Heteropogon contortus with Cymbogon caesius tend to predominate. Silt collecting sites of this general area support Setaria verticillata, Panicum maximum and an assortment of forbs, notably Chenopodium, Amaranthus, Sonchus, Commelina, Crassocephalum, among others.

(vii) Barren Land (Z)

Some patches of the area where young volcanic rock has not been sufficiently weathered, have very little or no vegetative cover. These tend to support species of Caralluma, some Notonia, Portulaca oleracea, which are all succulent dry land plants with water storage and conservation physiological adaptation mechanisms. These are harsh environments for plant growth with extremes of temperatures and low moisture availability. Others in this category are areas inhospitable to plant growth due to excessively high temperatures from steam vents. A few species are however adapted to these very high temperature conditions, notably the sedge, Fimbristylis exilis and the red algae together with some lichens, and ferns.

A ground reconnaissance survey over the area following the plant communities as delineated above, produced an ecological checklist of the plants of the area. This is organised by plant families and is presented in **Appendix 6.2.1. Plates 13 to 16 (Appendix 6.2.1)** show examples.

6.2.2 Vegetation Dynamics

Vegetation maps, like the one presented in this report, record the current nature of the vegetation and indicate such features as dominant species, height of canopy, and extent of canopy closure and areas where the vegetation has been cleared. A key factor to be remembered about the vegetation around Olkaria is that it is not static but continuously changing with time. The changes in abundance and composition of the species present in the various communities will be occurring in response to stress from the environment. Such continuous changes are referred to as succession. In the case of Olkaria the successional changes are also likely to be interrupted by occasional wildfires (episodic changes).

The map of the current vegetation associations is designed to act as a baseline reference document. From this document, comments can be made about the pattern of species associations and any anomalies as well as possible geothermal "impact" interpretation. However, before discussing any such impacts, it is vital that the reader appreciate the natural continuous and episodic processes (ie vegetation dynamics) so that these are not confused as changes brought about by development activity (ie impacts).

A number of ecologists have noted that as the intensity and periodicity of stress in the environment change, different patterns of longevity and reproduction are favoured. For example, MacArthur and Wilson (1967) examined what attributes of a species would be most adaptive in a near-equilibrium climax community in which competition for resources becomes fierce, as the carrying capacity (*K*) is approached. They reasoned that under such circumstances species will be favoured which have long life expectancies and low proportions of energy devoted to reproduction, freeing energy to enhance mechanisms of competition for resources ("*K*-selection"). By contrast, in nonequilibrium, early successional habitats, species with short generation times and large reproductive effort will be selected for, since the need to disperse and colonize over large areas rapidly is the key to resource domination in such temporary habitats ("*r*-selection").

Successional changes in the predominant Acacia-Tarchonanthus communities seen at Olkaria exemplify this trend. In the first year following a wildfire, such shrubland sites are dominated by a profusion of annual and short-lived perennial species which produce large numbers of seeds. Within 2-5 years, the sites are shaded by resprouting Tarchonanthus camphoratus (Ol'leleshua) shrubs of 20-30+ year longevity which reproduce seed only scantily; the annuals and short-lived perennials meanwhile decline in abundance drastically. The cycle repeats at each successive fire.

On 13 February 1991, a large fire swept through the area adjacent to the existing geothermal station and then travelled northwards into North East Olkaria area. An extensive area was burnt. The fire resulted in much of the climax or stable state communities, dominated by Acacia-Tarchonanthus, being destroyed and the area has now reverted back to vegetation typical of early successional development (ie annuals and short-lived perennials or characteristic *r*-type species). The fact that the area was dominated by Acacia-Tarchonanthus dry woodland species before the fire, indicates that fires are relatively infrequent. Even though this may be the case, fire management needs to be considered and preventative measures taken. Vegetative mass (fuel loads) and climate (wind, air temperature, relative humidity) are important predictors of fire hazards, and such factors as slope help predict rate and pattern of fire spread. At temperate latitudes, aspect also serves as a predictor because of its influence on fuel moisture. In relation to the vegetation, the changing potential fuel load with successional changes (ie duff build-up) needs to be taken into consideration.

The observed profusion of annuals in areas burnt by the recent fire seems to indicate that the existing geothermal development has not affected either the process or pattern of recolonization by pioneer species. However, the comment can only be made about the lack of visible effects (ie acute symptoms) at this early stage. Long term monitoring is needed to detect any chronic changes.

6.3 SOILS

Introduction

The most noticeable impact of current development on land and soils in North East Olkaria has been erosion by water. A major part of the impact study has been an assessment of the problem of erosion and the way in which it can be mitigated. Data on soil physical properties have been used to explain the prevalence of erosion and the principles of its control. A study on soil chemical properties has also been initiated to determine whether there are any negative impacts of well testing on soil fertility.

Soil Erosion and Sediment Deposition

Investigations have concentrated on erosion by water, as erosion by wind is of minimal importance in this area. Erosion by water involves the processes of detachment and transport of soil. Detachment occurs in five ways. Firstly, it is caused by raindrop impact on all exposed surfaces which have not been stabilised with murram. These include the cut slopes and fill slopes of well pads, and other areas from which vegetation has been removed, for example, in laying pipelines. Secondly, it is caused by runoff scour forces wherever water concentrates in rills, gullies or unlined channels. Due to the erodible nature of the soil, bare surfaces are very susceptible to runoff scour. Thirdly, the force of gravity leads to slumping where cut slopes or fill slopes are too high or too steep and where gully sides have been undermined by flowing water. Fourthly, it is caused by pore water forces that lead to the breaching of sump ponds that has caused serious gullying in several places. Lastly, the tractive forces of vehicles on roads and tracks which have not been stabilised, contributes to the downward movement of soil.

Transport of sediment has taken place mainly by runoff during rainy periods but also by waste water during well testing. For example, waste water was discharged into a nearby valley during the testing of Well 713 and led to the formation of a large gully. As the water ran continually for about two months, it was able to transport a considerable amount of sediment, some of which, ended in the channel alongside the power station. Leakage from water pipes has also been responsible for eroding and transporting soil.

Forms of Erosion

The forms of erosion which can be observed at Olkaria are rill, inter-rill, gully and streambank erosion. Rills are common on all cut slopes and fill slopes which have not been stabilised with grass. Inter-rill erosion is that which takes places between rills. It is less easily detected but is indicated by exposed plant roots and by fragments of pumice or rock perched on pedestals of soil. Gully erosion is noticeable close to Wells 706, 707, 712, 709, 711, 713. Streambank erosion occurs in some of the concave bends of the normally dry watercourses that lead to the existing power station.

Erosion by mass movement can be observed in a few places where slumping and sliding of cut slopes, gully sides or head scarps has occurred. Erosion in one place leads to deposition wherever there is a reduction in velocity or volume of sediment laden runoff. This may be caused by a decrease in gradient on a hillslope or in a channel. It may also be caused by the widening of a channel or resistance to flow created by a denser, vegetative cover on the ground, for example, by star grass which is common in valley bottoms (**Plate 17**). Reduction of volume by seepage into the ground, also reduces the transport capacity of runoff. As there are no permanent rivers or streams, eroded material does not usually move far from the place of origin.

6.3.1 Natural Erosion Hazard in North East Olkaria

The natural erosion hazard in North East Olkaria is high due to the nature of the soil and the sloping terrain. The soils have been formed from quaternary to recent volcanic eruptions during which lava flows have been overlaid by airborne ash, pumice and dust, often in well defined layers. These layers are poorly consolidated although there has been some redistribution of the original material under the action of rainfall and runoff. Little weathering has taken place due to the relatively recent origin and semi-arid climate. **Figure 6.3.1** shows the detailed map of soil erosion hazard.

The texture of the soil is that of a sandy loam or loamy sand. The soils are non-cohesive.

Plate 17 - Main drainage channel upstream of the power station. Note excellent growth of star grass on alluvial soil. Channel is very established and there is no indication of accelerated erosion.

Plate 18 - Loose spoil from OW-712 in urgent need of stabilisation by planting grass.

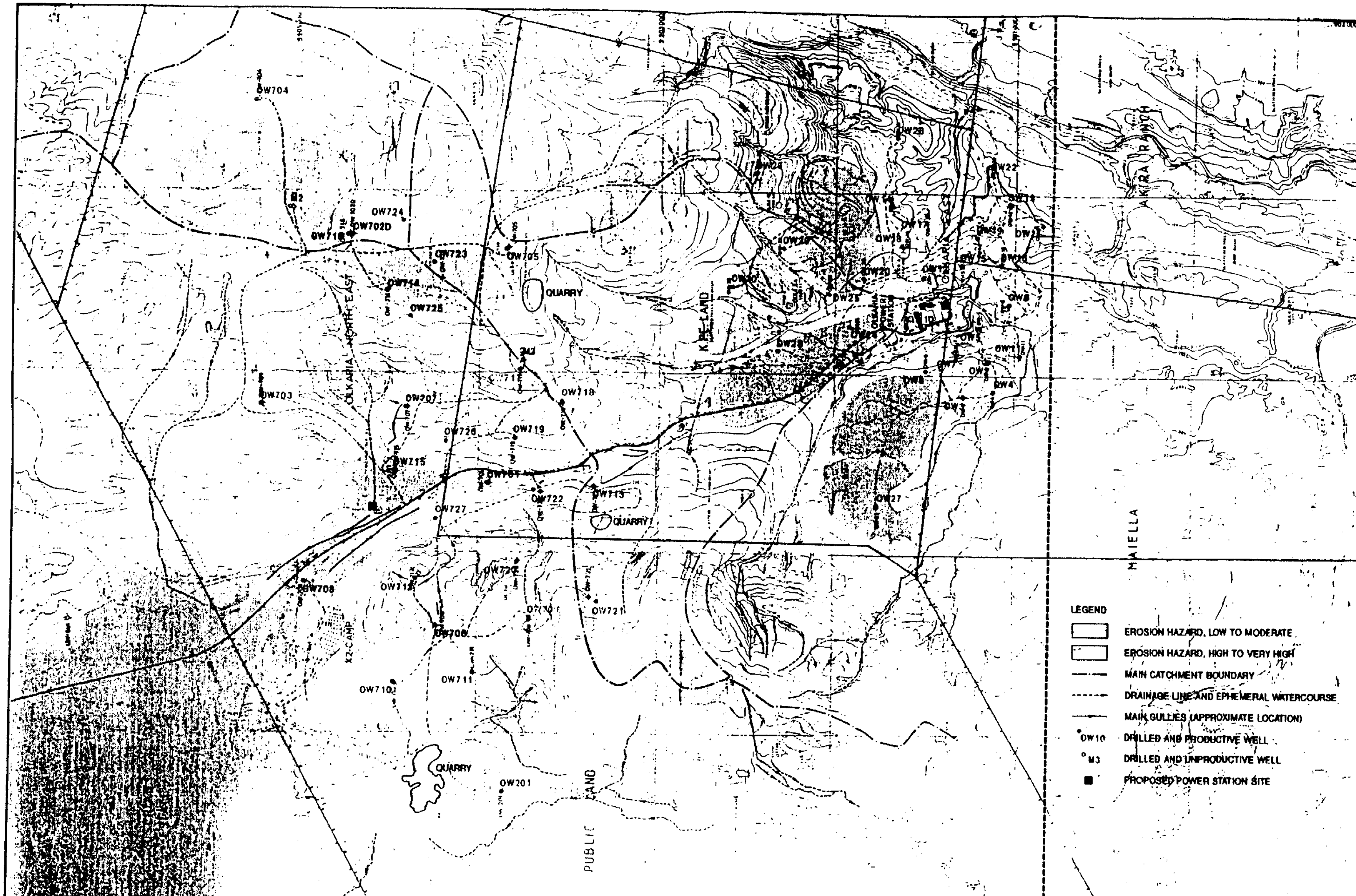


Figure 6.3.1
SOIL EROSION HAZARD

Clay content is around 5 per cent, silt is in the region of 15 - 30 per cent and sand around 65 - 80 per cent. Details of two separate soil analyses carried out in the Department of Civil Engineering and the Department of Soil Science of the University of Nairobi, are shown in **Appendix 6.3.1**. In many places the soils are up to 7 m or 8 m in depth and if the surface cover is removed, concentrated runoff easily cuts through the upper horizons until it reaches the underlying lava, creating spectacular gullies in the process.

Water which enters the soil profile can percolate rapidly but the high content of silt and fine sand (about 50 per cent in total) leads to surface sealing under raindrop impact. Provided there is a vegetative cover, the surface is kept open and rain can infiltrate but, once the cover is removed, sealing takes place and runoff rates are high. In an experiment with simulated rainfall on a similar soil near Longonot (**Barber and Thomas, 1981**), a storm of 40 mm in one hour, on a bare plot of 1.5 square metres, led to 30 per cent runoff when the soil was dry and 70 per cent when it was wet. The erodibility of the above soil was found to be ten times greater than the erodibility of the red soils at Kabete, Nairobi.

Where land is undisturbed, the generally good ground cover encourages infiltration of rainwater, and the porous nature of the underlying strata allows rapid percolation. Soil erosion becomes a serious problem only when the ground cover is removed, or runoff patterns disturbed, as a result of development activities and fire.

Although the erosion hazard is mainly due to the nature of the soil, it is aggravated by the steep slopes, in many places up to 20 or 30 per cent. Even under the natural vegetation of Leleshwa (Tarconanthus camphoratus), Whistling thorn (Acacia drepanolobium) and tufted perennial grasses such as Cymbopogon sp., some erosion takes places especially after a fire has reduced the cover of the ground. There was an extensive fire in February 1991, which caused a major reduction in ground cover and increased the potential for natural erosion and the risk of sedimentation. However, by the middle of June, the cover had improved significantly.

An erosion hazard map has been prepared (**Figure 6.3.1**) to indicate the potential for rill and inter-rill erosion if vegetative cover is removed. It is based on slope and two categories have been defined as follows: low to moderate erosion hazard (0 - 10 per cent slope) and high to very high erosion hazard (over 10 per cent slope). The rate of erosion is roughly proportional to the square of the slope expressed as a percentage (**Hudson, 1981, Page 197**). The figure of 10 per cent appears somewhat arbitrary but slope does not fall into sharply defined categories and visual inspection supports the contention that the risk of erosion and the problems of its control are much less below 10 per cent slope, than on steeper land.

The following limitations to the erosion hazard map should be noted. Firstly there are some steep areas, for example around Well 721, which have a lower hazard because they are rocky. Further field work would be needed to define these areas. Secondly, it does not reflect the problem of gully erosion which is often caused on low slopes by concentrated runoff from higher ground.

The Drainage System and Sedimentation

The drainage system falls into three main areas. The main dividing line runs near to Wells 721, 713, 718, 717, 723 and 724.

To the north of this line there are several small valleys which drain the upper slopes and discharge into the foot slopes and plains below without connecting to a common watercourse. Sediment moving down the valleys is trapped in the grass on the lower slopes. A good example of this is the area of grass and bush, 100 m north of Well 715, where the new power station may be constructed. It receives substantial quantities of sediment from the gully below Well 707.

To the south of the main divide there is a well defined catchment of 388 ha in which the valleys connect to a common watercourse (Plate 17) that runs past the existing power station. Sediment moving in this catchment is deposited alongside the power station and has to be removed periodically. Areas which contributed to this sediment in mid-1991 included the fill slopes of Wells 717, 718, spoil from the quarry near 705, and the gullies below Well 713 and alongside the old road nearby.

To the north-east of the study area, there is an area of internal drainage of approximately 175 ha. At present there is not much sediment moving within this area. Any sediment which does move is deposited in the grass on the lower slopes.

Where there have been no development activities, the valleys and drainage lines are well vegetated and there is little sign of erosion. This is consistent with a pattern of ephemeral stream flow and very low runoff rates. Where soil is deep and cover is intact, runoff is minimal; but where soil is shallow or cover has been destroyed, significant runoff can be expected during periods of heavy rainfall. Prior to development there was probably very little runoff except when storms occurred soon after a major fire or after a period of severe overgrazing.

Current Erosion Related to Power Development

The existing problems of erosion are related to the excavation of well pads, the discharge of waste water and the construction of roads. Clearing of vegetation for the purpose of laying pipelines has also contributed to the erosion problems but to a lesser extent. These points will be considered in turn.

Well Pads

There are about 25 well pads which have been constructed in North East Olkaria. Each pad measures about 60 - 70 m long and 30 - 40 m wide. The surface has been strengthened by a layer of about 50 cm of compacted murram, consisting largely of rock fragments. The spoil which has been excavated is pushed to the lower side. It has usually been dumped in an irregular manner (**Plate 18**) but recently there has been an effort to smooth the surface to a uniform slope on which grass can be planted (**Plate 19**). The cut slopes range in height from about 2 to 7 m and in angle from 45 to 80 degrees. The fill slopes have a similar range of height but are less steep and generally below 45 degrees. The stability of slopes is discussed in greater detail later.

The exposure of an area of around 0.25 ha at each well site creates a major erosion hazard. Erosion of cut slopes takes place by runoff and slumping but much of the sediment is deposited at the foot. Erosion of fill slopes is more serious because of the lack of compaction and because the sediment is likely to be carried further downslope. Runoff which accumulates on the pad itself usually finds its way out through the fill slope and where this has not been grassed, the potential for gully erosion is high. **Appendix 6.3.2** gives an assessment of the erosion risk at each well pad at North East Olkaria.

The need to stabilise all bare surfaces with vegetation as quickly as possible has been

Plate 19 - Planting grass on fill slope of OW-717 after smoothing. Well OW-712 under test in background.

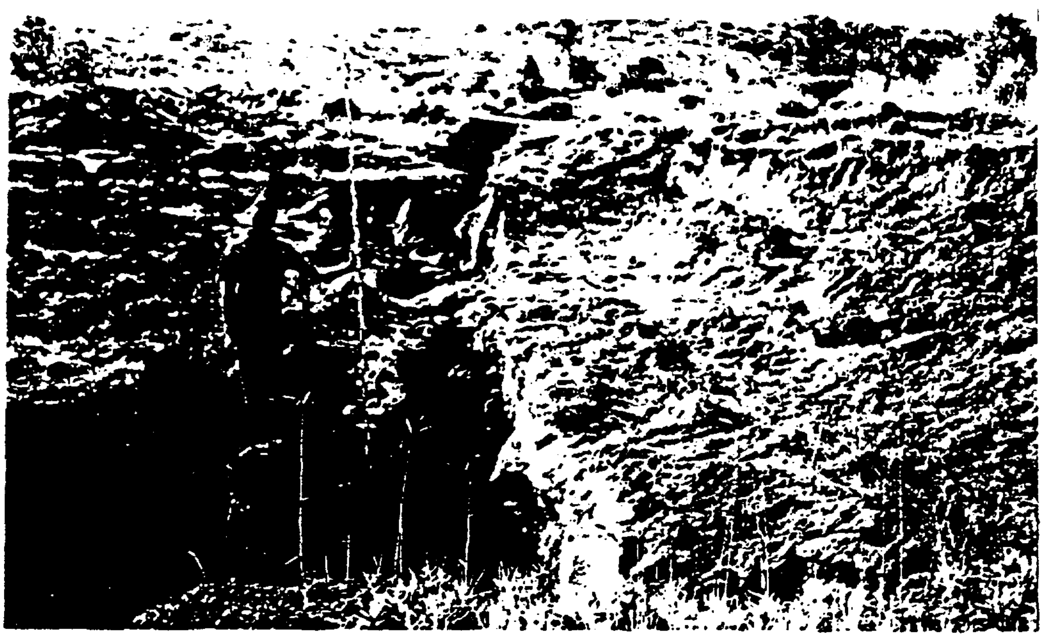


Plate 20 - Gully below OW-707. Note that bulldozer was used to push soil into the gully but runoff from upslope has cut out the channel again.tails).

stressed during the impact study. Fortunately the soils are reasonably fertile and star grass, which can be planted from splits and spreads rapidly, is indigenous to the area. However, in spite of the need, almost the only planting which has been done has been on the fill slopes of 714, 717 (Plate 19) and 726. These comments apply to mid to late 1991.

Waste Water

Waste water is discharged from well pads during two phases, the drilling phase and the testing phase. In some situations this water has been discharged directly to a valley and has created serious gullying. In others it has been discharged to a sump pond but several ponds have breached and the sudden outflow has been responsible for gullying. Although there is currently a greater attempt to control waste water and to pipe it from sump ponds to the reinjection Well 708, much damage has already been done. There are major gullies associated with Well 707, 709, 711, 712 and 713 due to failure to cope adequately with waste water. The most serious gully is that in the valley below Well 713 which is now up to about 10 m wide and 8 m deep in places. The gully sides are slumping and the sediment in the floor can easily be transported and deposited in the channel by the existing power station, if there is a heavy storm. The risk of gullying *should* be taken much more seriously because once gullies develop they are hard to control. An attempt to fill the gully below 709 with soil using a bulldozer was not successful as runoff simply cut a new channel through the loose material which had not been compacted or stabilised with grass (Plate 20).

Roads

Runoff from roads has the potential to cause serious erosion either in the drains which run parallel to the road, in the mitre drains which discharge runoff into the bush or where concentrated runoff is discharged from culverts. Provided the road surface itself is stabilised with murram, as most of them are, and runoff is diverted at regular intervals before it accumulates to problem levels, the situation can be kept under control. The potential dangers are illustrated by the gully which has developed alongside the road to Well 707. The gully has arisen due to a culvert which has become blocked.

Trouble arises with roads which are too steep such as that to Well 712. Discharge from this road is already causing a gully to develop in the adjacent bush. Clearing land for roads before determining the best alignment can cause serious problems as for example the road which runs directly downslope from Well 717. As it proved too steep it was replaced with another road with a better alignment but at the time of writing, it still needs to be revegetated.

During the construction phase there is likely to be much more traffic on the roads and greater attention to road drainage will be needed.

Quarries

There is a quarry above Well 713 and another below 705. The former is in a rock area and there is not much loose soil to be carried away. The latter has a large amount of loose spoil which can easily be transported to a valley leading to the existing power station. It should be stabilised urgently with grass.

6.3.2 Significance of Erosion

Soil erosion causes damage in several ways. On agricultural land the main problem is loss of soil productivity. In North East Olkaria it is the formation of gullies and the deposition of sediment.

Gullies are major sources of sediment and the gully below Well 713 is particularly serious because sediment from it can be deposited at the power station. Gullies are also a hazard to the unwary and pose a risk to hikers who may be roaming on foot through those areas of Hell's Gate National Park, which are under development for geothermal power. Gullies are also aesthetically unwelcome and in certain valleys they destroy the natural vegetation which may be a habitat for interesting plants or birds.

North East Olkaria is an area of considerable natural beauty and land denuded of vegetation is an eyesore. Every effort should be made to restore vegetative cover and repair damage to the land as quickly as possible. How this should be done has already been discussed with KPC's Environmental Monitoring Unit and is discussed further in **Section 7**.

Soil Fertility

The most likely impact of geothermal power development on soil fertility would be connected with well testing and would be either from the disposal of waste water, or from the condensation of steam on the adjacent vegetation. The current policy of re-injection of waste water has minimised any potential damage. Those channels which have carried waste water for several months, show only slight damage to the adjacent vegetation. Waste water from the old Well no. 26, which is supplying steam to the existing power station, has been running continuously down a small valley with minimal effect. Preliminary indications are therefore that well testing does not have a serious impact on soil fertility. However, in order to confirm this, soil samples were taken downwind at 50 to 100 m from the following wells, which are due to be tested: Well 712, 717, 718, 719, 720 and 721. These samples have been taken for analysis to the National Agricultural Laboratories in Nairobi.

Well Pad Slope Stability

The stability of cut slopes and fill slopes depends on various factors such as the soil texture and drainage, the amount and frequency of runoff from higher ground, the likelihood of saturation during periods of heavy rainfall and the amount of overburden.

Stability implies that there will be no slumping and that erosion by rainfall or runoff will be prevented by a permanent cover of vegetation on the cut slopes and fill slopes.

The soil has a low clay content and therefore very little cohesion but is deep and very well drained. Saturation is most unlikely to occur as water will not be ponded. If the upslope areas have a good vegetative cover, runoff should be infrequent and of limited amount. The risk of slumping due to overburden is slight except with the abandoned well pad, NE-G, which was cut into a very steep slope.

Ideally cut slopes should be battered to an angle of not more than about 35 degrees (70 per cent), which allows a safety margin below the theoretical limit for a cohesionless soil given by the angle of internal friction (approximately 50 degrees for the soil samples listed in **Appendix 6.3.1**). An angle of 35 degrees should permit vegetation to be established easily.

Stabilisation of existing fill slopes requires little extra work apart from smoothing and planting with star grass which should be a top priority whenever the ground is wet enough or watering can be carried out. Although top soil and subsoil have been mixed up, there appears to be adequate fertility (judging by the way grass grows in gully floors) to get good establishment.

Stabilisation of cut slopes involves battering to an angle of about 35 degrees and planting grass. This is a more difficult exercise because it means exposing even more bare ground. Cutting back an 80 degree slope of 7 m height to an angle of 35 degrees exposes an extra 9 metres of soil to erosion by raindrop impact and runoff. Unless a complete cover of grass is established quickly, there is likely to be an even greater problem of erosion.

At present cut slopes, though unpleasant to look at, do not provide anything like the quantities of sediment that come from the fill slopes and gullies. The reason is that much of the soil that slumps, or is washed down, remains on the pad itself at the foot of the cut slope.

The best policy would be to stabilise all existing bare ground, including the well pad itself, and any cut slopes which are not more than say 45 degrees, before tackling the steeper cut slopes.

Any measures which involve further soil disturbance at the present stage before the existing bare ground has been revegetated will lead to increased problems of erosion and sedimentation

Effects on Existing Power Station Infrastructure
Soil erosion is presently affecting the operation of the existing Olkaria Power Station because sediment has been deposited along the eastern side of the power station (see **Figure 6.3.1**). A report by H P Gauff has been prepared to address this problem.

It proposes that flood water flowing down the drainage line to the east of the existing power station should be prevented from reaching the power station and should be diverted along a concrete lined channel and discharged into Hell's Gate. The report rightly points out that the most urgent need is to arrest silt at its source and it makes proposal for stabilisation of the well pads and the adjacent slopes by installing drains and establishing vegetation cover.

The critical areas for revegetation are the bare surfaces associated with Well pads 718 and 717, the quarry slope near 705 and the gullies below 713. Until revegetation has been carried out, it will be difficult to assess the seriousness of the siltation problem and whether or not a diversion channel is needed. It is possible that if the catchment area is properly vegetated a diversion channel would not be necessary. The reasons are as follows:

- The existing channels in the power station catchment are mainly well vegetated and, just upstream of the road to Hell's gate, where it crosses the main channel, there is no evidence of stream bank erosion and the channel sides are very well vegetated with star grass. This is consistent with a flow that diminishes in velocity and perhaps also in volume (through seepage in the banks and bed) as it moves downstream. A channel that grows wider and deeper and has banks that become increasingly bare and eroded, as occurs in some semi-arid areas, would be a much better candidate for diversion

- The gully below 713 has probably been a major contributor to sediment at the power station but it was caused by waste water during well testing. This has now stopped and the gully floor should stabilise with vegetation in due course.

- The catchment is in a semi-arid zone with rainfall in the region of 20 - 40% of open water evaporation. Soils are mainly deep and free draining. There is no overgrazing and provided there are no fires, ground cover is good and there should be very little runoff. The general absence of deeply incised drainage channels in the area is consistent with a pattern of low runoff.

It is suggested that the first step should be to carry out revegetation of all bare surfaces with star grass and/or rhodes grass as quickly as possible. This includes cut slopes, fill slopes and well pads themselves - both old ones and new ones. Detailed recommendations on this can be provided if needed.

Some temporary dams of poles and brushwood, or of stone, may be needed in gullies to assist the process of stabilisation if the natural processes appear to be too slow. If revegetation alone proves to be inadequate, the next step would be to install permanent silt interceptor dams (check dams) in the channels which appear to be carrying most silt. As mentioned by H.P. Gauff there are certain problems associated with this approach but they can be overcome. Silt dams would help to dissipate energy of flood flow and cause deposition of sediment. Grass would grow in the area of the reservoir and encourage deposition. If the amount of sediment became excessive, the sediment could be removed during the dry season. A suggestion has been made that the interceptor dams should be constructed in a manner which allows continual seepage through the wall so that they can retain sediment but not water.

A diversion channel would create new problems in Hell's Gate and the proposal should only be entertained if the above measures prove inadequate.

As part of determining baseline conditions there is a need to determine absolute height datum for this area, against which subsequent subsidence (if any) can be measured. Currently there is no Benchmark survey of North East Olkaria and it is essential that this be established as soon as possible.

6.4. FAUNA

Introduction

This section describes the fauna of the North East Olkaria region. Of greatest importance is the fauna of Hell's Gate National Park, located within North East Olkaria geothermal development. This report gives a quantitative presentation of data and information gathered with the aim of identifying unique and important habitats together with the spatial and temporal patterns of habitat use by animals.

Density and distribution of large mammals, within Hell's Gate National Park, were estimated by surveying along the road transect network. Only 33% (approximately) of the park is accessible and utilised by the animals. During the surveys in the park, the species, number of individuals, group and/or herd size, age category (adult, subadult, juvenile) were recorded. In Kedong and Kongoni ranches estimates were established by total counts and/or population indices.

The avian community was assessed during mammal counts and routine systematic searches and also from published materials. In addition, the report attempts to elucidate the structure and dynamics of the fauna community and how it relates to vegetation, topography and other features of the park. Detailed description of Hell's Gate National Park fauna is followed by a description of Olkaria's mammals and birds. **Appendices 6.4.1** and **6.4.2** list the mammals and birds of Hell's Gate National Park.

6.4.1 Mammals in Hell's Gate National Park Area

Numbers and Density

Twenty-three species of mammals were recorded; of these 14 were large herbivores and 3 were small herbivores. No elephants or rhinoceros were present in the park. In addition the tally included the jackal, olive baboon, rocky hyrax, and the hedgehog. Reliable evidence also indicated presence of the lion, leopard and the aardvark (**Appendix 6.4.1**). Leopard is a threatened species according to the 1990 IUCN Red List of Threatened Animals. A variety of rat-like rodents, which are difficult to identify, were also recorded. The study area is therefore characterised by low numbers of species and consequently low species diversity. This could be due to the lack of a wide variety of habitats, or past human and other influences.

Densities of the 14 large herbivores were established for Hell's Gate National Park, Kedong Ranch and Kongoni Ranch (**Tables 6.4.1 and 6.4.2**). Two density values were established for the park: one for the whole park area; and the other for the area that was normally utilised by the herbivores. Density values of the latter were significantly higher for all the fourteen species and indicated possibilities of habitat overuse and competition in future. Densities of the herbivores in Kedong and Kongoni ranches were much lower than in the park.

TABLE 6.4.1 - MEAN ESTIMATES OF POPULATION SIZE AND DENSITY IN HELL'S GATE NATIONAL PARK

	Population Size	Density/km2 Total Park	Density/km2 Utilised Area
Kongoni	479	6.95	29.87
Zebra	295	4.33	18.43
Thompson's Gazelle	165	2.43	10.31
Grant's Gazelle	136	2.00	8.50
Giraffe	40	0.58	2.50
Eland	102	1.50	6.37
Reedbuck	32	0.47	2.00
Warthog	50	0.74	3.12
Impala	30	0.44	1.87
Dik-dik	25	0.36	1.56
Steinbuck	24	0.35	1.50
Klipspringer	10	0.15	6.25
Buffalo	105	1.54	6.70
Wildebeest	-	-	-
Waterbuck	5	0.07	3.12

There is limited movement of animals between Kedong Ranch and the park whose future cannot be guaranteed without active involvement of the ranch ownership in the management of the park.

As mentioned above, only part of the park (33%) is accessible and utilised by the animals. Consequently everything should be done to make sure that the expansion of geothermal activity in the current project does not reduce the useable area.

Within the park, animals move from open grassland (grazing areas) to the bushland areas. For most species this occurs during the hot hours of the day. The reason for this movement is to seek shade, however the animals also engage in limited grazing. Most of the bushland is at higher elevation and access is only through natural erosion gullies. These gullies should not be interfered with during any stages of the project cycle.

TABLE 6.4.2 - MEAN ESTIMATES OF POPULATION SIZE AND DENSITY IN KEDONG AND KONGONI RANCHES

Species	Kedong Ranch		Kongoni Ranch	
	Population size	Density /km^2	Population size	Density /km^2
Kongoni	380	3.16	260	3.25
Zebra	294	2.45	381	4.76
Thompson's Gazelle	1016	8.46	82	1.03
Grant's Gazelle	72	0.60	50	0.63
Giraffe	15	0.13	20	0.25
Eland	87	0.73	29	0.36
Reedbuck	6	0.05	5	0.16
Warthog	11	0.09	-	-
Impala	42	0.35	110	1.37
Dik-Dik	1	-	-	-
Steinbuck	-	-	-	-
Klipspringer	-	-	-	-
Buffalo	-	-	-	-
Wildebeest	2	-	-	-
Waterbuck	-	-	-	-

Community Structure
The large herbivores species show associations amongst themselves and preferences for some habitats over others. Zebra often occur together with kongoni, this association arises from ecological facilitation of grass leaves for kongoni by zebra, which eat the tougher stalks and stems of grass. Thompson's gazelle and warthog often associate in areas of very low grass, where herbs and soft grass are available. The aardvark occupies slightly elevated areas in flat grassland areas or on gradual slopes, of under 45°, in association with termites and mole rats.

The mean group and herd size for the large herbivores species is shown in Table 6.4.3. These socio-organisation structures are similar to those of other areas. The small body-sized herbivores do not form groups or herds due to their solitary lifestyle. These herbivores require cover for protection together with a high quality diet of rare food items.

TABLE 6.4.3 - SOCIO-ORGANISATION OF LARGE HERBIVORE SPECIES IN HELL'S GATE NATIONAL PARK

Species	Mean Group Size[1]	Mean Herd Size[2]
Kongoni	15.8	32.0
Zebra	7.2	31.5
Thompson's Gazelle	3.6	-
Grant's Gazelle	1.8	-
Giraffe	2.4	5.5
Eland	6.4	26.1
Reedbuck	1.6	-
Warthog	3.0	7.8
Impala	5.2	-
Dik-Dik	1.0	-
Steinbuck	1.0	-
Klipspringer	1.0	-
Buffalo	8.0	23.2
Wildebeest	-	-
Waterbuck	3.0	6.2

Note:
1. An evident family unit.
2. An aggregation of more than one family unit and where clusters of individual units can be picked out.

Distribution and Habitat Preferences
Distribution of animals in the park is mainly determined by terrain (topography), vegetation cover together with quality and quantity of food plants. Only 33% of the park offers suitable habitat. Overall the distribution is clumped in this useable area. Zebra, kongoni, Thompson's gazelle and warthog occupy the open grasslands. Steinbuck and klipspringer both occupy steep bushy areas while giraffe and eland are found in the open bushland areas. Another factor that influences the spatial and temporal patterns of habitat use is water. Water is provided in troughs at waterholes at several points. **Figure 6.4.1** shows the distribution of major herbivores in the park.

No detailed studies were conducted on habitat preferences. Generally the open grassland areas were most preferred. Open bushland areas followed and closed habitats were not used at all. The open grasslands were dominated by Themeda triandra, Digitaria scalarum and Cynodon dactylon. These three grass species formed the main component of the grazers' diet.

In the bushland the giraffe was found to subsist mainly on Acacia drepanolobium.

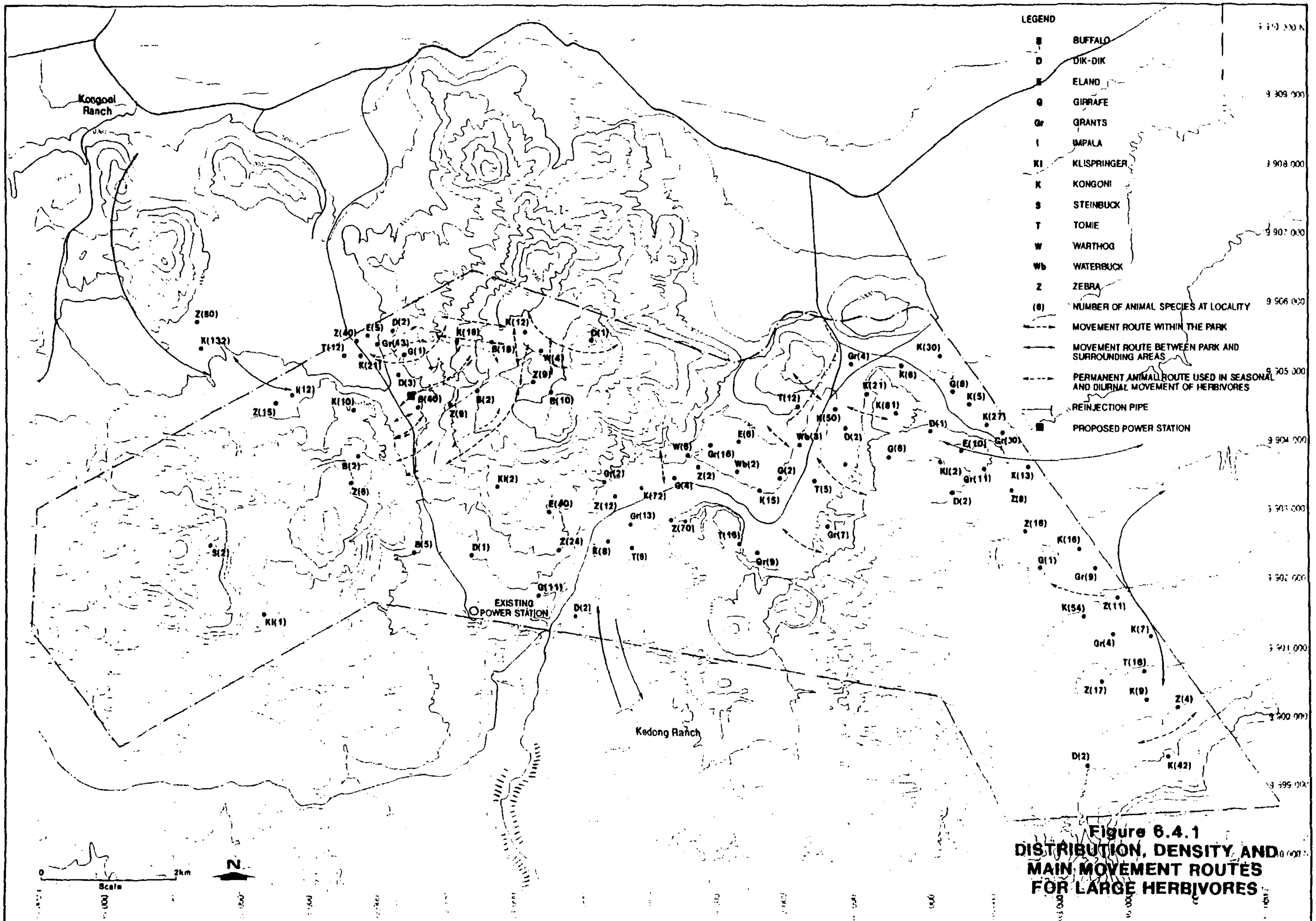


Figure 6.4.1
DISTRIBUTION, DENSITY AND MAIN MOVEMENT ROUTES FOR LARGE HERBIVORES

Tarchonanthus camphoratus was an unimportant food item but was important in that it provided cover and habitat for other fauna components.

Population Structure

The estimates of population structure were aimed at assessing the current performance and predicting future trends of the populations of species in the park. Most species had a low proportion of subadults and juveniles (Table 6.4.4). This is a sign of poor recruitment and overall population growth. Predation, limitation by food and nutrition, disease and human influences can be the cause of the current situation.

Analysis to isolate the responsible factor(s) is in progress. Hopefully, after the cause is determined, a better management of wildlife population could be taken into consideration. Sex ratios for most species deviated from 1:1 which is normal in most wildlife communities. Due to the limited and poor quality of data no detailed analysis was carried out.

TABLE 6.4.4 - POPULATION STRUCTURE: PROPORTIONS (PERCENTAGE) OF CATEGORIES IN POPULATIONS OF SOME OF THE LARGE HERBIVORE SPECIES IN HELL'S GATE NATIONAL PARK

Species	Adults	Subadults	Juveniles
Kongoni	71.6	9.6	18.8
Zebra	84.3	7.2	8.5
T. Gazelle	84.7	12.3	3.0
G. Gazelle	51.1	39.7	9.2
Giraffe	66.5	24.7	8.8
Buffalo	49.6	26.3	24.1
Eland	41.8	39.1	19.1
Warthog	38.4	15.1	46.5

Birds

Appendix 6.4.2 shows the species of birds occurring in Hell's Gate National Park. None of the listed species is in the IUCN Red List of Threatened Animals.

One hundred and eight species of birds have been recorded in the park. During the survey 65 species of birds were recorded. During this survey the rare Lammergeyer or Bearded Vulture which has been recorded previously was not recorded. However it is worthwhile noting that this species has not been seen in the park for decades and was probably never a common bird in the park. No attempt was made to estimate population size of the avifauna.

The avifauna is diverse because of habitat heterogeneity and also because of proximity to Lake Naivasha. The cliffs and gorges are important breeding grounds for vultures, swifts and other species. The vultures move in from far places while the swifts engage in displays, nesting and mating during the rainy season.

The maintenance of natural habitat of these breeding grounds is a concern which should be given special focus. Dusts, gases, and destruction of vegetation all have the potential to affect the bird life.

Impact Assessment Issues of Concern
These matters will be adressed in the impact assessment section.

1. Possible contraction of the scarce and limited herbivores habitats which already show signs of overuse and congestion.

2. Active involvement of ranch owners and intensive management of large mammal populations. Kedong ranch can offer a refuge and migratory area during the full project cycle.

3. Ensuring that the current limited movement of animals from low grassland areas to higher elevations and bushland cover areas is not interfered with. Development of infrastructure and physical facilities has the potential to interfere with current movement routes and gullies.

4. That effluents and gases from the geothermal facility may destroy vegetation cover which provides food, shelter and cover for mammals and birds. Special attention and care for the 33% of the park area that is used by animals. Special attention to negative impacts on preferred food plants.

5. Possible negative impacts on the current interspecific association together with intraspecific social organisation structures of large herbivores, and the possible effects of the project on the population recruitment rate which is currently low for most species.

6. Impacts of the project on the cliffs which are important and rare breeding grounds for some bird species.

7. Further overall insularization of the fauna of Hell's Gate National Park.

8. Acceptable pressures from the project and tourism.

9. Role of the proposed Geothermal Project in the improvement of infrastructure, planning and active management of the park.

Animal Distribution and Density
North East Olkaria, though not part of the major areas used (by herbivores) has significant numbers of buffalo, giraffe, kongoni, eland, Thompsons and Grants gazelle, impala and warthog. The buffalo spend most of the day in the (narrow valleys) gullies vegetated by thick bushland. These areas provide cover from human disturbance and shade during the heat of the day. During the night, the buffalos move down to the flat grassland dominated areas on lower elevations, for grazing. During the dry season the buffalos occupy the upper elevation open grassland and bushed grassland areas during the day and move down through the permanent and well established trails and routes. These routes are shown in **Figure 6.4.1**. Some of these routes follow the gullies thereby facilitating gradual access and avoidance of the exposed steep areas.

Zebras and kongoni also use the higher ground during the dry season and move down to lower grassland areas for water and nocturnal grazing. The grazing is mainly along the main tar-road to Olkaria Geothermal Station and the open lawn behind the park's Olkaria Gate. There is also considerable movement between the spatially limited flat top ridges shown in Figure 6.4.1. The two species also concentrate in upper open flat grassland areas during the wet season. Since zebra and kongoni are water dependent species, they disperse all over the North East Olkaria area during the wet season where water availability is also widespread.

The warthog occupies open grassland areas. This habitat preference is mainly due to avoidance of predators in more closed bushland areas. The limited open grassland areas are therefore vital for this species' continued occupance and survival in North East Olkaria. Thompson's gazelle habits are the same as those of the warthog. The "tomie" however, occupies open grassland areas at lower elevation. Tomie and warthog also prefer areas characterised by low-grassland. These areas provide easy access and availability of soft grass and herbs for the tomie and warthog together with roots and tubers for the warthog.

Eland is mainly a browser but the range of food items broadens during the wet season to include some grass species. The eland occupies the Tarchonanthus open bushlands in North East Olkaria. Often it is found in association with zebra and kongoni. Eland displays the diurnal and seasonal movements from upper to lower areas and vice-versa.

The eland also uses the bushland to cool off during the hottest part of the day. Its activity patterns have changed since drilling started in North East Olkaria, becoming mainly a nocturnal feeder in North East Olkaria. This shows that unlike the kongoni and zebra which can still be seen not far from human activity during the day, the shy eland has to wait till dark to start feeding.

Impala were found to occupy bushland grassland ecotone areas. Like most other species they have moved out from North East Olkaria due to the drilling activity. The more solitary steinbuck and klipspringer have also retreated to higher elevations.

Klipspringer, steinbuck and dik-dik occupy permanent territories. The species are very selective feeders. The permanent residency in a territory makes them acquire knowledge on the locations of the rare food items thereby enhancing feeding and survival. The territory owner(s) also knows the best areas to hide when attacked or threatened by a predator. Displacement from a territory and attempts to establish a new territory, therefore, can expose the species to predators and inadequate nutrition.

Movements and Migration Corridors

Figure 6.4.1 shows the movement routes within the park and migration corridors between the park and the surrounding areas. The site of the proposed power station has been surveyed intensively to provide information that can be used in the layout of the pipelines. The layout should be such as to ensure the minimum disruption that is practical to the indicated migration routes. Animals concentrate more in the park during the dry season. This is because of the provision of water holes, or waste water from human settlements. During the wet season the animals are widespread both within and outside the park in areas which offer suitable feeding areas. During the dry season, the herbivores gradually shift from open grassland and open bushed grassland feeding areas to more bushed areas. They do so to shelter from the heat of the day. The routes (trails),which the animals use in the course of these movements are permanent and have been used for a very long time. Disruption of these routes should therefore be avoided.

Some Impacts of Current Activities at North East Olkaria

1. Habitat destruction: by roads; resultant gully erosion and drilling platforms. The road network seems unnecessarily extensive. The platforms are too large (about $1000m^2$ on average) especially when compared with those in the old Olkaria Power Station.

2. Habitat change: Soil disturbance along roads and at platforms has caused invasion by Cynodon dactylon, a less nutritious grass species.

3. Animals drinking water from the drilling sites.

4. Change in activity patterns, habitat preference and habitat utilisation.

5. Disappearance (local extinction or movement to other areas) of dik-dik and other solitary species.

6. Roads cutting across, within park, movement trails.

6.5 CLIMATE AND METEOROLOGY

6.5.1 Monitoring Programme

Information on local meteorological conditions is important for assessing the dispersion of gaseous emissions from sources associated with the development. Dispersion of stack emissions is influenced by wind speed, wind direction, temperature, atmospheric stability class[1] and the height of the mixed-layer[2].

The following section provides a brief description of the climate and meteorology of the area. It includes a review of the wind conditions as well as a summary of data on temperature, humidity, rainfall and evaporation. For temperature, humidity, rainfall and evaporation, long-term data bases have been used to describe the environment. For wind conditions and the dispersion modelling studies, data collected by two specially installed meteorological stations have been used.

Monitoring Program

The monitoring program was designed to provide data suitable for use with a computer-based dispersion model, which has been used to simulate hydrogen sulphide dispersion and to provide general climatic and meteorological data. Because initially two sites were

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[1] In dispersion modelling, stability class is used to categorise the dispersive capacity of the atmosphere, that is, the rate at which a plume will disperse. In the Pasquill-Gifford stability class assignment scheme used in this study, there are six stability classes A through to F. Class A relates to unstable conditions such as, might be found on a sunny day with light winds. In such conditions, plumes will spread rapidly usually resulting in high ground-level concentrations close an elevated source and rapidly decreasing concentrations downwind. Class F relates to stable conditions such as occur when the sky is clear, the winds are light and an inversion is present. Plume spreading is slow in these circumstances. The intermediate classes B, C, D and E relate to intermediate dispersion conditions.

[2] The term mixed-layer height refers the height of the turbulent layer of air near the earth's surface into which ground-level emissions will be rapidly mixed. A plume emitted above the mixed-layer will remain isolated from the ground until such time as the mixed-layer reaches the height of the plume. The height of the mixed-layer is controlled mainly by convection (due to solar heating of the ground) and by mechanical turbulence resulting from turbulence as the wind blowing over the rough ground.

considered for the siting of the power station, two sites were monitored. This has also allowed the effects of terrain on wind speed and wind direction to be evaluated.

One meteorological station was established near X2-Camp (X2 Station) and the other (North East Station) was sited approximately 2 km to the east (see **Figure 6.5.1**). These have been operated since early 1991. A perspective view of the area is shown in **Figure 6.5.2.**

Each site is equipped with a microprocessor-controlled weather station. The two stations are identical except that the North East Station supplements a conventional meteorological station, which has been operated by KPC's Environmental Unit for several years. The two microprocessor stations monitor the following parameters:

- Wind speed and wind direction at 10 m above local ground level using a Met One 024A wind direction sensor and a 014A wind speed sensor (starting speeds 0.5 m/s)

- Temperature at 1.5 m using a Unidata Model 6505D ambient temperature sensor

- Humidity at 1.5 m using a Unidata Model 6505D humidity sensor

- Solar radiation using a Unidata Model 6505D global radiation sensor

- Rainfall using a Model 6506A tipping bucket rain gauge (0.2 mm resolution)

Data from these sensors are sampled every five seconds and average values of the sampled wind speed, wind direction, temperature, humidity and solar radiation are logged to a solid state memory every ten minutes. Rainfall data is logged at the end of each ten-minute period and value logged is the total rain during the ten minute interval.

The memory in the loggers has sufficient capacity to store over one month of data. Data are transferred to a computer for checking and subsequent processing at approximately one month intervals.

In addition, the North East Station is equipped with a Stevenson screen containing wet and dry-bulb thermometers, and a Lambrecht Thermohygrograph, which makes continuous records of humidity and temperature. A conventional rain gauge and Class-A evaporation pan are also in place. The rain gauge and evaporation pan are read at 9 am each day and the other instruments are read at 9 am and 3 pm.

Table 6.5.1 summarises the data available from the two microprocessor-controlled weather stations.

Examples of the format of the data collected by the microprocessor controlled weather stations and the format of the processed data used in the dispersion modelling studies are shown in **Appendix 6.5.1**.

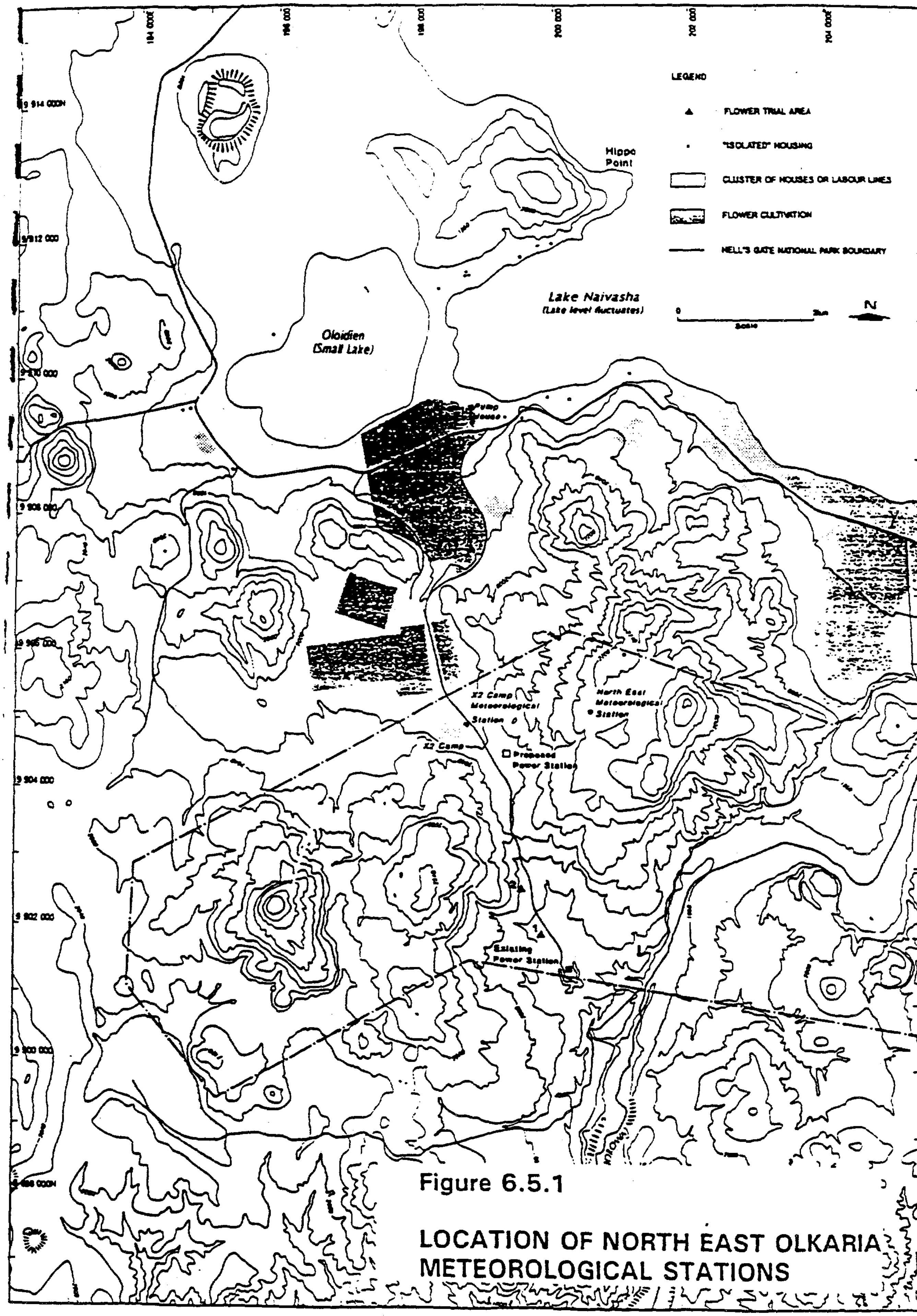
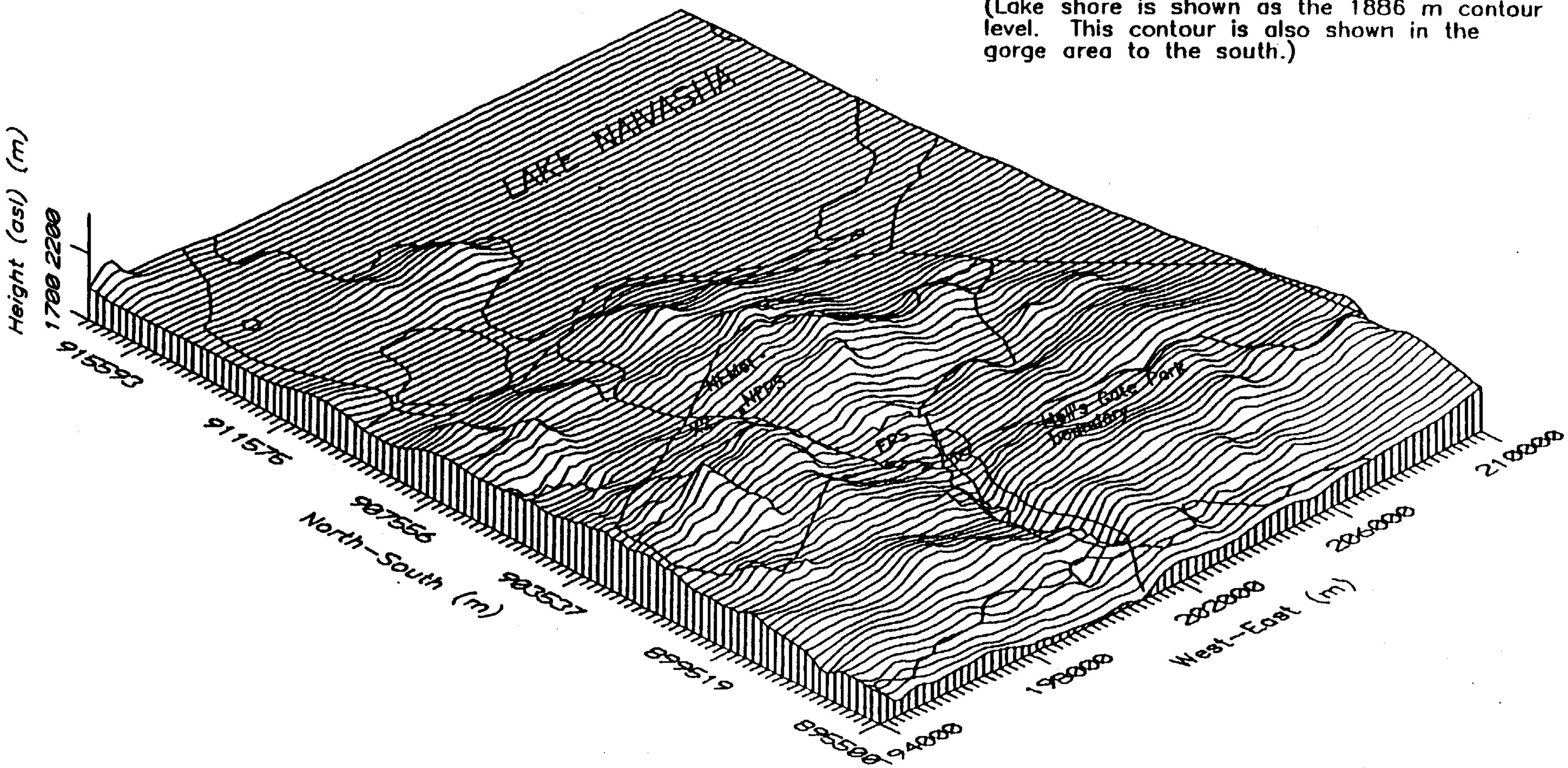


Figure 6.5.1

LOCATION OF NORTH EAST OLKARIA METEOROLOGICAL STATIONS

NEMet – North East Meteorological Station
NEPS – North East Power Station
EPS – East Power Station
X2 – X2-Camp
(Lake shore is shown as the 1886 *m* contour level. This contour is also shown in the gorge area to the south.)



PERSPECTIVE VIEW OF LAKE NAIVASHA (SOUTH) AND OLKARIA AREA

Figure 6.5.2

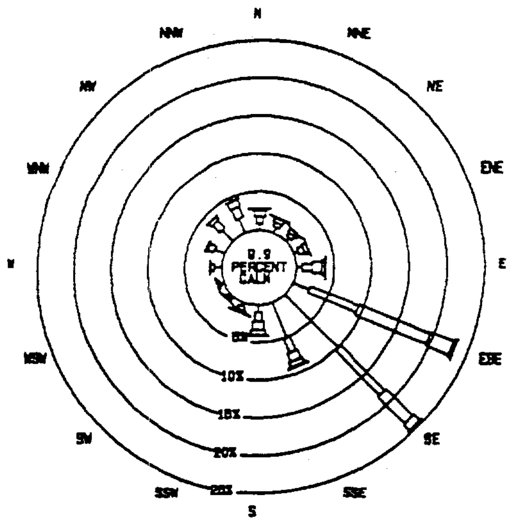
Wind Speed and Wind Direction
Wind roses diagrams for the two stations are presented in Figures 6.5.3 and 6.5.4. Comparison of wind roses patterns from the X2-Camp Station and the North East

TABLE 6.5.1 DATA RECOVERED BY MONTH FOR EACH METEOROLOGICAL STATION EXPRESSED AS A PERCENTAGE OF MAXIMUM POSSIBLE RECOVERY[1]

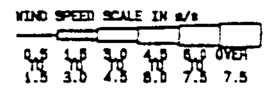
Month	X2-Camp Meteorological Station	North East Meteorological Station
November 1990	71% (09-11-90 16:00 to 30-11-90 24:00)[2]	85% (05-11-90 14:00 to 30-11-90 24:00)[2]
December 1990	100%[2]	14% (01-12-90 to 05-12-90)[2]
January 1991	100%[2]	0 %
February 1991	5 % (01-02-91 00:00 to 02-02-91 12:00)[2] 71% (05-02-91 10:30 to 26-02-91 10:30)	84% (05-02-91 10:00 to 28-02-91 23:50)
March 1991	63% (01-03-91 00:00 to 20-03-91 09:50)	100%
April 1991	95% (02-04-91 09:40 to 30-04-91 23:50)	100%
May 1991	100%	100%
June 1991	100%	100%
July 1991	100%	100%
August 1991	100%	14% (01-08-91 00:00 to 05-08-91 09:00)
September 1991	100%	89% (04-09-91 10:00 to 30-09-91 23:50)
October 1991	100%	100%

[1] Data comprise a computer-file of average values of wind speed, wind direction, temperature, humidity, solar radiation and total rainfall over the each ten-minute period except where noted (see footnote 2). (Averages are formed from data sampled at five-second intervals).

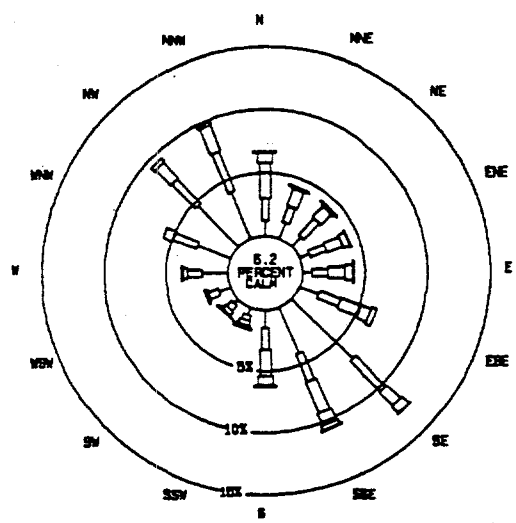
[2] Indicates that data were collected using Lambrecht Model 1482 wind recorders, which were the only instruments available at the commencement of the study. In this case only chart records of wind direction and wind speed are available. (Temperature and humidity data are available from a continuous recorder maintained by the Environmental Unit at the North East Station). The Lambrecht wind recorder charts have been decoded to produce hourly average computer data files of wind speed, wind direction and the standard deviation of wind direction.



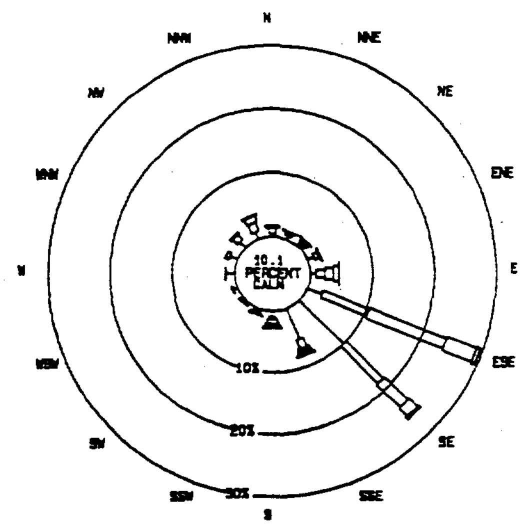
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
X2 Camp Annual Wind Data 1990/91



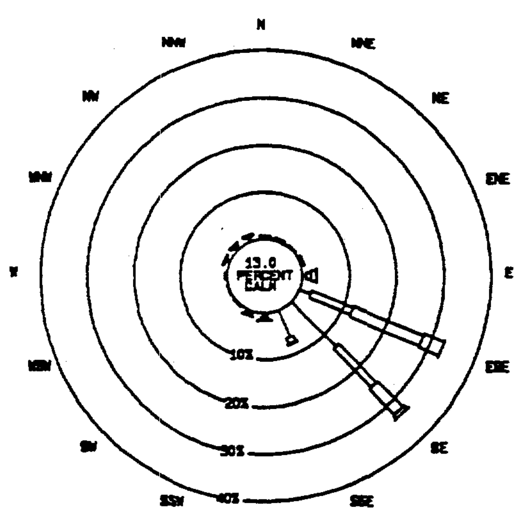
SEASONAL AND ANNUAL WIND ROSES FOR X2-CAMP METEOROLOGICAL STATION



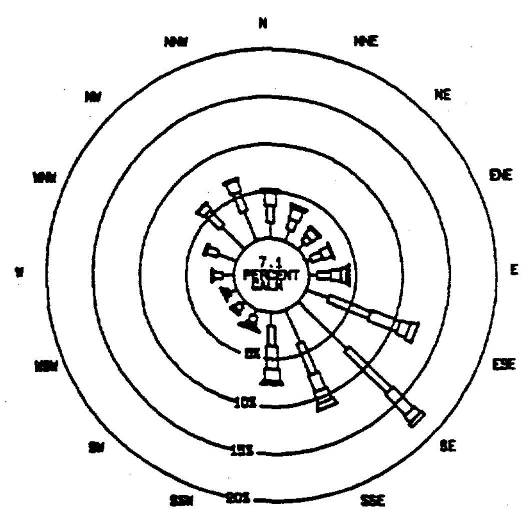
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
X2 Camp Wind Data - Jan/Feb 1991



DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
X2 Camp Wind Data-March/April/May 1991



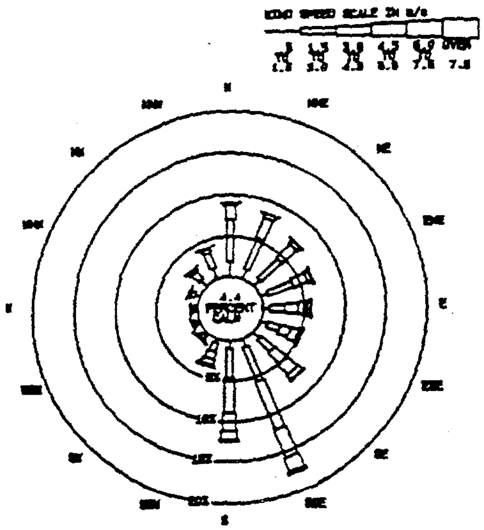
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
X2 Camp Wind Data-June/July/August/September 1991



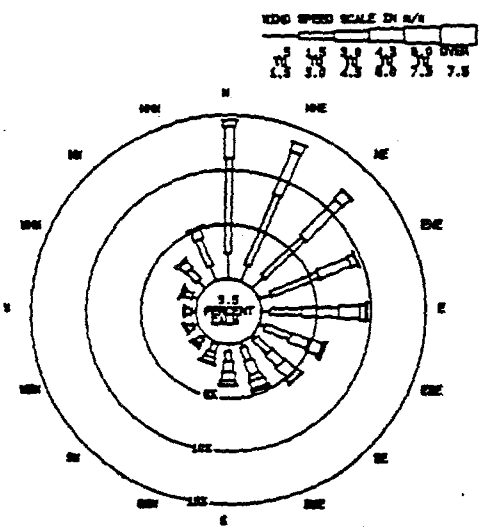
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
X2 Camp Wind Data-October/November/December 1990/91

Figure 6.5.3

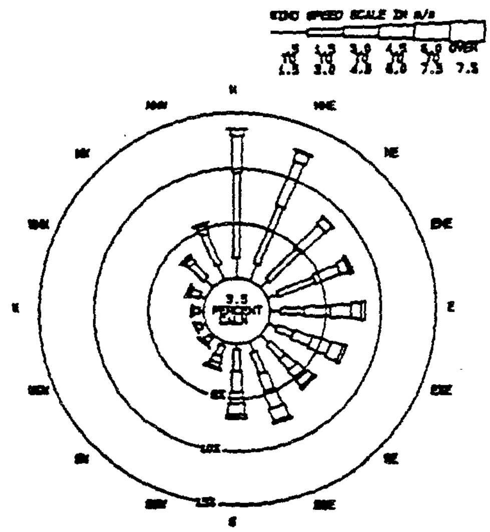
Monthly Windroses
North East Meteorological Station
February to May 1991



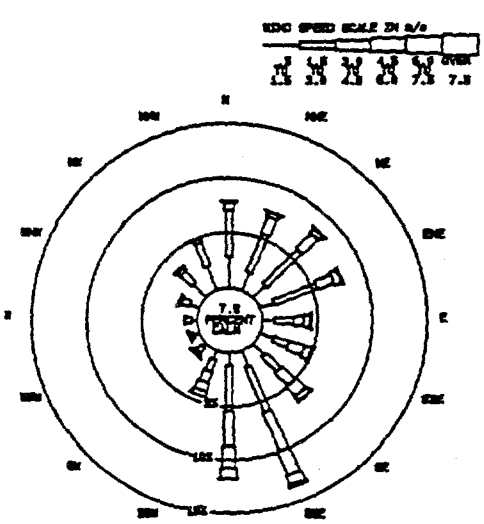
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
North East Meteorological Station Feb to May 1991



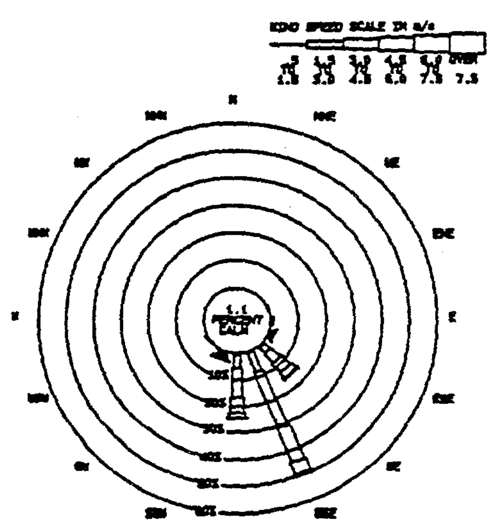
DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
North East Meteorological Station Feb 1991



DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
North East Meteorological Station Mar 1991



DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
North East Meteorological Station Apr 1991



DISTRIBUTION OF WINDS
FREQUENCY OF OCCURRENCE IN PERCENT
North East Meteorological Station May 1991

Figure 6.5.

Station (which is on higher ground, limited data presented) shows that the high ground to the north and east of the proposed power station (close to X2-Camp) has a very significant effect on the winds that would transport and disperse emissions. At the lower site, winds from the north and east are essentially blocked by the terrain. The perspective diagram showing the local terrain illustrates the broad features of the land-form. The terrain forms a funnel that steers the wind into the northwesterly and southeasterly directions that are shown on the wind roses in **Figures 6.5.3.**

Temperature
Hourly data from the X2-Camp meteorological station have been used for the dispersion modelling studies. However, to describe climatic features of the area such as temperature and other parameters, it is more useful to review the longer record of data available from the East Olkaria Power Station. Plots of monthly average maximum and minimum temperatures for 1985 to 1988 are shown in **Figure 6.5.5.** It can be seen that the annual range in average monthly maximum temperatures is from 21 to 29 C. For minimum temperatures the range is even less, from 11 to 15 C. The warmest period of the year is generally February and the coolest June. A secondary warm period occurs in September, October and December, with a slight decrease in monthly average maximum temperature in November.

Humidity
Monthly average 9 am and 3 pm humidity observations are presented in **Figure 6.5.6.** As expected these show higher humidities at 9 am than at 3 pm. Lower monthly average values of humidity are close to 30 per cent and high values are marginally above 90 per cent.

Rainfall
Rainfall data are presented in **Figure 6.5.7.** These data have been collected from three data bases: Naivasha Water Supply Department (24 years from 1965-88), Naivasha District Office (79 years 1910-88) and Kongoni Ranch (21 years 1968-88). Annual rainfall received by these three stations is similar: long-term annual averages have been 697 mm for the Naivasha Water Supply Department site, 625 mm for the Naivasha District Office and 673 mm for Kongoni Ranch. For all sites the wettest month is April followed by May and the driest month is July for the Naivasha Water Supply Department, January for the District Office and August for Kongoni Ranch.

Evaporation
Evaporation data for Naivasha Township (29 years 1959-87) and Kongoni Ranch (Office) (31 years 1957-87) are presented in **Figure 6.5.8.** Annual average evaporation for Naivasha Township and Kongoni Farm was 1912 and 1763 mm, respectively. Annually, evaporation exceeds rainfall by more than a factor of two. This, combined with the very porous nature of the soils, accounts for the arid nature of the area. As expected the maximum evaporation for both sites occurs during the warmer periods, namely February and March and October and November.

6.5.2 Meteorological Data File for Modelling and Description of Dispersion Conditions

For dispersion modelling an hourly meteorological data file has been developed from the Lambrecht wind recorder data and the 10-minute data collected at X2-Camp. It also includes some temperature data from the North East Station for the initial period (1 November 1990 to 2 February 1991) before temperature recording equipment was included at the X2-Camp.

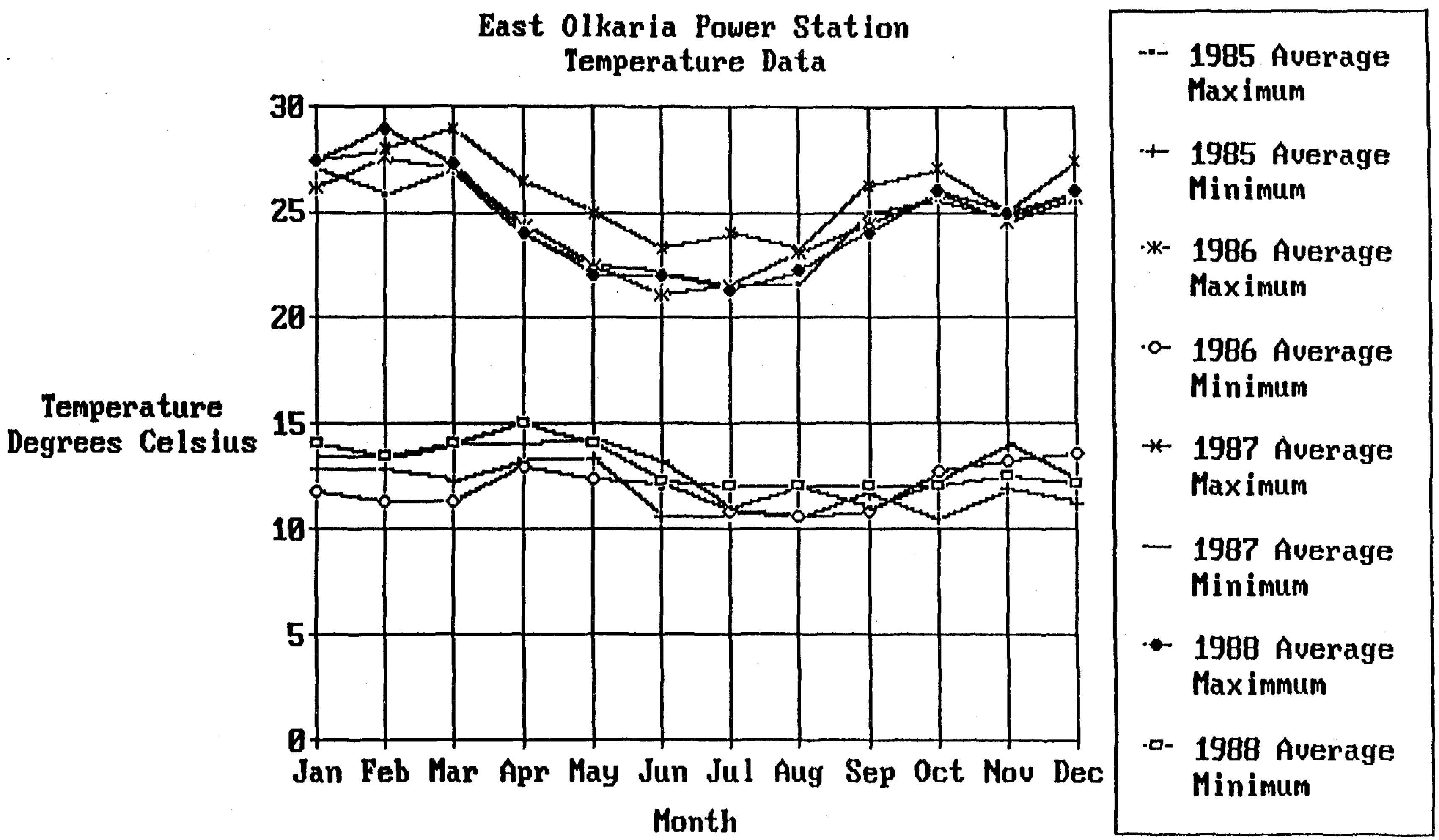
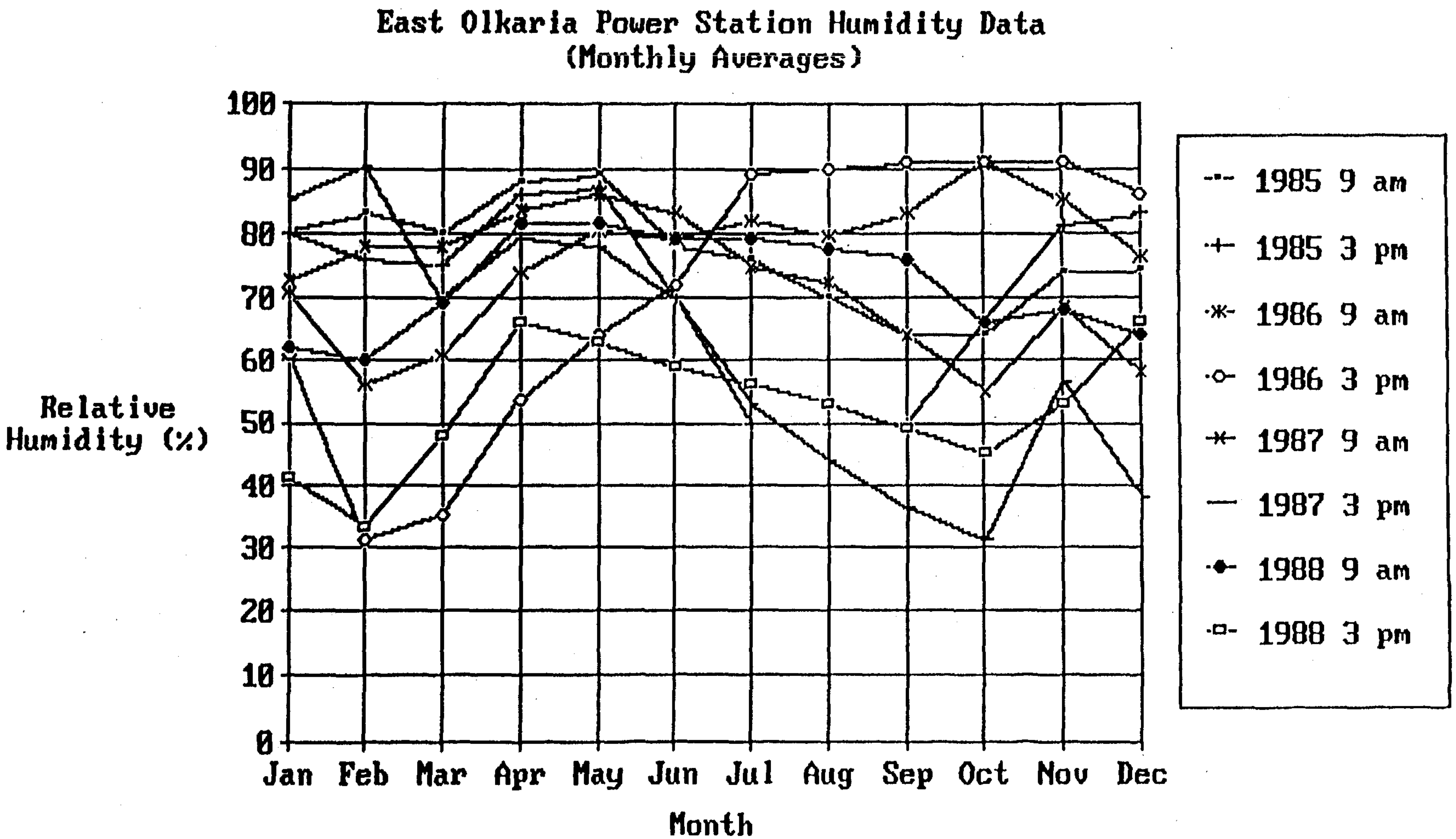

East Olkaria Power Station
Temperature Data
Temperature
Degrees Celsius
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1985 Average Maximum
1985 Average Minimum
1986 Average Maximum
1986 Average Minimum
1987 Average Maximum
1987 Average Minimum
1988 Average Maximmum
1988 Average Minimum

Figure 6.5.5



East Olkaria Power Station Humidity Data
(Monthly Averages)
Relative Humidity (%)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1985 9 am
1985 3 pm
1986 9 am
1986 3 pm
1987 9 am
1987 3 pm
1988 9 am
1988 3 pm

Figure 6.5.6

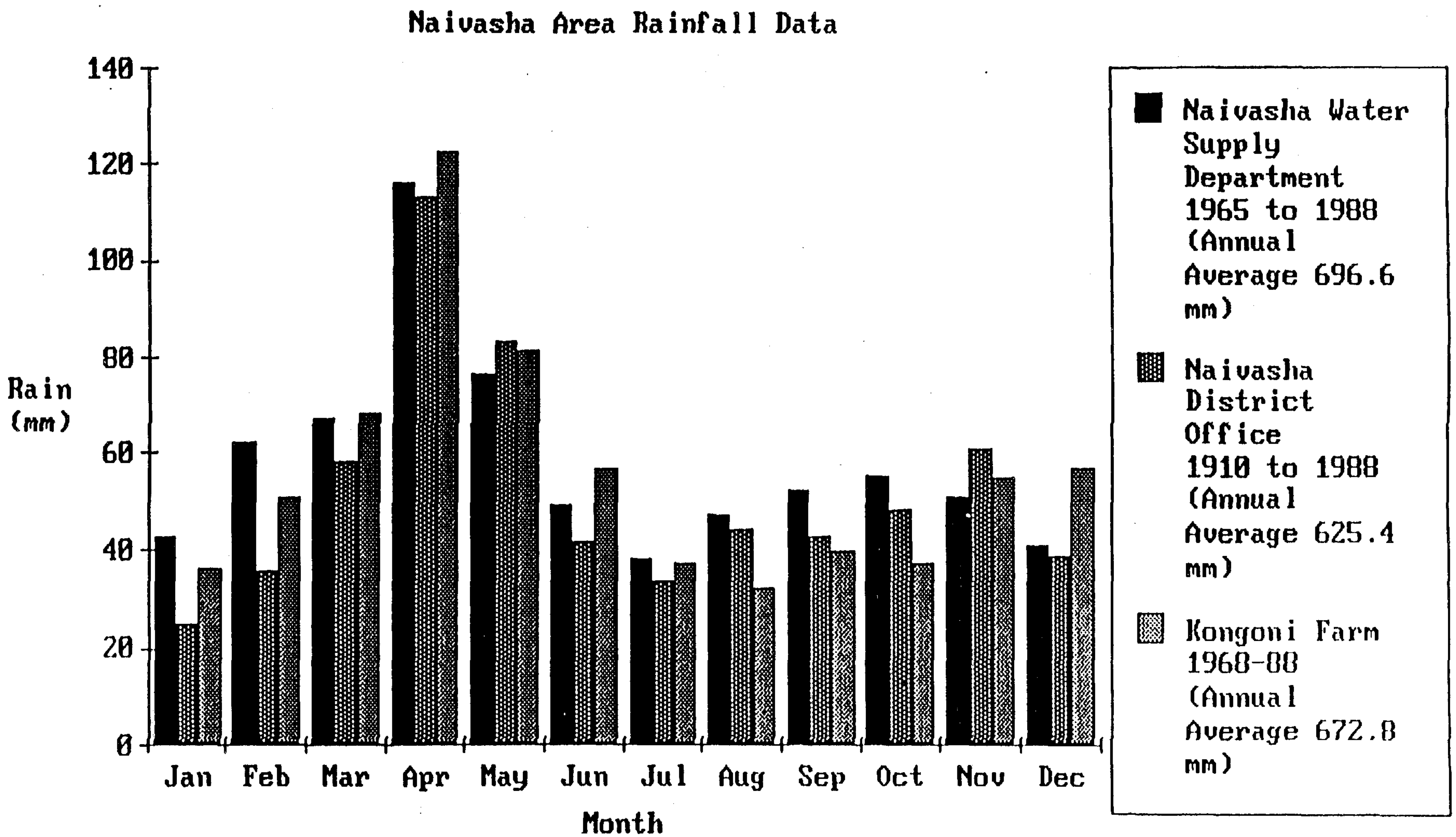
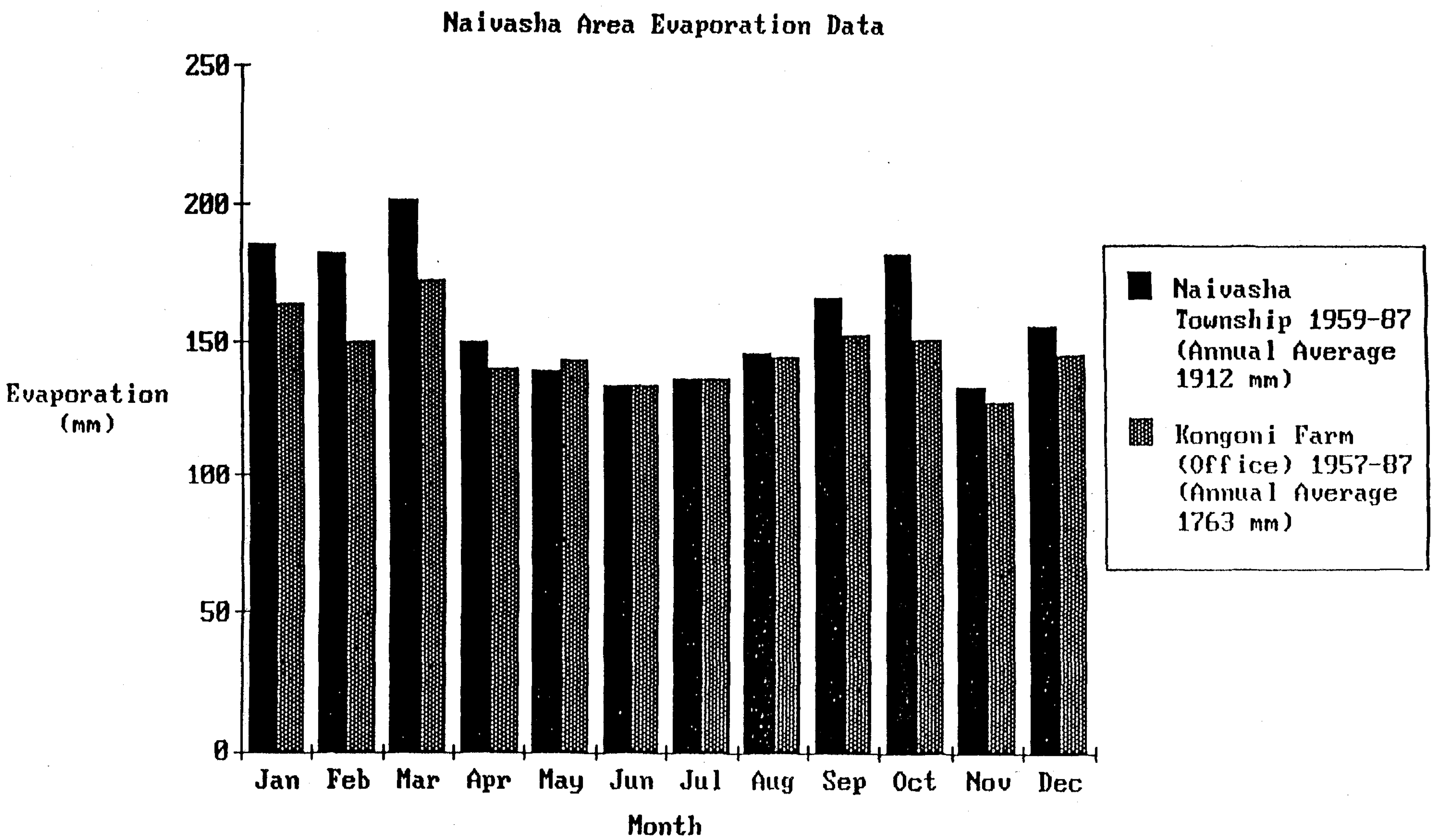

Naivasha Area Rainfall Data
140
120
100
80
60
40
20
0
Rain (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Naivasha Water Supply Department 1965 to 1988 (Annual Average 696.6 mm)
Naivasha District Office 1910 to 1988 (Annual Average 625.4 mm)
Kongoni Farm 1968-88 (Annual Average 672.8 mm)

Figure 6.5.7



Naivasha Area Evaporation Data
250
200
150
100
50
0
Evaporation
(mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Naivasha
Township 1959-87
(Annual Average
1912 mm)
Kongoni Farm
(Office) 1957-87
(Annual Average
1763 mm)

Figure 6.5.8

It was decided to use data from X2-Camp rather than the North East Station because the power station site lies in the base of the valley (see Figures 6.5.1 and 6.5.2). Plume buoyancy will of course take the plume to higher levels where the wind patterns that apply at the North East Station will begin to have some influence, but it was judged that the X2-Camp data would better represent conditions experienced by the dispersing plume. Further information on estimated plume rise from the proposed and existing power station is presented in impact assessment section (Section 7).

As discussed in Section 6.5.1, the dispersion modelling file requires information on wind speed, wind direction, temperature, atmospheric stability and mixed-layer height. Wind speed and direction data have been taken either directly from the monitored data after averaging, or for the period when Lambrecht wind recorder data was used (November 1990, December 1991 and five per cent of February 1991) hourly average wind speed and wind direction have been read from the wind recorder charts. The standard deviation of wind direction (sigma-theta) has been determined using the procedure described in Slade (1968).

The remainder of the wind speed and wind direction data have been taken from the Unidata data logger. The hourly average wind speed has been taken to be the arithmetic average of the 10-minute averages recorded by the data logger and the hourly average wind direction has been taken to be the vector average of the 10-minute average wind vectors. The estimate of sigma-theta has been obtained from the recorded wind direction data.

Temperature data for the initial period have been estimated from monthly average data collected at the East Olkaria power station. The hourly temperatures have been estimated by fitting a sinusoidal function that gives a maximum daily temperature at 3 pm and oscillates about the mean monthly temperature with an amplitude determined by the mean monthly maximum and minimum temperatures. For the remainder of the data set the hourly temperatures have been the arithmetic averages of the 10-minute data.

Atmospheric stability has been determined using the scheme outlined by Mitchell (1982) in which sigma-theta data are used to determine the prevailing Pasquill-Gifford stability class.

Mixed-layer height is a measure of the depth (or height) of the layer of turbulent (well-mixed) air close to the ground. The depth can vary from zero to several thousand metres above ground-level. In dispersion models, this information is used to calculate the volume of air in which emissions will ultimately be mixed. The top of the mixed-layer is capped by an inversion, which may be thought of as a lid through which the pollution cannot pass unless the plume is sufficiently buoyant to penetrate the inversion. If the plume rise takes the plume above the mixed-layer then the plume will remain isolated from the ground. This may be the case at night, or in the early morning. If the plume is emitted below the top of mixed-layer, then it will be trapped within the mixed-layer. In many cases the precise value of the mixed-layer has only a marginal influence on the predicted ground-level concentration, but it is important that the meteorological data file contains a representative range of mixed-layer heights likely to be encountered in the course of a year.

Information on mixed-layer heights can be obtained using balloon-borne temperature and humidity sensors, or by using remote sensing instruments. For dispersion modelling, estimates are required for each hour of the day. Both balloon-borne sensors and remote sensing techniques are expensive and most dispersion modelling studies use the alternative approach of providing estimates using theoretical methods with some field observations. For the present study the latter method has been used.

Typically the mixed-layer height will be least at night, usually in the pre-dawn period. Following sunrise, the ground will be warmed and convection will cause the air near the ground to become well-mixed. The maximum height of the mixed-layer will occur in the early afternoon and may be 1000 m or more above ground level. On days when the wind is strong, the mixed-layer will be determined largely by mechanical turbulence, which is generated by the wind blowing over the rough terrain. On days when there are thunderstorms mixing of the air caused by the rain (and associated processes causing the rain) will give rise to large values of mixed-layer.

For the present study, where the emission points are only 20 m or so above ground-level and plume rise is small (see **Section 7.4**), it is of little practical importance whether the maximum mixed-layer depth is 500 m or 2000 m and the use of theoretical methods to estimate mixed-layer heights is justified, provided a wide range of mixed-layer heights is used in the data file. This will ensure that model predictions do in fact include days where the mixing-height could determine the maximum value of ground-level concentration.

The approach used has been to estimate mixed-layer height using theoretical procedures developed by boundary-layer meteorologists over a number of years. For the day (one hour after sunrise to one hour before sunset), these have been based on radiosonde data collected by the Meteorological Department in Nairobi. These data have been used to provide an indication of the maximum daily mixed-layer heights that are to be expected in the Rift Valley. The procedure adopted is that outlined by **Powell (1976)**. A quasi-sinusoidal function, with its minimum value at sunrise and a maximum value 10 hours after sunrise (approximately 4 pm), is used to represent the day time variation in mixed-layer height. The equation for the mixed-layer height (h) can written as follows:

$$h = h_{mech} + (h_{max} - h_{mech}) Sin[\frac{\pi(t-t_{sr})}{20}] \qquad t_{sr} < t < t_{ss} \tag{1}$$

where,...

h_{mech} = *mechanical mixing height,*
h_{max} = *maximum mixed-layer height from Nairobi radiosonde data,*
t = *time,*
t_{sr} = *time of sunrise, and*
t_{ss} = *time of sunset.*

The mechanical mixed-layer height (h_m) is calculated using an approach described by **Venkatram (1980)**, which is summarised by the following equation as follows:

$$h_m = 2.4x10^3 u_*^{\frac{3}{2}} \tag{2}$$

where, ...

u_* = *the friction velocity.*

The value for u_* required in Equation 2 was obtained by first estimating the Monin-Obukov length (L) using the Pasquill-Gifford stability class, the roughness length (0.3 m) and the observations. For the present study the latter method has been used.

Typically the mixed-layer height will be least at night, usually in the pre-dawn period. Following sunrise, the ground will be warmed and convection will cause the air near the ground to become well-mixed. The maximum height of the mixed-layer will occur in the early afternoon and may be 1000 m or more above ground level. On days when the wind is strong, the mixed-layer will be determined largely by mechanical turbulence, which is generated by the wind blowing over the rough terrain. On days when there are thunderstorms mixing of the air caused by the rain (and associated processes causing the rain) will give rise to large values of mixed-layer.

For the present study, where the emission points are only 20 m or so above ground-level and plume rise is small (see Section 7.4), it is of little practical importance whether the maximum mixed-layer depth is 500 m or 2000 m and the use of theoretical methods to estimate mixed-layer heights is justified, provided a wide range of mixed-layer heights is used in the data file. This will ensure that model predictions do in fact include days where the mixing-height could determine the maximum value of ground-level concentration.

The approach used has been to estimate mixed-layer height using theoretical procedures developed by boundary-layer meteorologists over a number of years. For the day (one hour after sunrise to one hour before sunset), these have been based on radiosonde data collected by the Meteorological Department in Nairobi. These data have been used to provide an indication of the maximum daily mixed-layer heights that are to be expected in the Rift Valley. The procedure adopted is that outlined by Powell (1976). A quasi-sinusoidal function, with its minimum value at sunrise and a maximum value 10 hours after sunrise (approximately 4 pm), is used to represent the day time variation in mixed-layer height. The equation for the mixed-layer height (h) can written as follows:

$$h = h_{mech} + (h_{max} - h_{mech}) Sin[\frac{\pi(t-t_{sr})}{20}] \qquad t_{sr} < t < t_{ss} \qquad (1)$$

where,...

h_{mech} = *mechanical mixing height,*
h_{max} = *maximum mixed-layer height from Nairobi radiosonde data,*
t = *time,*
t_{sr} = *time of sunrise, and*
t_{ss} = *time of sunset.*

The mechanical mixed-layer height (h_m) is calculated using an approach described by Venkatram (1980), which is summarised by the following equation as follows:

$$h_m = 2.4x10^3 u_*^{\frac{3}{2}} \qquad (2)$$

where, ...

u_* = *the friction velocity.*

The value for u_* required in Equation 2 was obtained by first estimating the Monin-Obukov length (L) using the Pasquill-Gifford stability class, the roughness length (0.3 m) and the Golder nomogram and then using the Dyer-Hicks profile functions of z/L.

These two equations indicate how the hourly values of the approximate mixed-layer height were obtained for use in the model.

6.6 AIR QUALITY

This section considers air quality issues. It identifies the matters which are important in assessing the air quality impacts from the proposed power station, discusses how the impacts will be assessed, reviews air quality criteria for assessment and presents the results of some air quality monitoring.

6.6.1 Air Quality Issues

The local setting and a description of the project are presented in **Sections 2.0 and 5.0**, respectively. The predominant land uses in the area are conservation (Hell's Gate National Park), grazing and flower cultivation. Some scattered residential developments (worker housing, private residences and tourist accommodation) are located nearby, mainly to the north and to the east of the proposed power station site (see **Figure 6.5.1**).

The main gaseous emissions from the power station are carbon dioxide, hydrogen sulphide, hydrogen, nitrogen and methane. Of these, hydrogen sulphide is the only emission likely to have significant local environmental effects. Carbon dioxide and methane are greenhouse gases and may have some global impact, but these will be dealt with separately.

6.6.2 Review of Hydrogen Sulphide Properties

This section is a review of the properties of hydrogen sulphide and the air quality criteria that have been formulated by regulatory bodies in other countries to maintain acceptable environmental quality. Criteria which are appropriate for local conditions at Olkaria are discussed.

At present, Kenyan authorities in common with authorities in many other countries, have not formulated ambient air quality standards. However, for the present study it is necessary to establish criteria by which the effects of the project can be assessed. As discussed earlier the only atmospheric emission with the potential to cause local pollution, is hydrogen sulphide.

Occurrence of Hydrogen Sulphide

Hydrogen sulphide (H_2S) is a noxious and potentially poisonous gas, with the odour of rotten eggs. It occurs naturally, and approximately 90 per cent of global emissions are estimated to be of natural origin (**WHO 1987**). It has long been recognised as a potential health threat to man both from natural and man-made sources and there are over 150 years of scientific literature describing its properties and toxicity (see review by the **Subcommittee on Hydrogen Sulfide, 1979**). However, it is not a widespread urban pollutant and is generally localised near emission sources such as sewage treatment plants, petroleum refineries and kraft paper mills.

Typical concentrations vary widely in different parts of the world, for example, over a 2.5

year period in northwest London, concentrations were generally found to be less than 0.0002 ppm (0.3 $\mu g/m^3$). In and around the city of Rotorua, New Zealand there is usually sufficient hydrogen sulphide to cause detectable odours and during continuous monitoring hydrogen sulphide concentrations of 0.05 ppm (80 $\mu g/m^3$) were exceeded for more than 55 per cent of the time in winter (WHO, 1987).

Properties

Hydrogen sulphide is colourless, flammable, denser[3] than air and liquefies at -60 °C. It is soluble in both polar and non-polar solvents and is rapidly oxidised in air and in solution. It is corrosive to many metals and may discolour paint by its reaction with the metals present in the pigments. Because of its density when it is concentrated, it will have a negative buoyancy and sink to the lowest point. In geothermal projects it is usually associated with high concentrations of carbon dioxide which is also denser than air. Thus a slow leak of the non-condensable fraction of cooled geothermal gas emitted into a sheltered environment, can allow a build-up of dangerous concentrations of hydrogen sulphide in low-lying or sheltered and enclosed areas. Such areas are unlikely to be naturally occurring topographical features such as gullies or valleys, but could be the concreted cellars that are part of the well-heads, or sumps within the power station.

The controlled discharge of non-condensable gases from the power station may contain initially up to approximately 4.9 per cent hydrogen sulphide and 96 per cent carbon dioxide (**Ewbank Preece Limited, 1989** (Page B/16)). This mixture is initially denser than air, but it is mixed very rapidly with the ambient air. For practical purposes, the hydrogen sulphide emitted from the gas ejectors will not preferentially settle out from the plume any more than the oxygen, which comprises approximately 20 per cent of the ambient air, will settle out from the less dense nitrogen, which forms approximately 78 per cent of the ambient air. The only time when this is likely to be a potential safety hazard, is in enclosed areas.

There is considerable variation in the response of the human nose to odour. A range of odour thresholds (where 50 per cent of the population can detect the presence of the odour) have been reported for hydrogen sulphide (0.76-3.21 $\mu g/m^3$) 0.00047-0.002 ppm (**Warren Springs Laboratory, 1980**). Other studies give different values. The most recently published study (**Nagy, 1991**) presents detailed information on the percentage of people responding to the odour of hydrogen sulphide at different concentrations. Nagy's paper is particularly useful because it provides information on the response of the 18 people in the two odour panels as the concentration varies. From the data it is possible to determine the percentage of people who would be expected to detect the odour at a given concentration. One person out of the 18 (approximately 5 per cent) reported an odour at 0.0013 ppm[4] (2 $\mu g/m^3$), nine of the 18 (50 per cent) detected the odour at 0.0046 ppm (7 $\mu g/m^3$) and 17 of the 18 (approximately 95 per cent) reported the odour at 0.023 ppm

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[3] If the specific gravity of air is taken as 1.00 then the specific gravity of H_2S gas is 1.189.

[4] Note: in converting from $\mu g/m^3$ it has been assumed that the pressure is 760 mm of Hg and the temperature is 0 °C. At Olkaria the pressure is typically 80 per cent of seal-level pressure. While there is no information on the way in which humans respond to odour as pressure changes, it is known that odour is sensed by molecules of odourant stimulating odour-sensing cells in the nose, consequently it is likely that the intensity of an odour will depend on the number of molecules of odourant per unit volume. Thus $\mu g/m^3$ would be a more fundamental variable when discussing odour. However most people are more familiar with the units ppm so, in the impact assessment section, the adjustment has been made and concentration has been expressed as ppm at 80 per cent atmospheric pressure. This adjustment has also been made for the dispersion model predictions.

(35 $\mu g/m^3$).

Nagy also provides information about the number of people describing the odour at a complaint level as the concentration varies. Approximately five percent consider the odour at a complaint level at 0.0017 ppm (2 $\mu g/m^3$), 50 per cent at 0.016 ppm (20 $\mu g/m^3$) and 95 per cent at 0.247 ppm (395 $\mu g/m^3$).

At the above concentrations, no harmful effects to human health are known. At higher concentrations, where it is extremely toxic, it produces complete fatigue of the olfactory nerve and its presence cannot be detected. Its odour therefore serves as an important warning of its presence at safe concentrations.

In the above discussion, it should be remembered that the odour panel studies select panellists who pass a test which ensures a certain minimum sensitivity to odours and they are not permitted to eat, drink flavoured beverage or smoke for 30 minutes prior to the test, nor are they permitted to use scented cosmetics for at least one hour before the test. In addition, the test room is free of interfering odours. Given test conditions and the fact that people regularly exposed to hydrogen sulphide have a decreased sensitivity to its odour, it is considered that using these criteria for assessing the response of the exposed population at Olkaria may significantly overstate the incidence of odour. The criteria would be more appropriate for short-term visitors, but they would still be subject to interfering odours.

Effects on Humans and Other Animal Life

The toxic effects of hydrogen sulphide vary according to the dosage and have been classified in the scientific literature into three categories, namely, acute, sub-acute and chronic. In view of some lack of agreement in the literature about these different nomenclatures, the Subcommittee on Hydrogen Sulfide has determined some clarifying definitions of these terms.

Acute intoxication refers to the effects of a single exposure to a massive dose of hydrogen sulphide of the order of 1000 ppm (1.61 g/m^3). There is evidence that at this concentration hydrogen sulphide exerts an effect on the whole nervous system by inhibiting the enzyme cytochrome oxidase, which is involved in the aerobic metabolic pathway. The symptoms are an initial stimulation of respiration resulting in very rapid breathing and subsequent depletion of carbon dioxide in the blood. This leads to respiratory inactivity that may spontaneously reverse if the depletion has not gone too far. However, if breathing does not spontaneously recommence and artificial respiration is not given, death from suffocation occurs. At concentrations above 1000 ppm (1.61 g/m^3), hydrogen sulphide may have a direct paralysing effect on the nervous system. In this case no stimulation of breathing occurs and there is immediate respiratory failure. However the heart does not stop beating immediately and artificial respiration can be given until the levels of hydrogen sulphide in the bloodstream drop sufficiently to allow breathing to resume. Hydrogen sulphide is very rapidly oxidised in the blood and is not considered a cumulative poison.

Sub-acute intoxication refers to the effects of continuous exposure to mid-level concentrations of hydrogen sulphide, 100-600 ppm (0.16-0.96 g/m^3). At these concentrations irritation of the mucous membranes of the eye and all of the respiratory tract can occur. While eye irritation is by far the most common symptom of sub-acute poisoning, irritation of the respiratory tract can in some circumstances lead to severe and even fatal complications such as pulmonary oedema.

Chronic intoxication is defined as the effects of intermittent exposure to low or intermediate concentrations 50-100 ppm (80-160 mg/m^3) of hydrogen sulphide. These are characterised by "lingering" largely subjective manifestations of illness. There is no universal agreement in the literature about this category as a clinical entity distinct from repeated episodes of sub-acute intoxication.

The effects of hydrogen sulphide exposure at various concentrations are summarised in **Table 6.6.1** (adapted from "Hydrogen Sulfide", The **Subcommittee on Hydrogen Sulfide, 1979** and including data from **Nagy, 1991**).

The effects of hydrogen sulphide on other animal species have been the subject of laboratory investigation and some insights into the biochemical mechanisms by which the gas exerts its toxic effects have resulted from this work. The toxicity of hydrogen sulphide for several species is summarised in **Table 6.6.2** and compared with the effects on humans (prepared from data published in "Hydrogen Sulfide", **Subcommittee on Hydrogen Sulfide, 1979** and **WHO, 1987**).

The symptoms of hydrogen sulphide poisoning are similar across species and as can be seen from **Table 6.6.2**, the susceptibility of different animal species does not vary greatly.

6.6.3 Effects on Vegetation and Aquatic Animals

The effects of hydrogen sulphide on vegetation are not well documented largely because, in contrast to animals, there appears to be a wide variation in response across species. Sulphide taken up by plants is primarily metabolised to sulphate, or incorporated into plant proteins and as in the case of sulphur dioxide, low concentrations may have a growth-stimulating, or fertilising effect. At higher concentrations, hydrogen sulphide can cause leaf lesions, defoliation and reduced growth, with young plants being the most susceptible.

A study by **Thompson and Kats (1978)** who were investigating the effects of continuous hydrogen sulphide fumigation on crops and forest plants, showed that concentrations in the range 0.3-3 ppm (0.48-4.82 mg/m^3) caused injury that was correlated with dosage. Rapidly growing species such as grapes, alfalfa and lettuce were more damaged than the more slowly growing buckeye and ponderosa pine. Sugar beets were more resistant to hydrogen sulphide than the other fast growing crops. Lower doses (0.03-0.1 ppm (0.05-0.16 mg/m^3)) caused stimulation of growth to some of the rapidly growing species that appeared to be related to other environmental factors such as day length, humidity or temperature. The biochemical basis for hydrogen sulphide toxicity in plants is not well understood.

Potential effects on flora, even low-level effects, are particularly important for the Olkaria development because of the proximity of commercially important flower farms, which are located approximately 1.2 km to the northwest of the proposed power station site. For this reason KPC have initiated a series of flower growing trials at two sites; one 0.6 km and the 1.2 km to the northwest of the existing power station's cooling towers. These flower trials have been set up to determine the sensitivity of the commercially most important flowers grown nearby. This issue is discussed further in **Section 7.1.3**

TABLE 6.6.1- EFFECTS OF HYDROGEN SULPHIDE EXPOSURE AT VARIOUS CONCENTRATIONS

Effect	ppm	mg/m^3
Lowest reported odour threshold	0.00047	0.00066
5% detection limit 50% detection limit 95% detection limit	0.0013 0.0046 0.0230	0.002 0.007 0.035
Offensive odour	0.003-0.005	0.004-0.007
Threshold limit value [a]	10	14
Threshold of serious eye injury	50-100	20-140
Olfactory paralysis	150-250	210-350
Pulmonary oedema, threat to life	300-500	420-700
Strong nervous system stimulation	500-1000	700-1400
Immediate collapse with respiratory failure	1000-2000	1400-2800

[a] Permissible concentrations in the workplace assuming 8-hour shifts, 5-day weeks.

TABLE 6.6.2- CONCENTRATIONS OF HYDROGEN SULPHIDE RESULTING IN SUBACUTE OR ACUTE INTOXICATION SYNDROMES IN VARIOUS SPECIES

Species	Subacute syndrome mg/m^3 (ppm)	Acute syndrome mg/m^3 (ppm)
Canaries	80- 321 (50-200)	$\geq$ 321 (200)
White rats	80- 884 (50-550)	$\geq$ 804 (500)
Dogs	80-1045 (50-650)	$\geq$ 964 (600)
Guinea pigs	161-1205 (100-750)	$\geq$ 1205 (750)
Goats	160-1446 (100-900)	$\geq$ 1446 (900)
Humans	161- 964 (100-600)	964-1607 (600-1000)[a]

[a] Immediately fatal

The effects of hydrogen sulphide on aquatic animals has been evaluated. In his report on the environmental impacts of a geothermal power plant in New Zealand, **Axtmann (1971)** discussed the effect of dissolved hydrogen sulphide on the eggs and fry of rainbow trout inhabiting a river used to receive waste water from a geothermal power station. He concluded that only concentrations in the water of less than 0.006 ppm were safe. Experiments with algae indicate that differences in metabolism may be the cause of different susceptibilities. Since the possibility of hydrogen sulphide contamination of significant bodies of water is not a credible event for the Olkaria geothermal field, this matter is not discussed further.

6.6.4 Effects on Materials

Hydrogen sulphide is corrosive to metals including copper, silver and even gold. It also reacts with lead-based paints to produce discolouration. Apart from aesthetic considerations, this corrosion of metals can cause problems with malfunction in electronic equipment when connecting wires are affected.

6.6.5 Air Quality Criteria for Hydrogen Sulphide

The setting of air quality standards is based on considerations of health and amenity. Clearly, concentrations must be set that protect against adverse impacts on human well-being. However, in the case of odorous compounds it may be necessary to set limits lower than those at which no effect on human health is experienced. In addition, the effects of pollutants on flora, fauna and materials is a matter for consideration. For hydrogen sulphide all of these factors should be taken into account and ideally criteria that protect against all adverse impacts adopted.

Threshold Limit Values
A distinction needs to be made between air quality standards for the ambient air and those for the workplace, the latter being referred to as threshold limit values (TLV). TLVs are those doses that cause no apparent harm to workers exposed for eight hours a day, five days a week. In the United States the TLV for hydrogen sulphide is set at 10 ppm (15 mg/m^3).

Ambient Air Quality
Several countries have adopted both long and short-term hydrogen sulphide standards for ambient air quality criteria (see **Table 6.6.3**, prepared from data published by the **Subcommittee on Hydrogen Sulfide (1979)** and from information published by **WHO (1987)**). The US EPA has not yet formulated a standard for hydrogen sulphide although several states in the United States have developed independent regional standards. Selected examples that span the range of criteria are also presented in **Table 6.6.3.**

The short-term concentrations are generally higher than those for long-term exposure and it is useful to note that short-term exposure to a given concentration of pollutant will in general have less effect than a long-term exposure to the same concentration. Therefore the air quality standards for long-term exposure are usually lower than those for short-term exposure.

The most stringent air quality goal presented in **Table 6.6.3** is based on considerations of odour and is applied by the Victorian Environment Protection Authority (VEPA) (Australia).

VEPA sets a goal of 0.0001 ppm (0.14 $\mu g/m^3$) for the maximum 3-minute average ground-level concentration of hydrogen sulphide. This value is approximately 20 per cent of the odour threshold of 0.00047 ppm (0.76 $\mu g/m^3$), which is the lowest odour threshold reported in the literature. The value is referred to in Victoria, as the **design ground-level concentration** and it is used by VEPA as the objective, which must not be exceeded when determining stack heights. The reason for selecting an air quality criteria that is apparently less than the odour threshold and well below the concentration at which any health effects have been reported, is that the concentration is expressed as a 3-minute average. The human nose responds to odour exposures of the order of seconds. During any 3-minute period, concentrations at ground-level close to a stack emitting a pollutant may fluctuate by as much as ten times the average value, so that if the 3-minute average air quality goal is set at the odour threshold, this value will be exceeded some of the time. For this reason a level of one-fifth to one-tenth of the odour threshold is usually set as the maximum 3-minute average concentration to protect against such impacts. In practical terms this would result in little or no detectable odour of hydrogen sulphide at ground-level. This is clearly not a necessary goal for all areas, in particular areas such as Olkaria, or for example Rotorua, where natural hydrogen sulphide emissions occur.

The implications of applying the VEPA air quality criteria to the Olkaria project are that human health and amenity would be protected. In addition, in view of the similarity of the response of other animal species to hydrogen sulphide, no adverse impacts are likely to be experienced by the local fauna. For continuous exposure, levels of hydrogen sulphide that are 300 times the odour threshold may be damaging to crops. Thus the adoption of the VEPA criteria should protect against crop damage. Similarly it is unlikely that at these levels there would be any significant deterioration of materials, particularly metals, in the vicinity of the plant. However, in practical terms this is an unrealistic goal as the stack concentration of hydrogen sulphide in a 64 MWe power station will be of the order of 4.5 g/m^3. To achieve the VEPA ground-level concentrations a dilution of over 32 million would be needed. The VEPA goal is not considered appropriate for the present environment.

The approach adopted is to select criteria that protect human health, local crops and fauna, but will not protect all areas against an odour impact. The WHO (1987) provide useful guidance in this respect (for non-occupational exposure), where it states the following:

1. "The lowest-adverse health effect of hydrogen sulphide is 15 mg/m^3 (9.9 ppm), when eye irritation is caused. In view of the steep rise in dose-effect curve implied by reports of serious eye damage at 70 mg/m^3 (46 ppm), a relatively high (safety) protection factor of 100 is recommended, leading to a guideline value of 0.10 ppm (0.15 mg/m^3) with an averaging time of 24-hours."

2. "... In order to avoid substantial complaints about odour annoyance among the exposed population, hydrogen sulphide concentrations should not be allowed to exceed 0.0046 ppm (7 $\mu g/m^3$), with a 30 minute averaging period......".

The information presented by **Nagy (1991)** appears consistent with (2) and allows the incidence of odour events to be estimated. This will form the basis of the impact assessment presented in **Section 7.**

6.6.6 Summary and Recommendations for Air Quality Criteria

There are no ambient air quality criteria for hydrogen sulphide currently in force in Kenya. Geothermal wells emit substantial quantities of this gas and it is necessary to set some targets that define environmentally acceptable levels.

As an interim measure it is suggested that the WHO 24-hour guideline should be used to assess impacts beyond the immediate power station boundary. That is 24-hour average concentrations should not be permitted to be above 0.10 ppm (0.15 mg/m^3), beyond the immediate power station boundary.

Provided this level is complied with, then health will be safe-guarded with an appropriate margin of safety (namely a factor of 100). All other suggested criteria in this report are to protect against nuisance impacts and therefore should have some flexibility in their application.

Areas where non-KPC workers are located (for example Oserian Development Company work force) should be assessed on the 60-minute Californian Standard of 0.03 ppm (0.042 mg/m^3) and residential areas should be considered affected if 30-minute concentrations are above 0.0046 ppm (7 μg/m^3). It is proposed, that in this regard, residential areas housing KPC workers be treated in the same way as other residential areas.

It is also proposed that areas supporting commercially, culturally or scientifically important vegetation should not be permitted to experience exposures above 0.03 ppm (0.042 mg/m^3) long-term average. These criteria are intended to protect all elements of the environment from the adverse effects of hydrogen sulphide and when used with the dispersion modelling study, results will define what level of effect may be expected in particular areas.

The protection of workers within the power station is beyond the scope of an Environmental Assessment, but it is suggested that the United States TLVs for work-place exposure, namely 10 ppm (15 mg/m^3) 8-hour average, be used for this purpose.

TABLE 6.6.3- AMBIENT AIR QUALITY STANDARDS FOR HYDROGEN SULPHIDE

Country/State	Concentration mg/m^3	ppm	Averaging time
California USA	0.042	0.03	60 minutes
New Mexico USA	0.0042	0.003	30 minutes
Texas USA (industrial area)	0.168	0.11	30 minutes
Victoria Australia	0.00014	0.0001	3 minutes
Alberta Canada	0.017 0.014 0.004	0.011 0.009 0.003	30 minutes 60 minutes 24 hours

Bulgaria Czechoslovakia Hungary USSR Yugoslavia Poland (protected)	0.008 0.008	0.005 0.005	30 minutes 24 hours
Finland	0.15 0.05	0.1 0.3	30 minutes 24 hours
Hungary	0.30 0.15	0.20 0.10	30 minutes 24 hours
Israel	0.15 0.045	0.10 0.03	30 minutes 24 hours
Italy	0.10 0.04	0.07 0.03	30 minutes 24 hours
Poland	0.06 0.02	0.04 0.013	30 minutes 24 hours
Romania	0.03 0.01	0.02 0.006	30 minutes 24 hours
Spain	0.01 0.004	0.006 0.00025	30 minutes 24 hours

6.6.7. Existing Air Quality

6.6.7.1 Monitoring Program

Measurements of air quality have been made to determine existing concentrations of hydrogen sulphide in areas close to the existing power station. The approach has been to attempt to determine the highest short-term concentrations that occur from the existing power station. Measurements were made with a Kitagawa Model AP-1 gas detector tube system. This system measures hydrogen sulphide using an aspirating pump to draw 100 ml of air through a specially prepared reagent, which changes colour (is stained) as the hydrogen sulphide in sampled air is drawn through the reagent. The concentration of hydrogen sulphide is proportional to the length of the stained reagent. The gas samples are taken manually and the measured concentrations relate to a 1-minute averaging period. The sensitivity of the measurement device is approximately 0.05 ppm (0.07 mg/m^3).

In most cases the procedure adopted for the study was to wait until ground-level concentrations appeared to be at a maximum as determined by the intensity of hydrogen sulphide odour. The point of likely maximum impact was determined by visual observation of the plume from the gas ejectors on the existing power station and from the cooling tower. In two cases, measurements were made in the steam from Well 709 which was under test at the time and discharging directly to the atmosphere.

Measurements were made over the period 7 May to 27 May 1991 and 18 November to 27 December 1991 . The locations of the measurement sites and are shown on **Figure 6.6.1.** The results are discussed in **Section 6.6.7.2.**

6.6.7.2 Existing Air Quality

Results of the monitoring program are presented in Table 6.6.4, which shows the times, locations, wind speed, wind direction and concentration of each measurement.

The data in Table 6.6.4 relate to 1-minute average concentrations, and while higher concentrations would undoubtedly be measured if more data were to be collected, they are representative of the higher concentrations that occur in the vicinity of the existing power station.

It should be noted that the concentrations measured over a 1-minute interval should not be compared directly with the ambient air quality goals listed in **Table 6.6.3** which refer to longer averaging times. Concentrations over longer averaging periods, such as the 30 minutes, 60 minutes and 24 hour periods will be lower than over 1-minute. Using basic dispersion theory it can be estimated that 30-minute averages would be approximately 50 percent of the 1-minute values, 60-minute averages would be 44 percent and 24-hour averages would be still lower. Site specific factors which determine the distribution of winds prevent any reliable quantitative estimate from being provided for periods of 24 hours or greater. The data show that in the raw gas (and condensing steam) approximately 10 m from a well, the hydrogen sulphide concentrations can be just above safe limits. (See for example the data from Site C where 1-minute average concentrations of 0.15 ppm (0.23 mg/m^3) were measured, compared with the WHO 24-hour guideline value of 0.10 ppm (0.15 mg/m^3). This is not to say that all wells would be the same, and it should also be recognised that subsequent processing of the steam results in a concentration of the non-condensable hydrogen sulphide to levels that would certainly be harmful if not managed properly. Thus it is relevant to note that concentrations of hydrogen sulphide from the power station emissions will often be higher than the concentration of hydrogen sulphide in the raw steam plumes associated with wells under test. In other words concentrations in these steam plumes will not necessarily be the highest concentrations in the area as is evident from the data in **Table 6.6.4**.

The monitoring data indicate that air quality close (within a few hundred metres) to the existing power station complies with the WHO 24-hour guideline values and certainly, beyond the fenced areas, hydrogen sulphide concentrations would be expected to be within the guidelines for the protection of health.

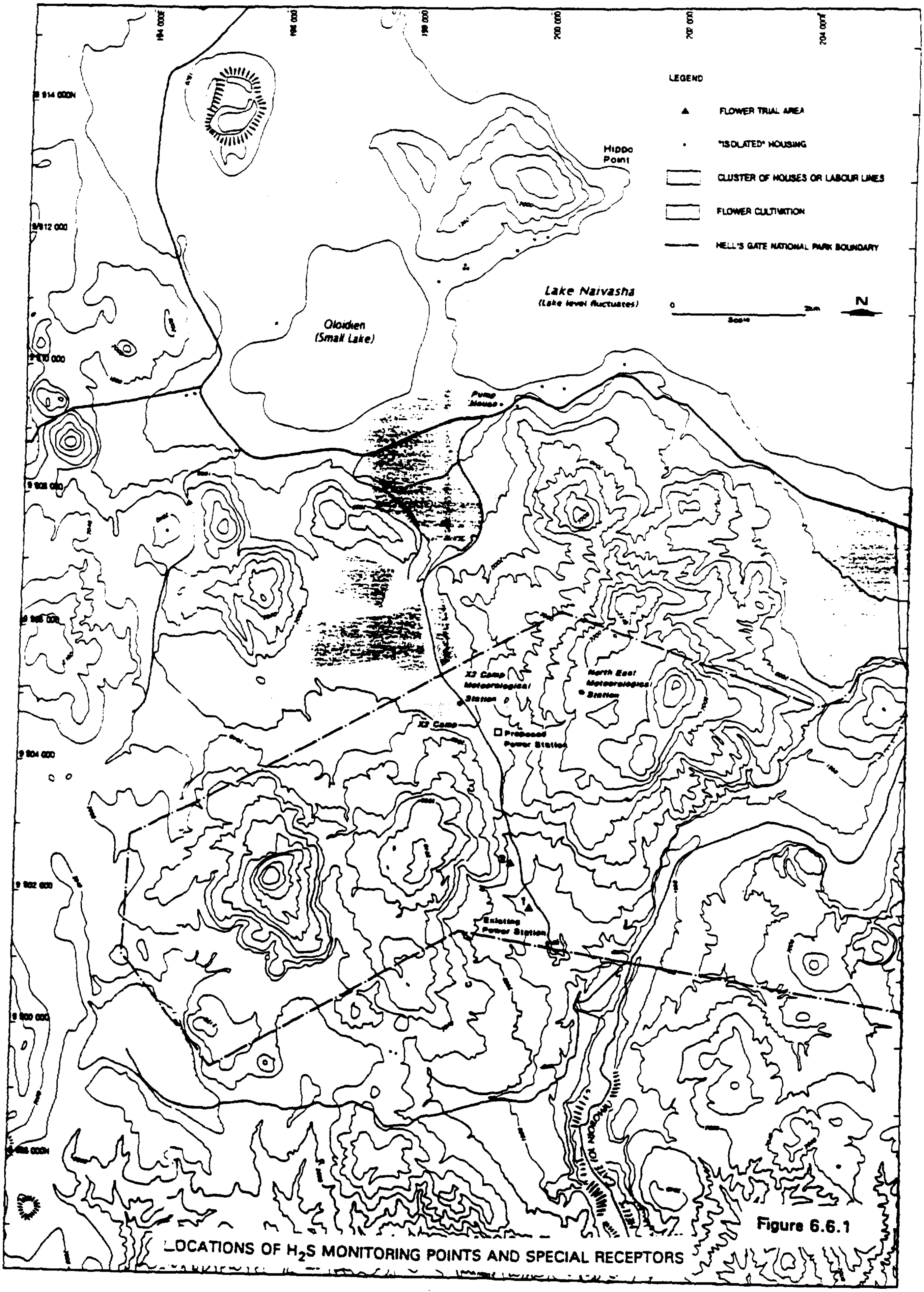


Figure 6.6.1

LOCATIONS OF H_2S MONITORING POINTS AND SPECIAL RECEPTORS

TABLE 6.6.4- RESULTS OF HYDROGEN SULPHIDE MONITORING (1-minute average concentrations)

Date and time	Location	Wind speed (m/s)	Wind direction (degrees)	Concent-ration ppm (mg/m^3)
7-May-1991 12:03 pm	Site A	5.1	178	0.30 (0.46)
8-May-1991 6:30 pm	Site A	2.7	161	0.20 (0.30)
10-May-1991 11:25 am	Site B	5.9	196	0.20 (0.30)
10-May-1991 3:30 pm	Site C (in steam plume, approx. 10 m from Well 709)	7.0	147	0.15 (0.23)
19-May-1991 4:20 pm	Site C (in steam plume, approx. 10 m from Well 709)	3.8	136	0.15 (0.23)
20-May-1991 3:01 pm	Site D	5.3	176	0.60 (0.92)
26-May-1991 11:30 pm	Site D	4.5	155	0.18 (0.27)
26-May-1991 5:15 pm	Site E	7.5	165	0.20 (0.30)
27-May-1991 12:40 pm	Site F	5.1	168	0.05 (0.08)
27-May-1991 1:15 pm	Site D	4.3	179	0.25 (0.38)
27-May-1991 1:18 pm	Site D	3.0	171	0.25 (0.38)

TABLE 6.6.4 (cont)- RESULTS OF HYDROGEN SULPHIDE MONITORING (1-minute average concentrations)

Date and time	Location	Wind speed (m/s)	Wind direction	Concentration ppm (mg/m^3)
18-Nov-1991 1:30 pm	E	3-4	SE	0.22 (0.27)
18-Nov-1991 1:35 pm	H	2-5	ENE	0.45 (0.55)
18-Nov-1991 1:38 am	H	2-5	ENE	0.65 (0.79)
27-Nov-1991 8:36 pm	H	0-3	ENE	0.42 (0.51)
27-Nov-1991 8:41 pm	H	1	ENE	0.15 (0.18)
27-Nov-1991 9:15 am	H	0-3	ENE	0.50 (0.61)
27-Nov-1991 9:38 am	H	0-3	ENE	0.58 (0.70)
27-Nov-1991 10:30 am	H	4	ENE	0.30 (0.36)
28-Nov-1991 12:45 pm	G	3	NE	0.30 (0.36)
2-Dec-1991 4:42 pm	E	3-4	SE	0.20 (0.24)
19-Dec-1991 8:12 am	H	0-2	ENE	0.15 (0.18)
19-Dec-1991 8:26 am	I	0-2	WSW	0.05 (0.06)
19-Dec-1991 8:35 am	H	0-3	ENE	0.05 (0.06)
19-Dec-1991 8:37 am	H	0-3	ENE	0.45 (0.55)
19-Dec-1991 8:42 am	H	0-3	ENE	0.20 (0.24)
24-Dec-1991 8:50 am	G	0-4	NNE	0.35 (0.43)
24-Dec-1991 5:40 pm	D	0-4	SSW	0.45 (0.55)
27-Dec-1991 8:58 am	G	2-3	NNE	1.25 (1.52)
27-Dec-1991 9:04 am	G	2-3	NE	1.00 (1.21)
27-Dec-1991 9:06 am	G	2-3	NE	1.25 (1.52)
27-Dec-1991 9:10 am	G	2-3	NE	0.70 (0.85)

6.6.8 Emissions of Radioactive Gases

The issue addressed in this section is whether radon, which will form a very small fraction of the non-condensable geothermal emissions from the power station, could pose a health risk.

Radon is a radioactive noble gas that occurs in several isotopic forms, only two of which occur in significant concentrations in the general environment. One form, radon-222 is a member of the decay chain of uranium-238 and the other, radon-232 occurs in the decay of thorium-232. Because uranium occurs widely throughout the earth's crust, radon is also present in small quantities in the atmosphere. The average level at the earth's surface is estimated to be 3 Bq/m^3, with a range of 0.1, over the oceans, to 10 Bq/m^3 (WHO 1987). (Note one Becquerel (1 Bq) is the unit of activity of radioactive substances and is equivalent to one radioactive decay per second).

Clarke et al. (1990) present a diagram showing the complete decay chain and the half lives of all the daughter products (decay products) involved. In summary radon gas decays, by losing an alpha particle (two protons and two neutrons), to polonium-218. The half life of the decay is 3.83 days. Further decays take place until the final product lead-206 is reached. Lead-206 is a radioactively stable isotope.

Apart from exposure of workers in uranium mines, most of the current concern with radon is with indoor exposures in poorly ventilated buildings, where radon emanations from mineral-based building materials and from soil and rocks can cause radon levels to reach levels of concern. Because of the mild climatic conditions in the Olkaria area, ventilation of housing is unlikely to allow a build-up of radon in residences.

Radon gas itself does not pose a particularly serious threat to human or animal health because it is breathed in and out and is not retained by the body. However, the decay products (referred to as radon daughters) can lodge within the lung and air pathways and cause adverse health effects. The WHO (1987) suggests that the radon daughter concentration that would be in effective equilibrium with 3 Bq/m^3 of radon gas, will be of the order of 1-1.5 Bq/m^3 equilibrium equivalent radon (EER) concentration. Because of various removal mechanisms for the decay products, equilibrium does not always apply and an equilibrium factor F has to be applied. Values of F reported for residential buildings in different areas are in the range 0.3-0.5.

Models have been developed which relate the radon concentration in the air to the radiation dose that will be received by a particular individual. WHO (1987) sets the following guideline for buildings; (1) remedial action should be considered in buildings where radon daughter concentrations are higher than 400 Bq/m^3 EER annual average and (2) building codes should include sections designed to ensure that radon daughter levels do not exceed 100 Bq/m^3 EER in new buildings.

Clarke et al. (1990) present the results of a field survey of radon-222. Part of the survey included measurements of radon-222:carbon dioxide ratios in fumaroles in the Olkaria geothermal area. The data presented are relative measurements of activity and percentage carbon dioxide expressed as counts per minute for particular values of concentration of carbon dioxide expressed as a percentage of the fumarole gas. Data on the absolute level of activity in Bq/m^3 are not available. They can however be approximately estimated by assuming that the volume of the enamometer (the device which is used to measure the radioactivity) is 250 ml. If this is the case and the efficiency of the counting system is 100 per cent then data reported by Clarke et al. (1990) can be used to provide an indication of the radon-222 levels in the emitted fumarole gas and of the resulting ground-level levels of radon-222 (expressed in Bq/m^3). The data presented in Table 5.1 of **Clarke et al. (1990)** shows that the radon-222 levels in the Olkaria area (including the domes and Hell's Gate area) were in the range 255 to 3000 counts per minute. The level of the maximum (3000) was in fact off the scale of the measuring device so the reading would have been higher than this, by an unknown margin. If it is assumed that the maximum level would have been 5000 cpm and the volume of the enamometer chamber was 250 ml and its efficiency was 100 per cent, then the activity of the fumarole gas would be 3.3×10^5 Bq/m^3. Radon-222 levels were found to be strongly correlated with carbon dioxide concentrations and the carbon dioxide concentration that corresponded to the maximum radon-222 level, was 30.6 percent.

The potential impacts of radon released as a result of the North East Olkaria development will be discussed in **Section 7.4.**

6.7 NOISE

The potential for a noise to annoy depends on the loudness of the noise relative to the existing noise levels. Thus to undertake an impact assessment it is necessary to determine the existing noise environment in the absence of noise emissions from the project. In addition it is necessary to obtain information about the noise emission levels from the project during its various phases. This section describes the studies and presents the results of noise level measurements that have been made. The use of these data in noise impact assessment for impact assessment is presented in **Section 7.5.**

The relative remoteness of the project from non-KPC controlled residential areas ensures that no serious noise impacts are occurring during the present well testing program, although some temporary impacts on the noise environment has occurred at the X2-Camp. These impacts are now declining, but will continue until the well testing phase has been completed. There will also be some noise impacts at X2-Camp from the operating power station, if X2-Camp were to remain in its present location.

6.7.1 Noise Measurement and Background Noise Monitoring Program

Data on background noise levels are important from the point of view of noise impact assessment because it is the difference between the background noise and the project related noise that most closely correlates with the perceived annoyance of a noise. Unfortunately, because of the well testing program it has not been possible to determine pre-project background noise levels. To obtain these data it has been necessary to undertake a noise monitoring study at a remote location not affected by noise emissions under test. The selected monitoring site was on the northern side of Olkaria Hill.

Background noise levels were determined using a Bruel and Kjaer (Type 2214) noise level meter and a microprocessor controlled data logger, which sampled and recorded the noise level at one-second intervals over a 24-hour period.

6.7.2 Background Noise Levels

The noise levels measured are summarised for each hour of the 24-hour monitoring period in **Table 6.7.1**. The readings taken were the L_{A10}, L_{A50}, L_{A90}, L_{A99} and L_{Amin}. The "A" in the reading signifies that the measurement is A-weighted, which means that the sound level reading has been adjusted, according to its tonal composition, so that the level represents the loudness that would be perceived by the "standard" human ear. The subscripts 10, 50, 90 and so on indicate percentile levels, so that the L_{A90} is the sound level exceeded for 90 per cent of the measurement period. In the **Table 6.7.1** all measurement periods were one hour.

For assessment purposes the L_{A90} level is particularly relevant because it represents the noise levels at the site under the quieter periods that occur at the site. It is often referred to as the background noise level. For this site the L_{A90} levels ranged from 24 to 34 dB(A). A background noise level of 24 dB(A) represents extremely quiet conditions. In the absence of wells under test it can be considered that background noise levels in the vicinity of the proposed power station will be low. They may not be as low as those recorded at Olkaria Hill because the power station site is closer to existing noise sources such as the existing power station, the Oserian flower farm and X2-Camp. These areas and associated transportation activities would cause noise levels to be higher than those at Olkaria Hill.

TABLE 6.7.1- NOISE LEVELS MEASURED AT OLKARIA HILL

Date	Time	L_{A10}	L_{A50}	L_{A90}	L_{A99}	$L_{Aminimum}$
02/12/91	13:00	50	34	28	26	26
02/12/91	14:00	50	34	28	26	26
02/12/91	15:00	50	32	26	24	23
02/12/91	16:00	44	30	27	24	24
02/12/91	17:00	32	27	24	23	23
02/12/91	18:00	29	27	24	23	23
02/12/91	19:00	38	34	27	25	25
02/12/91	20:00	37	34	32	31	30
02/12/91	21:00	35	32	31	30	30
02/12/91	22:00	38	33	31	30	30
03/12/91	23:00	32	31	30	29	29
03/12/91	00:00	42	35	32	30	30
03/12/91	01:00	34	31	30	30	29
03/12/91	02:00	36	32	31	30	30
03/12/91	03:00	45	35	32	31	30
03/12/91	04:00	40	35	32	31	30
03/12/91	05:00	40	36	33	32	32
03/12/91	06:00	41	37	34	33	33
03/12/91	07:00	37	35	33	32	32
03/12/91	08:00	39	32	30	29	29
03/12/91	09:00	38	33	31	30	30
03/12/91	10:00	40	35	32	30	30
03/12/91	11:00	46	35	32	30	29
03/12/91	12:00	54	39	32	31	30
03/12/91	13:00	51	35	31	30	30

6.7.3 Measurements of Noise Emission Sources

Measurements of noise emission levels from various items of plant on the existing Olkaria power station have been made. This information will be used with a noise prediction model in the **Section 7.5** to determine areas affected by noise from the new power station project during the operational phase.

The data are summarised in Table 6.7.2.

TABLE 6.7.2- NOISE LEVELS FROM EXISTING PLANT [5]

Source	Distance - m	Noise level - dB(A)
Cooling towers	35 100	71-72 59-63
Wells under test OW-715 (5-Feb-1991)	 15 30 60	 90-101 86-92 82-86
OW-716 (5-Feb-1991)	15 30 60	101-104 95-100 90-96
Production well OW-11 (5-Feb-91)	 15	 68-74
Gas ejectors	30 to south of southern-most ejector	72-82

6.8 LAKE NAIVASHA

The key reason for the concern and inclusion of Lake Naivasha in this EA is the proposition that existing and proposed geothermal developments may affect lake levels through both direct and indirect water abstraction. This would be a matter of serious concern if lake levels were being or were likely to be significantly affected by geothermal development. This section provides a review of the lake and its regional setting and reviews data available to quantify as far as is possible the effect of geothermal development on the lake.

After a general introduction and basic description of the hydrology of the lake (**Section 6.8.2**), the discussion considers the direct effect which involves pumping water from the lake for uses such as drilling wells, current power station operation, and for domestic use in housing estates (**Section 6.8.3**). The potential indirect effect refers to a possible "hydraulic-link" from the lake to the geothermal field. The possibility of such a link is discussed (**Section 6.8.4**), using data and literature on the hydrology of the lake. Considerable work has already been done and described in recent studies completed by the British Geological Survey (**Clarke *et al.*, 1990**). However, it is important to emphasise that it is beyond the scope of this study to fully resolve the issue. A separate

[5] These measurements were made under neutral atmospheric condition with approximately 7/8 cloud cover and light winds in the range 0 to 3 $m.s^{-1}$.

commissioned study is needed specifically investigating the subsurface outflow from the lake and the "hydraulic-link" issue. The Consultants believe from discussions with KPC that such a detailed study is planned in conjunction with further exploration/development activity (Wasunna, personal communication, 1991). However, it is possible to show that even if a direct connection exists the effect of East and North East Olkaria geothermal developments based on reinjection would not be expected to significantly perturb the lake water balance.

Another factor, considered in the discussion of water abstraction is the current and proposed development of dams on the Malewa River; the major river which feeds into Lake Naivasha (Section 6.8.3).

Excessive water abstraction could have a direct impact on the commercial fishery of the lake, and the important habitats associated with the fishery. As a result, a review of the important aspects of the fishery was undertaken, including the distribution of aquatic vegetation, and potential spawning and fish nursery areas (Sections 6.8.5 and 6). Data on the yearly catch were also collected and discussed. This information is provided to establish the importance of the lake as a regional resource and to highlight the need for further studies to obtain basic data that will allow the lake to be managed in a sustainable manner.

6.8.1 Introduction

Lake Naivasha, a shallow freshwater lake at an altitude of 1 890 metres, is the highest of the Rift Valley lakes. The lake lies some 80 km south of the equator and 100 km north-west of Nairobi. The name Naivasha comes from the Maasai "e-naiposha", meaning approximately "that which is heaving, that which flows to and fro". The lake has always been an important ecological site to Kenya, because of the diversity of flora and fauna in the range of vegetation-zones associated with the lake and the hinterland, which is greater than that of other Rift Valley lakes (Lincer et al., 1981). This importance has been maintained even though the lake has no statutory protection or reserve status.

The area around Lake Naivasha also has high economic value. Cattle-watering by Maasai in former times has given way, during the present century, to settled agriculture - including the raising of export cash-crops around its shores. However this agriculture is heavily dependent upon lake water for irrigation.

Naivasha town is a centre for both the lake-shore farms and the ranches and small holdings of the adjacent Kinangop Plateau. A commercial fishery has been built up over the past 30 years on the basis of introduced species, the products being exported to Nairobi and Nakuru in addition to local consumption.

Lake Naivasha is also a focus for tourism and recreation, which have grown since the first sport-fishing began in the late 1920s. Its catchment streams provide the main water-supplies for both Naivasha and Nakuru towns. More recently, the area has become industrially significant as a consequence of the development of the existing Olkaria geothermal development.

Two official government bodies have direct control over some aspects of Lake Naivasha. The Department of Fisheries manages the fishery by the issue of licences and enforcement of mesh-size regulations. The Ministry of Water Development issues licences for the abstraction of water for irrigation. Several other bodies have interests in the lake - the local government agencies at Provincial, District, and Town Council, levels; national bodies such as the President's Commission on Soil Conservation and Afforestation, and local bodies such as the Lake Naivasha Riparian Owners' Association, are the main ones. The KWS now has increasing local interest as two areas adjacent to the lake - Longonot Volcano and Hell's Gate - were declared National Parks in the mid 1980s. KPC has a direct and long standing interest in the lake. This is because the lake provides the most economical source of water for not only drilling activity and current power station operation but also for domestic requirements in their housing estates.

6.8.2 Hydrology

The Naivasha catchment is separated from the Nakuru-Elementeita catchment mainly by the Eburru volcanic pile which is linked to the Mau Escarpment by a ridge at an altitude of around 2600 m (**Figure 6.8.1**). Between Eburru and the Bahati Escarpment the surface drainage divide runs via Gilgil along a culmination of the Rift floor at an altitude of approximately 2000 m.

South-east of the drainage divide the perennial Gilgil and Malewa Rivers provide much of the recharge to Lake Naivasha. The Gilgil River has its headwaters high in the Bahati Forest and drains parts of the eastern slopes of the Bahati Escarpment (drainage area 420 km^2). These slopes also provide some of the tributaries of the much larger Malewa River (drainage area 1,730 km^2). Most of the discharge of the Malewa River, however, at least in its upper reaches, derives from the western slopes of the high Nyandarua Range (formerly called the Aberdares). Further downstream the Malewa is joined by the Turasha River which is also perennial and drains the north Kinangop Plateau via deeply incised tributaries.

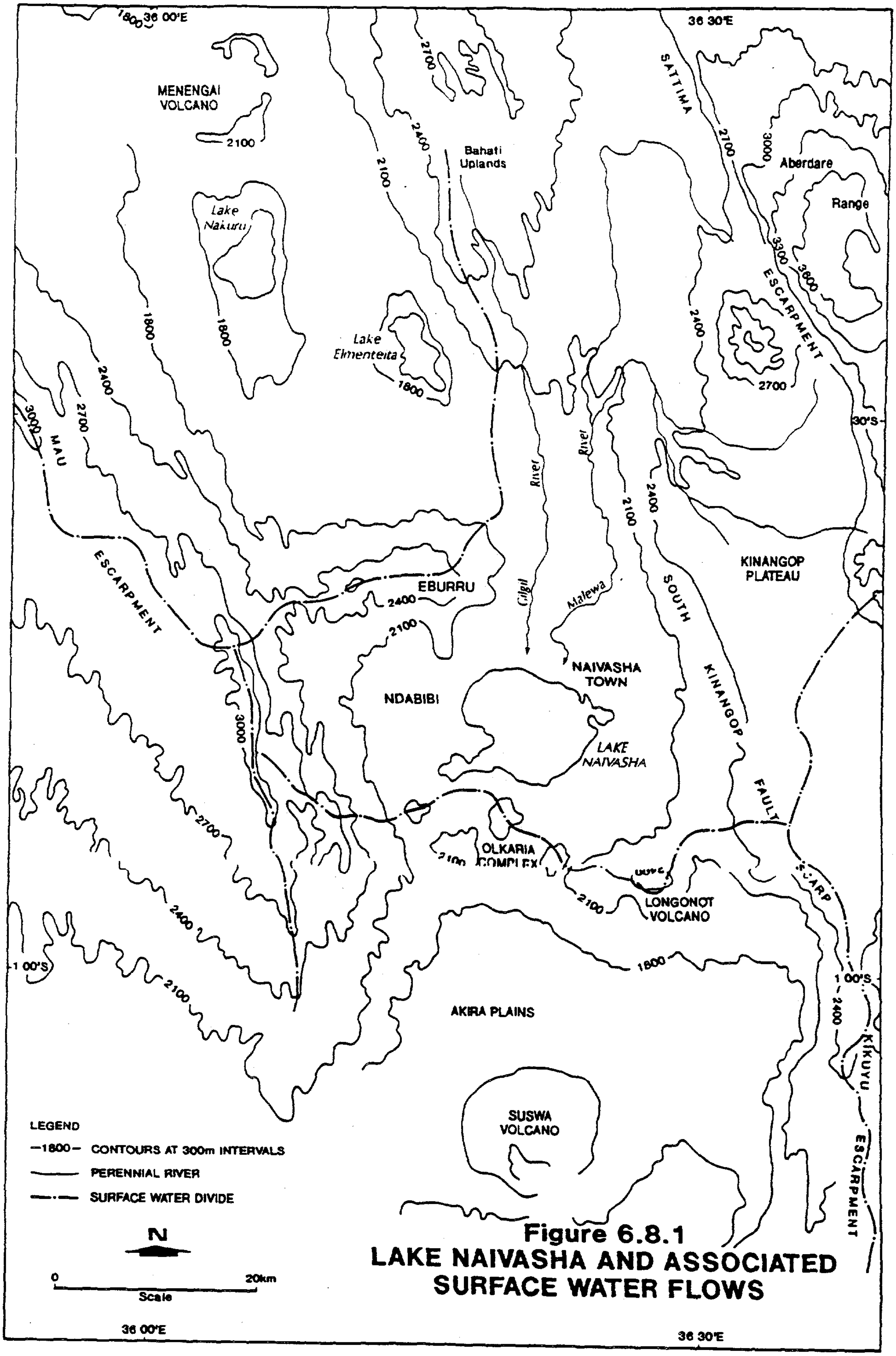


Figure 6.8.1
LAKE NAIVASHA AND ASSOCIATED SURFACE WATER FLOWS

On the west side of the Naivasha catchment, the main river draining the Mau Escarpment is the Marmonet, which flows towards the lake but fails to reach it, instead recharging the alluvium of the Ndabibi Plain. Similarly none of the numerous streams which incise the Eburru Ridge reaches Lake Naivasha.

To the south of Lake Naivasha, the surface water divide runs from the Mau Escarpment in the west via Mounts Olkaria and Longonot to the Kinangop Plateau and finally to the Nyandarua Mountains. Surface drainage in this region, at least at lower altitudes, is limited, only the River Karati providing perennial flow in its upper reaches, and cutting a deep gully as it descends the steep platforms east of Naivasha town.

A combination of intrarift faulting and the occurrence of recent volcanic activity has resulted in localised drainage basin development. A number of these basins are the site of present day Rift Valley lakes most of which show clear indications of being much larger in the past.

The relatively recent volcanic activity has left four depressions in Lake Naivasha, three of which are at least partly connected (**Figure 6.8.2**). The largest water area, the main Lake (approximately 150 km^2) is shallow, deepening towards its southwestern end to a maximum of 8 m (at 1983 water-levels). At the eastern side of the main Lake is a partially-submerged crater of which the highest rim section forms Crescent Island and of which the basin is the deepest part of the lake (18 m deep at 1983 water-levels). At low water-levels this partially-submerged crater is separated from the main Lake and becomes chemically distinct. A much smaller, more alkaline lake, Oloidien (5.5 km^2 in area), is adjacent to Lake Naivasha to the west of its southern end, separated by papyrus swamp but connected by an open-water channel at times of high water-levels. Within 3 km of the western shore of Oloidien Lake, lies an isolated, highly alkaline, crater lake - Sonachi - with an area of about 0.2 km^2 and maximum depth of about 4 m (in 1983).

Lake Water-level Variations

Recordings of the water level have been made at three different places around the lake. The details of these gauging locations, correction for datum height and discussion on the collation and presentation of the water level variations (shown in **Figure 6.8.3**) are given in **Åse (1987)**. For the construction of the part of the graph that covers 1880 - 1908 the data are uncertain and consequently are shown with a broken line (**Figure 6.8.3**).

The range of water levels during the past century can be seen to span 15 m (**Figure 6.8.3**). There are several periods of rapid rise or fall as well as a particularly protracted period of decline from the 1920s to 1950s. After the heavy "long rains" in 1977, the water level rose until mid 1979 by approximately 3 m. After some decline a new peak occurred after the heavy rains in April-May 1981. Since early 1984 the level has been falling steadily, and in January 1988, it was 5 m below the 1983 peak and was in fact at its lowest level this century. The onset of the long rains in April 1988, brought an end to this decline, at least for the time being.

Åse et al., (1986) concluded that the water balance of Lake Naivasha had a rather unstable equilibrium, and that river inflow just below the average makes the lake level drop considerably. On the other hand, lake level can be shown to be sensitive to high inflow lake level rose by over a metre in only a month in May 1977.

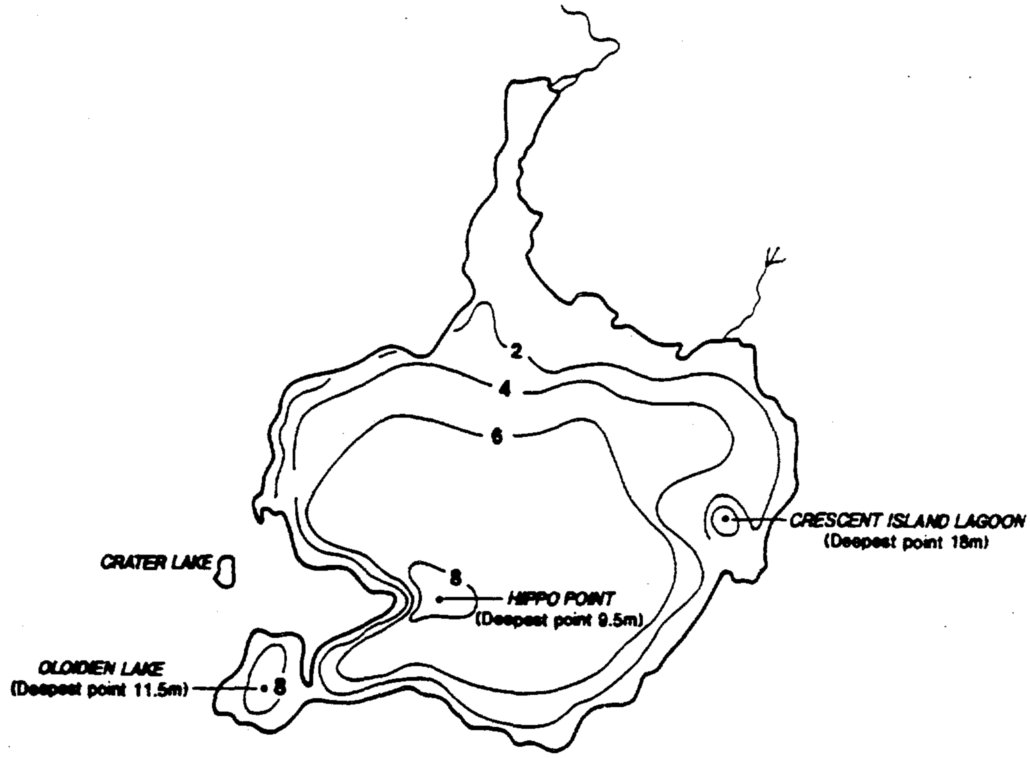


Figure 6.8.2
BATHYMETRIC DATA FOR LAKE NAIVASHA-1983 LEVELS
Source: HARPER et al. (1990)

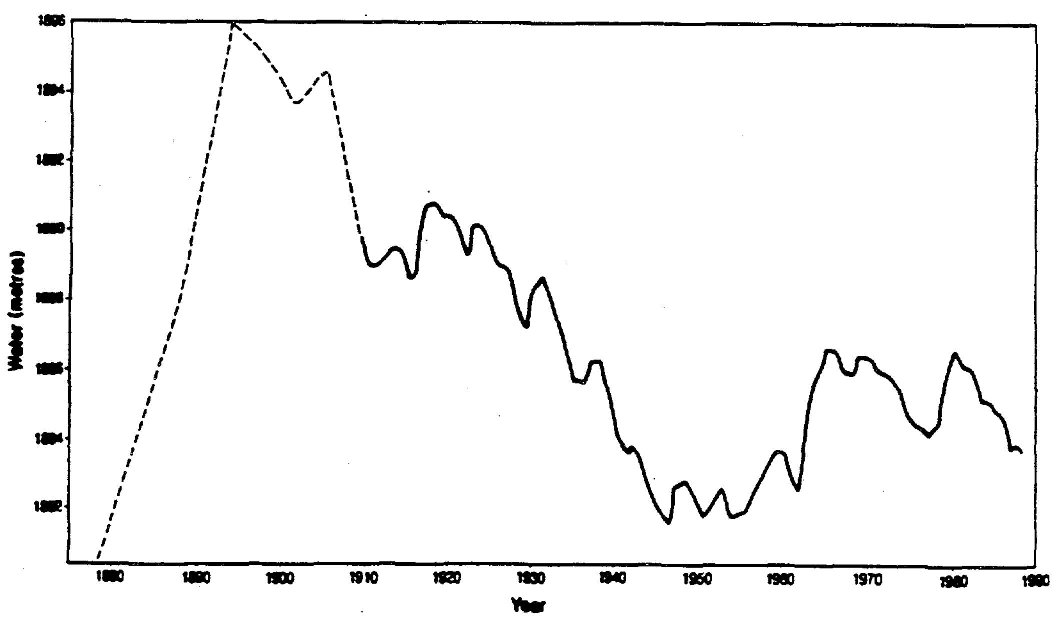


Figure 6.8.3
HISTORICAL LAKE LEVELS

The monthly variations in lake level were studied by Åse (1987) for the period 1911 to 1980. The data were presented as mean monthly levels (without confidence limits) and showed a general seasonal pattern of lowest lake levels around the beginning of the year (dry season) followed by a rise during the long rains in April-May. However, the characteristic dry period during the middle of the year (June-July) is not evident, and average levels continue to rise until September and subsequently decline. Such independence of rainfall was interpreted as being supportive evidence for the significant influence of groundwater flow.

To date, the studies on lake-level fluctuations have not been found to show any direct relationship with local rainfall (**Harper et al., 1990**), except that periods of exceptionally high rainfall are followed by lake-level rises (e.g. in 1922, 1930, and 1961-63)> Annual evaporation always exceeds rainfall (**Åse et al., 1986**). In a statistical analysis, however, **Vincent et al., (1979)** suggested that the lake's level is an indicator of the long-term pattern of high altitude climate - particularly the penetration of equatorial westerlies and their influence on land above 2500 m asl. Evidence for this hypothesis came from the correlation of monthly lake-level changes with precipitation data from high-altitude meteorological stations (at 2700 m), and the correlation of lake-level with the altitude of the snout of the Lewis Glacier on Mt Kenya. Long-term fluctuations showed close similarities with those of Lake Turkana, which also has a mountainous catchment and no surface outlet - compared to no similarities with the fluctuations in Lake Victoria.

6.8.3 The Water Balance of Lake Naivasha

Past Studies

Several water balances for the lake have been described. Three studies based on river gauging and evaporation-rate measurement, have given comparable results for subsurface outflow of 43 x 10^6 m^3/y (**Sikes, 1936**), 34 x 10^6 m^3/y (**McCann, 1972**) and 46-56 x 10^6 m^3/y (**Åse et al., 1986**). These are likely to be underestimates, as not all inflows could be gauged, but suggest that substantial outflow is occurring. The direction of this outflow and possible connection with the Olkaria geothermal field is discussed in (**Section 6.8.4**)

The extensive study by **Åse et al. (1986)** compared the observed with calculated changes in monthly lake-levels (ΔS). The calculations were done for two periods (January 1972 to December 1974; January 1978 to December 1980) based on the following equation:

$$\Delta S = P + R - E$$

Where,

ΔS = monthly calculated water level change,
P = average precipitation on the lake,
E = potential evaporation, and
R = rest (other losses).

The calculated lake levels were systematically greater than the observed. For the period 1972-4 this amounted to a lake level increment of 23 mm/month while, for the period from 1978-80, it was 28 mm/month and an overall average of 25 mm/month. This when expressed in m^3/y gives the range 46-56 x 10^6 m^3/y or an average of 50 x 10^6 m^3/y. **Åse et al.**, (1986) concluded that the most probable explanation was that of a subsurface outflow.

In a subsequent paper Åse (1987) presents a water balance for the entire period from 1936 to 1976 (**Table 6.8.1**) based on the following factors:

$$L_n = L + P + I - E - ET \pm S$$

Where;

L = a previous water level,
P = precipitation (between L and L_n),
I = surface inflow to the lake in the same time,
E = evaporation from the lake surface,
ET = evapotranspiration, and
S = normally storage, but in this case it should equal the difference between the assumed underground inflow and outflow.

The precipitation (P) and evaporation (E) figures have been obtained from Naivasha D. C. and the figures for surface inflow (I) have been taken from the Malewa and Gilgil Rivers. The results support the theory of an underground outlet, as there is a considerable rest sum (S) that could not be attributed to errors associated with the parameters used in the calculations.

TABLE 6.8.1- HYDROLOGICAL DATA FOR LAKE NAIVASHA 1936 - 1976

Inflow to the lake (from the Malewa and Gilgil Rivers) equalling a rise in lake level.	+91.45 m
Precipitation over the lake equalling a rise in lake level	+26.21 m
Evaporation from the lake (pan factor 0.8) equalling a drop in lake level	-67.94 m
Real or actual drop in lake level between 1936 and 1976	-1.5 m
Rest factor (probable underground outlet) equalling a drop in lake level of (i.e. 91.45 + 26.21 - 67.94 - 1.5 = 48.2 m)	-48.2 m

Source: Åse, (1987).

There are, however, two factors omitted from **Table 6.8.1**; namely water abstraction for irrigation and evapotranspiration (ET). The first factor is unlikely to have been an important influence on the water budget given that it was for the period 1936 to 1976 and only relatively small areas were under irrigation. This is no longer the case and the specific issue of water abstraction is discussed in **Section 6.8.3**.

The second omission, that of evapotranspiration, is more serious in terms of the calculations presented by Åse et al., (1986). The lake was assumed to have a surface totally free of vegetation, which is known not to have been the case. The realisation of this led to a subsequent publication by Åse (1987) in which Cyperus papyrus is reported to have covered 10 per cent of the surface of the lake during the period 1936 to 1976. Another aquatic plant, Salvinia molesta, occurred during only a small part of the period (see Section 6.8.6) and its influence on the water budget much less than that of Cyperus papyrus and was therefore not taken into account. This is certainly not true of more recent times, for example in 1983 Salvinia molesta is reported to have covered 20 per cent of the lake surface (Njuguna, 1983).

The study by Åse (1987) showed that transpiration was up to three times that of evaporation from a free water surface (note: this result differs markedly from that of Penman (1963), who is widely regarded as an authority on the subject). Nevertheless, such a rate would result in a change of evaporation in Table 6.8.1 from 67.94 m to approximately 85 m. This in turn would change the rest factor from 48 m to approximately 31 m. In the same study Åse (1987) also questioned if the pan factor for evaporation was realistic because of the notable influence of wind. When the pan factor was "converted" to take account of wind conditions experienced by the lake a further third of the rest factor disappeared. Consequently, as a result of the relatively small amount remaining, Åse (1987) ended by questioning the existence of any significant subsurface outflow from the lake.

While such statements contrast with the conclusions arrived at previously by the same author that there was a nett outflow of approximately 50 x 10^6 m^3/y (Åse et al., 1986), the evidence for evapotranspiration rate and pan factor conversion is very limited. Also, if the outflow is insignificant then the lake's relatively low salinity despite substantial evaporation is unexplained - a factor not considered by Åse (1987).

Current Study

There is an obvious need, from the above discussion, for a detailed water balance of Lake Naivasha, the scope of which is beyond the resources of this EA. The evapotranspiration issue alone requires experimentation and detailed monitoring for at least a year not only for Cyperus papyrus but also for the periodically extensive Salvinia molesta. Also, and perhaps more importantly, most monitoring of the lake ceased in 1988. Specifically, the Ministry of Water & Development stopped measuring the Malewa and Gilgil Rivers as well as lake levels in early 1988. Rainfall and evaporation data are available but there is no means of determining river flows since 1988. Consequently, for a "new" water balance to be determined, either it is necessary to re-initiate monitoring and collect data for at least a year, or it can only be calculated up to 1987. The latter option would have the problem of determining accurate abstraction rates because of missing records.

The approach taken in this study has been to present a modified balance based on the work by Åse et al. (1986) but taking into account recent abstraction levels. The important aspect to remember for this EA is the extent and magnitude of influence the proposed North East Olkaria development would have on Lake Naivasha. As mentioned in the introduction (Section 6.8.1), this relates to direct and indirect water abstraction. Direct abstraction is discussed below and indirect in the next section (Section 6.8.4). Thus for the EA there is no critical need for a water balance, only an investigation of the relative role played by the proposed geothermal development.

Water Abstraction Rates
The Water Bailiff of the Ministry of Water and Development issues licences for the abstraction of water from Lake Naivasha. Currently there are 108 registered direct water abstractions from the lake for a total of 83 340 m^3/day or 30.4 x 10^6 m^3/y. This figure represents 60 per cent of the estimated water storage (S) or outflow from the lake. This demonstrates that current water abstraction has a significant influence on the water balance. To what extent the abstracted water is "redirected" outflow, rather than additional to the normal outflow, is unknown. There is also the unknown proportion of irrigation water which recirculates within the catchment area rather than being "lost" through evaporation. The extremely permeable surface formations means that the probable rate of soakage is high compared with evaporation and therefore a large amount of irrigation water could be recirculated.

Table 6.8.2 lists the top-ten licensed water abstractors and shows that KPC is registered for 2622.56 m^3/day or 3.1 per cent of the total. This amount covers water taken from three intakes; one for Eburru, another for Olkaria and North East Olkaria, and the final smaller intake for the housing estate. The table also shows that KPC is only the eighth largest abstractor. The two largest abstractors account for virtually a third of the total on their own, compared to KPC's 3.1 per cent. Another important point is that the amount of water used by KPC will substantially diminish once drilling is completed. This is in contrast to other water abstractors who primarily use the water for irrigation and are more likely in the long-term to want to increase their usage[6]. Therefore, in terms of possible impact on the lake level because of water abstraction, it can be shown that KPC would not be a primary cause.

As an independent measure of lake water usage, an alternative approach was adopted in which the 1990 consumption of electrical power (kWh) for pumping was gathered. KPLC has a specific tariff rate for water pump installations used for irrigation and their Nakuru had records of whether the water pumps were for bore-holes or pumping from the lake. From their records a list of 224 pumps was obtained. Of these, those using a commercial quantity of power (ie biggest users; greater than 7000 kWh/month) were selected (42 users) and their annual total of power consumption determined. A pump efficiency of 65 per cent was used and a 40 m head since virtually all the water is used for local irrigation. The specific parameters used for the KPC pumped water differed since they pump to a significantly greater head and use the water differently. The following general equation was used to convert the annual electric energy used for pumping (kWh) to volume of water abstracted (m^3/y).

$$Q = (E \times W)/(H \times G) \qquad (6.3)$$

Where,
- Q = flow rate (kg/s), and
- W = electrical power (W),
- H = the pressure head (40 m),
- G = gravitational acceleration (9.81 m/s^2),
- E = pump efficiency (65 per cent).

[6] Note: until recently the large irrigators have used spray irrigation systems in which approximately 70 per cent of the water is lost by evaporation. In recent times there has been a trend to use drip irrigation, which uses only one third as much water for the same area of crop. Thus although areas under irrigation may expand the amount of water used could, in the short-term, fall.

TABLE 6.8.2- THE TEN HIGHEST REGISTERED WATER ABSTRACTORS FROM LAKE NAIVASHA BASED ON WATER BALIFF'S LICENCE RECORDS.

Company	m^3/day -1991	m^3/y
Oserian Limited	14936.7	5,451,896
Sulmac Limited	12283.5	4,483,478
Eskine Enterprises	7415.0	2,706,475
Kamuta Limited	4540.0	1,657,100
Indu Farm Limited	3589.4	1,310,131
Ministry of Tourism & Wildlife	2840.0	1,036,600
Loldia Limited	2727.3	995,465
Min of Envt & Reg Planning	2600.0	949,000
KPC	2622.6	957,249
Longmarch Development Ltd	2272.9	829,609
Others	27512.9	10,042,209
Total	**83,340.3**	**30,419,212**

TABLE 6.8.3- THE TEN HIGHEST WATER ABSTRACTORS FROM LAKE NAIVASHA BASED ON ELECTRIC POWER CONSUMPTION IN 1990.

Company - order different from Table 6.8.3	kWh Total	m^3/y
1	1765246	10,526,717
2	996755	5,944,536
3	870146	5,187,672
4	690190	4,115,448
5	598798	3,569,875
6	572916	3,415,349
7	429288	2,560,723
8	393797	2,349,432
9	368508	2,198,059
10 - KPC	287183	1,712,405
Others	2974562	17,739,000
Total	**9,947,389**	**59,319,216**

The estimate for the pumping rate in kilograms of water per second was then turned into an annual volume by multiplying by the number of seconds in a year and assuming that the density of water is 1 000 kg/m^3.

The estimated quantity of water pumped from Lake Naivasha in 1990 and the top-ten users are listed in Table 6.8.3. The total is conservative[7] since the numerous small-scale users were not included. The results show that abstraction estimates based on power consumption are almost twice that of the licenced amounts presented in Table 6.8.2. A total of approximately 59 x 10^6 m^3/y was abstracted for irrigation which is as least as great as the estimated annual outflow of Åse et al., (1986). However, as mentioned earlier, the amount abstracted for irrigation does not necessarily mean that the water is removed from the catchment and a proportion may recirculate.

The intention of the study was to accurately determine the role and significance of direct water abstraction by KPC and not that of the Ministry of Water and Development. Although the actual amount abstracted by KPC was more than its licence, the significant point is the company's tenth ranking (Table 6.8.3). As such, in terms of concern about influencing lake levels, the abstracted amount by KPC was 3 per cent of the total and substantially less than nine other companies. The study does not answer the question of whether or not abstraction does influence lake levels, but if this is the case, then KPC is not the major cause, only a contributor. There are two other points that should be considered. Water abstraction by KPC is fairly constant throughout the year, so water is taken from both periods of lake level increase and decrease. Most irrigation occurs seasonally (during dry periods) and this only accentuates lowering lake levels. The second point is that most of the water being currently abstracted is for drilling. Most of the wells will be completed by mid-1992 which will greatly reduce the water requirements. However it is likely that further (exploratory) drilling will continue, though the specific concerns for this assessment are only the proposed North East Olkaria development.

Malewa Dam Development

The Malewa Dam Project plans to transfer water from the Malewa River to the Greater Nakuru Municipal area. The Malewa River is the largest river discharging into Lake Naivasha and contributes 95 per cent of the inflow. The project aims to satisfy the long term potable water requirements for the townships of Nakuru, Gilgil and Naivasha, and surrounding rural areas in central Rift Valley Province which have experienced very rapid population growth in recent years. The project consists of two phases:

Phase I: Produce 18 000 m^3/day (6.57 x 10^6 m^3/y) from the Turasha river, 13 300 m^3/day to Nakuru city and 4 700 m^3/day to Gilgil. The dam is built and the pipeline is currently under construction.

Phase II: Two stages of development, each contributing 47 000 m^3/day (17.16 x 10^6 m^3/y) giving a final total supply of 113 600 m^3/day (41.46 x 10^6 m^3/y). The proposal consists of a 80 m high dam on the Malewa River and an inter-basin transfer tunnel from the dam to an intake structure on the Turasha River. Water will be abstracted from the Turasha and fed by pipeline to the water treatment works sited near Gilgil and from there distributed.

[7] Note: conservative in this context means the estimate will be too low, which has been taken to be conservative because it will result in an overestimate of KPC's abstraction as a fraction of the total.

A brief impact study has been conducted by Nippon Koei Co Ltd who are acting as consultants to the National Water and Pipeline Development Corporation. The second phase of development has been halted pending the findings of a full environmental study. The study is firstly to address the problem of disposal of the effluent water at Nakuru so that it does not all flow into Lake Nakuru with potentially serious ecological consequences. The second part will investigate the ability of Lake Naivasha to sustain such abstraction levels.

The latter is relevant to the Olkaria geothermal project. Given that the current abstraction from the lake for irrigation already equals or slightly exceeds the outflow from the lake, further abstraction of the magnitude proposed may not be sustainable, and a fall in lake level would seem likely. Even the first dam represents the second greatest source of water abstraction from the lake and as such its impact is much greater than that of KPC.

6.8.4 Hydrogeology

As mentioned in the introduction (Section 6.8.1), the floor of the rift valley has its highest elevation in the area of Lake Naivasha, generally falling both to the north and south. There is therefore a potential hydraulic gradient within the Rift in these axial directions. The often steep and markedly elevated boundary escarpments, however, develop the greatest head and lateral flow into the Rift from these highland areas must be extremely important. These highlands support well developed tropical rainforest, e.g. the Aberdares, Mau and Kikuyu escarpments, indicating that local recharge must be higher than in the Rift where the vegetation is of a semiarid character. Meteorological records confirm this difference - the escarpments having an annual rainfall of 1200-1500 mm with similar to lower evapotranspiration rates while the lower rainfall within the Rift (430 mm at Magadi, 980 mm at Nakuru, 627 mm at Naivasha), is accompanied by potential transpiration rates often many times the rainfall.

The high evaporation/precipitation ratio prevailing in the floor of the Rift, combined with the closed nature of the basins, results in the lakes being of generally brackish to saline character. An exception is Lake Naivasha, which is the freshest of the lakes. Its low salinity gives it high ecological and economic values. The low salinity is due in part to the large catchment area in the Nyandarua Mountain range and in part to outflow processes. Initially there was assumed to be some undiscovered subterranean outlet (**Gregory, 1921**) together with very dilute inflows (**Worthington, 1932**). This view was refined, however, by **Gaudet & Melak (1981)**, and **Åse (1987)**, who showed that the lake was, hydrologically, a seepage lake. They concluded that the lake remained fresh - partly because of its dilute inflows and seepage losses but additionally because of biochemical and geochemical sedimentation removing certain ions such as sulphates and carbonates. The opposite case is exemplified by Lake Magadi which has no outlet, is fed on all sides by springs which are themselves saline and much of whose surface is covered with a thick trona (salt) deposit which forms the basis of an important chemical industry.

The Naivasha catchment is in a hydrogeologically complex environment. Borehole record examinations by **Clarke et al. (1990)** showed that the piezometric surface generally follows the surface contours, i.e. underground movement of water is occurring both axially along the Rift (discharge), and laterally from the bounding highlands into the Rift (recharge). The data support discharge flow both north and south from Naivasha, with a steeper fall to the south. The geothermal field at Olkaria lies at the southern and northern edges of the Naivasha catchment and the recharge of these fields is therefore connected with subsurface flows within, or more precisely out of the catchment. However, the geothermal systems are not over-pressurised. This is illustrated by the lack of surface springs and the depth of the hot water below the surface. Such a situation could result from the axial permeability along the Rift faults being an order of magnitude greater than the lateral permeability.

Attempts to quantify groundwater flows in the Naivasha catchment comprised two types; water balance studies, and applications of Darcy's Law of groundwater flow on a regional scale. Both have tended to consider the Naivasha catchment to be a "cold" watershed and to follow classical cold water hydrology. In fact the catchment occurs in an active geothermal system and therefore conditions existing in a hot environment must determine the behaviour of the fluids. There is an increasing amount of evidence becoming available (**T. Mahon pers. com.**) to suggest that the various perched water tables in the catchment, particularly to the south, are intimately connected and this has been shown to be true in most active geothermal systems. A re-evaluation of lake level variations based on a "hot" catchment may show that the changes can be attributed to deeper water temperature/density oscillations and not volumes.

Based on past water balance studies, (reviewed in **Section 6.8.3**), preliminary estimates of subsurface flows from the Naivasha catchment, suggest that the amount contributed by Lake Naivasha is around 50 x 10^6 m^3/y (which is 20 per cent of the total recharge estimated by a previous water balance study). Flow to the south via relatively shallow aquifers (i.e. at depths at less than about 500 m) may be the most significant route for water flow from the catchment, accounting for perhaps 50 per cent to 90 per cent of the total (**Clarke et al., 1990**).

Estimates of the scale of the regional flow out of the Naivasha catchment have been attempted by **Clarke et al. (1990)** with certain assumptions concerning regional head gradients and permeabilities. In their calculations a north-south groundwater gradient of 0.1 m/m was used, a hydraulic conductivity of 3 x 10^{-3} m/d (across the Rift; 25 km), and flow assumed to occur to a depth of 5 km. This resulted in the estimated southerly flow at depth from the Naivasha catchment to be 14 x 10^6 m^3/y. On top of this must be added the amount of southerly flow in shallow aquifers. This was estimated to be between 27 x 10^6 m^3/y and 270 x 10^6 m^3/y. Although acknowledged by **Clarke et al. (1990)** as a crude estimate based on rudimentary data, the above figures do indicate the order of magnitude of southerly flows from the Naivasha catchment and suggest that the shallower aquifers may form a significant conduit for southerly flow.

McCann (1974) estimated a northerly flow of 39 x 10^6 m^3/y from the Naivasha catchment towards the Elementeita catchment. Data from the **Clarke et al. (1990)** study suggested much lower transmissivity values and therefore a shallow northerly flow of only 11 x 10^6 m^3/y. A deep northerly flow over the same cross-section was estimated as 0.3 x 10^6 m^3/y.

The implication deduced by **Clarke et al. (1990)** was that much of the subsurface outflow from the Naivasha catchment is to the south, via Olkaria-Longonot towards Suswa and eventually towards Magadi, although there is little evidence that such water ever reaches Magadi in an identifiable form.

known value is the hydraulic conductivity of relatively shallow material between Longonot and Suswa. If the higher value of the range given above is taken, then the total flow out of the catchment is estimated to be around 295 x 10^6 m^3/y - a figure which agrees reasonably well with McCann's (1974) figure of 250 x 10^6 m^3/y - of which around 20 per cent is lake recharge. Less than 5 per cent of this total would flow north, and of the southerly flow, only 5 per cent would occur at depth.

If the lower estimate of hydraulic conductivity is taken, then the total estimated recharge value is 52 x 10^6 m^3/y, virtually all of which could be lake recharge. Here northerly flow would account for about 20 per cent of the flow from the catchment, and of the southerly flow, around 25 per cent would be at significant depths.

Concern has been expressed about the possible effect of geothermal production on the level of Lake Naivasha. According to Bodvarsson et al. (1987) the average well at Olkaria produces about 6 kg/s of steam, equivalent to around 2.5 MWe. Therefore in order to produce 45 MWe the present wellfield discharges approximately 100 kg/s of steam, equivalent to a liquid discharge rate of approximately 3 x 10^6 m^3/y. This is only a small proportion of even the minimum estimated total natural southerly flow from the Naivasha area (41 x 10^6 m^3/y). With the North East Olkaria (64 MWe) development, reinjection is to be practised and there is also the proposal to reinject at the existing Olkaria field. Assuming that this will occur, then consumption would stay at about 4 x 10^6 m^3/y (J. Koenig pers. comm.), or less than ten per cent of the minimum Lake Naivasha underflow calculated for the region, or one to two per cent of the maximum estimated underflow.

The hydrogeological features of the Lake Naivasha area are; a poorly permeable unit (aquiclude) underlying the lake and separating it from the geothermal field; and the dual steam and hot-water zones of the Olkaria field. A secondary but significant feature, is the series of shallow, perched, unconfined aquifers on top of the aquiclude, which are found in numerous drill holes. The perched aquifers appear to be in direct hydraulic continuity with Lake Naivasha.

There appears to be leakage through the aquiclude into the deeper geothermal system (hydrologic continuity). Whether this is direct underflow from the lake, or comes indirectly via the perched aquifers is unknown. The isotopic identification of Lake Naivasha water in the geothermal steam is explained by Allen et al., (1989) as downward leakage followed by mixing with non-Naivasha water, and does not require direct pressure continuity between the lake and the geothermal field. Evidence in support of this, is given in the following paragraphs.

Pressure gradient profiles measured from wells of the Olkaria field show hydrostatic gradients associated with several perched aquifers. Below the perched aquifers, the pressure drops to nearly atmospheric, indicating no hydraulic continuity between the geothermal reservoir and the overlying perched aquifers. Pressure then rises in the aquiclude and becomes isobaric in the steam reservoir. Pressure then increases again at approximately a hydrostatic gradient in the underlying hot-water zone. If as this generalised pressure profile indicates, there is no direct pressure connection between the deep hot-water zone and the lake or the perched aquifers, lowering the pressure in the steam or hot-water zone may not have any measurable effect on the lake, or the perched aquifers. Indeed, data to date do not show any correlation. Therefore even if there is a hydrologic continuity between Lake Naivasha and Olkaria, increasing the output at Olkaria may not have any effect on the lake. The lowering of the perched aquifer levels could have an effect on the lake, however, geothermal operations are not expected to affect these perched aquifers because there is no production from them.

Based on isotopic data, it appears that the Olkaria reservoir water is a mixture of about 40 to 50 per cent lake water with 50 to 60 per cent groundwater, infiltrating from the western Rift escarpment. The lake water is identified by its relatively heavy oxygen and hydrogen isotopes (resulting from solar evaporation of ponded water) compared to the relatively light water of meteoric origin occurring as groundwater from the Rift margin.

For this lake water to originate in modern Lake Naivasha, it is necessary to envisage a system in which Lake Naivasha water percolates vertically downward for several kilometres, becomes heated then returns to within a few hundred metres of the surface as geothermal fluid only a few kilometres distant from its point of descent. Such a model appears unrealistic in view of evidence from drilling of very poor vertical permeability in the system.

An alternative explanation is that the Olkaria reservoir contains a high percentage of evaporated lake water, but that this water originates not from present-day Lake Naivasha, but from ancient lakes known to have formed and evaporated over the millennia of Rift valley history. These waters would have infiltrated the older Rift Valley sediments as the valley subsided, wherein they became trapped as new sediments and volcanic flows covered the old lake beds. The Olkaria wells have penetrated over 700 m of these old lake sediments. **Dr McNitt** (pers. com.) believes it is more probable that the Olkaria geothermal field consists of these "fossil" lake waters, rather than rapidly cycled, present-day Lake Naivasha water.

6.8.5 Fishery Development and Sensitivity

Fish Introductions

At the end of the last century, there was little permanent settlement, but with the advent of ranching and farming subsequent to the arrival of the railway, the population grew steadily. The settlers looked to the lake to provide not only some food but also leisure activity. Prior to 1925, there had only been a single species of fish in the lake - an endemic zooplanktivorous small-tooth carp (Aplocheilichthyes antinorii (Vinc.)). It is assumed that this paucity of species, highly unusual in a tropical freshwater lake, was due to earlier periods of the lake drying out. The indigenous carp were very palatable but offered no "sport" to fishermen. In 1925 and 1926 the mouth-brooding cichlid Oreochromis spilurus niger (Dunther) was introduced by the colonial Kenya Game and Fisheries Department. This fish flourished in the littoral fringe of the lake, and in 1927 the American large-mouthed bass (Micropterus salmoides Lacepede) was introduced to feed on it and provide a basis of a sport-fishery. The introductions led to a dramatic increase in the numbers of fish-eating birds such as fish eagles, pelicans, cormorants and herons. Such was the increase that in 1937, some 750 cormorants were killed to preserve the fish. Both fish species were successful until the low water-levels of the late 1940s and early 1950s, when they appeared to have died out (**Harper et al., 1990**).

Large-mouthed bass were re-introduced on several occasions between 1951 and 1956 - in 1956, together with a second cichlid, the herbivorous Tilapia zillii (Gervais). The batch of T. zillii unintentionally contained some individuals of Oreochromis leucostictus (Trewavas). The latter unexpectedly flourished and is now the basis of the subsequent commercial fishery. The Louisiana Red (Swamp) Crayfish (Procambarus clarkii (Girard)) was added in 1970 to broaden the range of the commercial fishery, and has been harvested since 1975 (Lowery & Mendes, 1977). The most recent new arrival is the only natural one - a small riverine fish Barbus amphigramma Blgr, which first migrated down to the lake from the Malewa during the high water-levels of 1982 (Harper, 1984) and at times since then, has been present in large enough quantities for limited commercial exploitation at the Malewa inflow (Harper et al., 1990).

Several other fish species have been introduced over the past 50 years without any lasting success. Sporadic reports of Rainbow Trout (Salmo gairdneri (L.)) derive from introductions to the catchment streams for sport. Three cyprinodont species were introduced for mosquito control - Gambusia sp., Poecilia sp., and Lebistes reticulata Peters, of which only the last named was found in 1982 (Harper, 1984). Oreochromis niloticus Linnaeus was introduced in 1965 and was last found in 1969. Recently, however, experimental netting during 1986 recorded this species in Oloidien Lake, and there are unconfirmed reports from fishermen since then of its presence in the main Lake Naivasha (Harper et al., 1990).

Other Introductions

In 1961 the first unintentional immigrant species, the floating water-fern Salvinia molesta Mitch., was reported. It was known in ornamental ponds, and was available from aquarists in Nairobi in the 1950s (Harper et al., 1990). Initially, Salvinia molesta was seen as a great potential threat because of experiences with the Kariba reservoir on the Zimbabwe/Zambia border and was sprayed with herbicide whenever discovered. However it increased in area and by 1973 had spread along the whole of the lake shoreline, but had no measurable effect at that stage on the overall ecology of the lake. Recently research into the possibility of releasing a weevil, Cyrtobagous salviniae Caldr & Sands, was initiated in Kenya. After initial rejection by the Kenyan National Environment Secretariat the weevil has been introduced but poor survival after quarantine has meant the impact has been low and it is too early to tell what the outcome will be.

The original arrival of Salvinia molesta was closely followed by the Coypu (Myocastor coypus (Molina)), which had been imported to the Kinangop Plateau for fur farming in 1950. Individuals escaped and arrived at Lake Naivasha from 1965 onwards (Harper, 1990) where by the early 1970s, there was a large population of Coypu. Biological control methods were also tried with the introduction of pythons (Python rebae), the descendants of which are still reported to exist in areas of the northern papyrus swamp of the lake. However these introductions were ineffective and a rapid population-increase occurred in the 1970s (Harper et al., 1990). For about a decade, Coypu were frequently observed by lakeside residents, though in decreasing numbers after 1980. No individuals have been seen since 1984, and it is assumed that the population has died out.

The Lake Fishery

The fishery of the lake is based (with the exception of the Barbus amphigramma catch) upon artificially introduced species. These species are also essential in the maintenance of some 80 species of piscivorous (fish-eating) birds, together with several species of amphibians and two mammals. Although fish introductions began in the 1920s the commercial gill-net fishery did not open until 1959, exploiting Oreochromis spilurus niger and Tilapia zillii. The latter was initially only present as a small portion of the catch: the first few years of the fishery coincided with a period of rapidly rising water-level which was probably not favourable for the feeding and nesting behaviour of Tilapia zillii (Harper et al., 1990). A hybrid between O. s. niger and O. leucostictus dominated the catch through the early 1960s.

From 1964 to 1976 the water-level remained high and was stable within a range of about 2 m, resulting in the formation of lagoons and littoral zones extensively colonized by macrophytes. Siddiqui (1979) found that the lagoons were the preferred habitat of the herbivorous, substrate-breeding T. zillii, whilst the lagoons and littoral were preferred by O.leucostictus, as accumulations of detritus provided its major food-source, namely chironomid larvae. Most hybrids and all O. s. niger had disappeared by 1971; this was attributed by Siddiqui (1979) to the disappearance of weed-free breeding and nursery grounds, the preferred habitat of this species. By 1975 the cichlid catch consisted of about 74 per cent O. leucostictus and 26 per cent T. zillii (Siddiqui, 1979). A decade later, following the high water-levels and disappearance of lagoons and submerged plants in the 1980s, the catch was less than 2 per cent T. zillii, being 98 per cent O. leucostictus (Table 6.8.4). This is still the approximate proportion of the commercial cichlid catch, although experimental netting during 1987 has recorded a higher proportion of T. zillii in the main Lake and the dominance of this species in Oloidien Lake (which is closed to commercial fishing) (Harper et al., 1990).

The gross tonnage of fish harvested from the lake has fluctuated considerably in the three decades of the fishery (Figure 6.8.4; Table 6.8.4). Initially the mesh-sizes of the nets used were 13 and 14 cm. This was reduced to 11 cm by 1961 and to 10 cm by 1970 (Siddiqui, 1977). There was a rapid decline in catches in 1970-72 which Siddiqui (1977) attributes to over-fishing, followed by strict enforcement of the 10 cm mesh by the Fisheries Department from 1973 onwards. The fishery started to recover after 1975-76; since then it has fluctuated, with two peaks and two troughs. In 1987-88 catches of both Tilapia and the Bass were low.

The crayfish fishery has had mixed fortunes in its shorter time-span. Initially opened in 1975, catches of several hundred metric tonnes annually were exported, mainly to Europe, up to 1983. Since then, annual catches have averaged around 44 tonnes - for local (tourist) consumption (Table 6.8.4).

6.8.6 Aquatic Vegetation in Lake Naivasha

The work by Gaudet (1977, 1979) described the aquatic vegetation of Lake Naivasha and established that, with the exception of the spread of Salvinia molesta, the overall species composition and distribution had remained relatively stable for forty years. Patterns of change were apparent, as in the successive "reefs" of Papyrus that were formed when "island" masses rooted in places of low water-level (Gaudet, 1977); but all the main vegetation types - terrestrial colonizers of the draw down, emergent swamp vegetation, a floating-leaf zone of water-lilies (Nymphaea caerulea Savigny), and a submerged-plant zone - were dynamic, with new populations developing as old ones were disappearing. However the last two decades have seen dramatic changes in the plant communities (Harper et al., 1990).

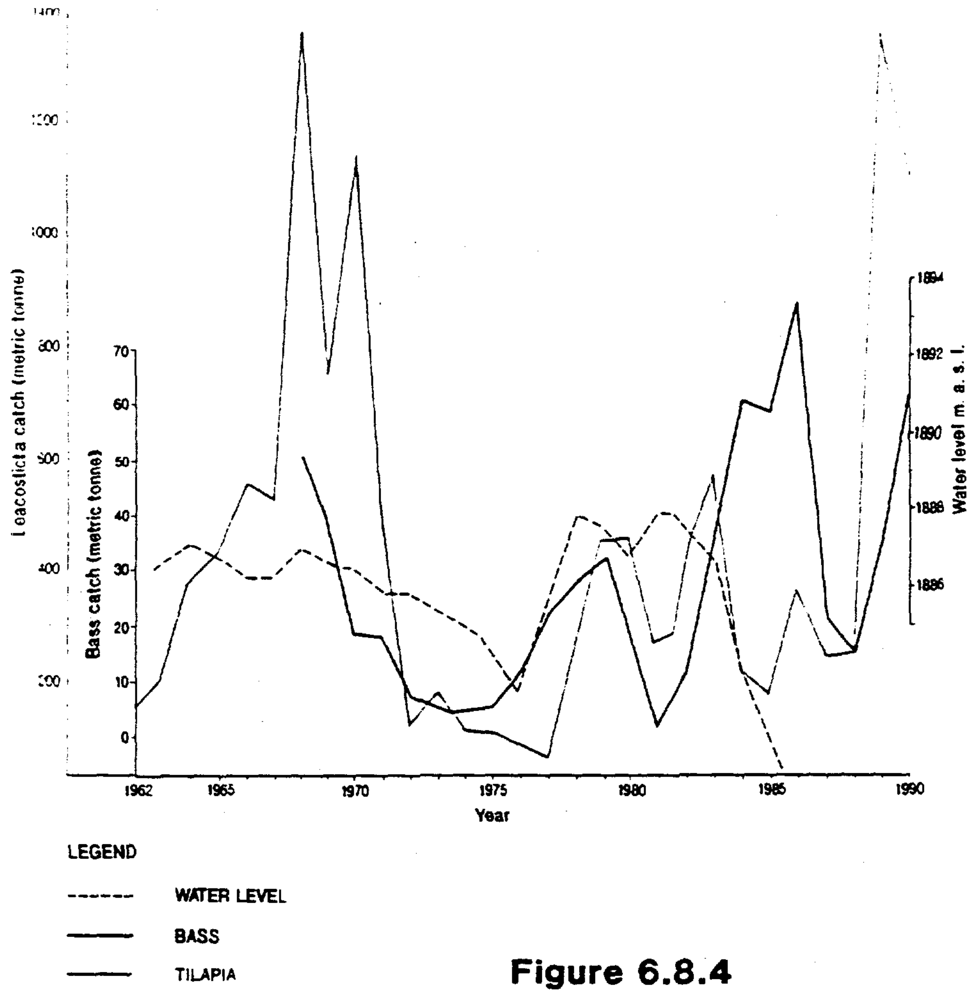


Figure 6.8.4
HISTORICAL FISH YIELDS FOR LAKE NAIVASHA
Source: HARPER et al. (1990)

TABLE 6.8.4- LAKE NAIVASHA FISH CATCHES (kg) FROM 1980 TO 1990.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Oreochromis leucostictus	452539	265069	5978	534608	212733	146247	384173	204067	22969	131472	107723	2,467,578
Tilapia zillii	0	0	0	0	0	0	0	64	833	1634	389	2,920
Micropterus salmoides	18082	3819	3004	4100	64162	60458	83607	19860	15063	36359	62437	370,951
Barbus amphigramma	0	0	0	0	0	0	62888	0	0	0	0	62,888
Procambarus clarkii	6454	0	322018	116165	340	38745	45372	63328	14175	93833	53040	753,470
Total	477,075	268,888	331,000	654,873	277,235	245,450	576,040	287,319	53,040	263,298	223,589	3,657,807

There was relatively little change between 1960 (a period at the end of a low water-level phase) and 1976 (a period of relatively high water-level), except that the raised levels in 1976 had resulted in the formation of more papyrus lagoons, islands and "reefs", than had existed previously (Harper *et al.*, 1990). Mats of S. molesta had formed within these lagoons in some areas.

By 1982, however, the period of rapid water-level increase had raised almost all the Papyrus to form floating islands. These together with an increased quantity of S. molesta mats, covered around 25 per cent of the lake's surface at any one time, moving to all corners of the lake, under the influence of the winds. The water-lilies and all species of submerged plants had completely disappeared from the main Lake, with consequences at all levels of the lake's ecosystems (Harper, 1984). Submerged plants grew continuously in the nearby Oloidien Lake throughout this period; but water-lilies, papyrus (Cyperus papyrus), and *Salvinia molesta*, cannot survive in Oloidien because of its higher alkalinity.

After 1983, the lake's water-level started to decline; between 1983 and 1985, Kenya, along with most of eastern Africa, experienced a severe drought. By 1984 most of the papyrus had become grounded again as reefs, and much of the S. molesta had been stranded by the receding water-line. By 1987 the lake had returned to levels similar to those experienced in the 1950s; but its appearance was considerably changed in two respects. The area of papyrus had been more or less restricted to fringing reefs, the swamps having been reduced by agricultural clearance in most of the northern half of the lake - such that, by 1986, approximately 12 km^2 of original swamp had been reduced to 2 km^2, causing public concern (Harper et al., 1990). Further, between 1986 and 1988, water-lily seedlings germinated in the lake's shallows, for the first time in almost a decade, producing flowering clumps in many places along the eastern shores. Extensive beds of submerged plants also reappeared, growing up to 400 m wide and in water down to 2 m in depth (Harper et al., 1990).

Coincident with the changes in the rooted aquatic vegetation, has been an increase in the phytoplankton and a decrease in transparency (Harper et al., 1990). The lake is now displaying the same signs of "cultural eutrophication" as many lakes in temperate regions.

Underlying Causes of Ecological Change

Most of the dramatic changes in vegetation and fisheries have occurred over the last 15 years, and as Harper et al. (1990) notes there has been no concurrent wide-ranging ecological monitoring of the lake, so explanations have been pieced together from scattered observations. The abundance of submerged plants in 1979 following a period of rapid water-level rise, and then again in 1984-87 during a period of water-level decline, suggests that aquatic plant species are able to adapt rapidly to water-level changes. The reappearance of both submerged vegetation and water-lilies after a period of up to 10 years' absence from the lake is almost certainly a result of the disappearance of Coypu and the population decline of crayfish.

The loss of papyrus between 1983 and 1988 has been due solely to clearance for both large-scale and subsistence agriculture, as Lake levels have declined. The reclaimed land is flat and fertile and almost all is used for arable crops. Inevitably, the process has increased the nutrient levels of the lake, both through leaching and runoff directly from farmed areas, and through loss of the swamps' buffering effect in the inflowing river deltas

(**Gaudet, 1979**). Nutrient concentrations measured in the lake had approximately doubled between August 1984 and August 1988, (for example from a median of 45 to 125 mg/m^3 of soluble nitrogen and from 5 to 12 mg/m^3 of soluble phosphorus; **Harper et al., (1990)**. These are still fairly low by temperate shallow-lake standards but indicate a worrying increase. Some studies are under way by Leicester University, England, on nutrient budgets and sinks in the lake and a water quality monitoring program is being conducted during this assessment study (and hopefully continued by KPC).

It could be argued that Lake Naivasha experienced low levels for more than a decade earlier in this century, and that the recent phase was merely a repeat episode of little concern. However, during the earlier period there was little agricultural activity and dense papyrus swamps developed. The severe reduction in papyrus swamp area has led to fears being expressed about the speed and incompleteness of recovery with increasing water levels (**Harper et al., 1990**).

The vegetation - particularly the papyrus swamps - is the key to the ecological health of the Naivasha Lake-system. The buffering effect of the papyrus is well documented, both for the former north swamp area (**Gaudet, 1979**) and for other wetlands (**Mavuti, 1981; Howard-Williams & Thompson, 1985**). The importance of papyrus and other aquatic vegetation types at Naivasha extends far beyond their role in water chemistry. They are a vital component in the habitat requirements of many birds and mammal species of the lake. Surveys have shown (**Harper et al., 1990**) that the highest species-richness of birds in the lake environs in 1987 occurred in marshland, submerged macrophyte and papyrus zones. Fish eagles (*Haliaetus vocifer*) were more abundant in areas of lake-shore fringed with papyrus and Acacia trees and less abundant where such vegetation had been cleared. Hippopotamus numbers (Hippopotamus amphibius) and group-sizes were highest in the western and southern areas of the lake, where papyrus and natural vegetation zones (*Acacia-Cassia* scrub) were most extensive.

6.9 WATER QUALITY AND MANAGEMENT

6.9.1 Introduction

Water quality and quantity are important issues at North East Olkaria because of the climate of the areas, the proximity and value of Lake Naivasha, and the problem of dispersal of water borne pollutants.

Existing water quality data on wells in the North East Olkaria sector collected by KPC have been reviewed in the following section (**Section 6.9.2**). A water quality profile of the geothermal well water (generally referred to as brine because of its high concnetraion of salts) in the north east field was initiated and is virtually complete apart from a few remaining wells still to be drilled or tested. A wider monitoring program of water quality was also initiated and the results presented in **Section 6.9.3**.

Disposal of geothermal waste waters poses a problem because the fluid is a brine containing chemicals in concentrations that are potentially injurious to both flora and fauna. A 64 MWe development produces a substantial volume of waste water, all of which needs to be disposed of safely. The preferred option for waste brine disposal during steamfield operation, and that recommended in the feasibility report, is for deep reinjection into a number of purpose drilled or unused production wells, and this option is to be implemented. This disposal option and temporary brine disposal options during the construction phase of the development are assessed in Section 6.9.4.

6.9.2 Well Water-Quality

A summary of the chemical constituents of geothermal brine from wells under test is presented in Table 6.9.1. These values can be compared with the general composition of brine from some other fields (Table 6.9.1). The health limits given in the table were obtained from the North East Olkaria Feasibility Study (1989) and the Ministry of Water Development.

The North East Olkaria geothermal water has been described as a slightly alkaline sodium chloride water containing approximately 0.3 per cent of gas and total dissolved salt content around 2000 mg/kg (Ewbank Preece Limited, 1989). Being an alkaline brine the water is saline though not to the same extent as many other geothermal locations and the levels of sodium and chloride are also much lower than that of sea water. The brine, when cool, has only a mildly salty taste and this does not seem objectionable to wildlife.

Comparison of the parameters with the listed health limits (Table 6.9.1) shows that the greatest health risk comes from both fluoride and lead concentrations. Some health limits, such as chloride, are primarily set for taste reasons rather than direct health concerns. Therefore, although the brine is in excess of the health limit, it was not considered a serious concern. With fluoride, an important point to remember is that the problem of high levels is common to all water sources around Lake Naivasha and not just to geothermal sources. However the levels in the brine are over twenty times greater than that found in the regions major fresh water source, Lake Naivasha (Table 6.9.2). Although beneficial in small concentrations (0.6-1.7 mg/l) for the structure and resistance to decay of children's teeth, the concentration in the brine would cause pronounced mottling and disfiguration of teeth and further related problems.

One interesting aspect with the North East Olkaria field is that the level of boron is very low compared to that experienced in other geothermal developments (Table 6.9.1). Normally, the concern with such developments is over boron toxicity and not fluoride and Olkaria would seem to be a unique field in this regard.

The other element of concern is lead which is a serious cumulative poison. However, the lead levels from the different wells are highly variable (Table 6.9.1) and consequently may not always be of serious concern over the entire geothermal field. Along with many other heavy metals, a substantial amount of research has been undertaken on the bioaccumulation of lead in food chains. The greatest threat is to animal species at the end of the food chain (for example carnivores including birds of prey).

Although by world standards the brine may not be considered particularly toxic, overall the levels in Table 6.9.1 show that the brine is a potential health risk and must therefore be disposed of in a safe manner. In particular, the concern would be for chronic symptoms to develop rather than acute. The lack of acute symptoms has meant that the brine has often been considered harmless and little precaution has been advocated for its disposal. However, it can take decades for accumulated levels of lead for example, to reach a point where severe symptoms are evident. Such an effect is a concern with the operation of the existing Olkaria power station, with break-through occuring into Hell's Gate gorge and adds support for deep reinjection.

TABLE 6.9.1 AVERAGE BRINE COMPOSITION FOR NORTH EAST OLKARIA AND COMPARISON TO SOME OTHER GEOTHERMAL FIELDS AND HEALTH LIMITS. The concentrations measured from each North East Olkaria well are given in Appendix 6.9 (All results in mg/l).

	Health Limits	NE Olkaria ($\pm\sigma$)	El Tatio, Chile	Mexicali, Mexico	Wairakei, NZ	Broadlands NZ
pH	6.5-9.2	9.1 ± 0.7	7.3	-	8.3	7.9
TDS	1500	2295 ± 270	-	-	-	-
Na	0.01	546 ± 118	5000	6000	1250	975
Cl	250	640 ± 129	9100	11500	2200	1740
K	-	101 ± 35	840	1125	210	232
Si	-	327 ± 87	810	678	670	796
Mg	-	0.08 ± 0.10	0.1	-	0.04	0.1
NH_3	-	1.1 ± 0.2	3.1	22	0.2	2.3
Zn	-	11.9 ± 24.8	-	6	2	1
Cr	0.05	<0.009	-	-	-	-
Fe	-	155 ± 308	-	200	12	360
B	1.0	3.2 ± 2.3	210	9	29	53
F	0.8-1.7	62.4 ± 36.3	2.5	2.2	8.4	8.4
Pb	0.05	3.66 ± 6.41	-	5	4	4
Hg	0.005	0.001	-	-	-	-
Ca	-	0.63 ± 0.93	203	321	12	3
As	0.05	<0.008	-	0.02	0.047	0.033

TABLE 6.9.2 WATER QUALITY DATA: LAKE NAIVASHA INTAKE.

(Samples for the EA commenced in March 1990: All results in mg/l)

	Health Limits	LLD	19Dec 1971	28Mar 1990	14May 1990	31Jan 1991	6June 1991	12July 1991[8]	20ct 1991	8Nov 1991
pH	6.5-9.2		8.4	7.30	7.60	7.10	8.3	7.95	8.30	8.4
Coliform bacteria	3/100ml	1	-	-	-	-	37	-	-	3
Turbidity	5 NTU		-	-	-	-	1.5	-	-	-
Sodium (Na)	0.01	0.5	28.0	40.8	33.8	35.4	52.0	32.0	38.5	39.2
Nitrate (NO_3)	45	0.001	-	0.382	0.454	0.735	<0.001	<0.001	0.100	-
Ammonia (NH_4)		0.001	-	0.10	0.234	0.10	0.086	0.11	0.10	0.22
Phosphorus (P)		0.01	-	0.105	0.029	0.082	-	-	0.023	2.33
Sulphur (S)		0.01	-	0.315	0.476	0.320	-	-	0.134	-
Boron (B)	30	0.01	-	0.021	0.035	0.014	-	-	0.037	-
Fluoride (F)	0.8-1.7	0.1	1.38	-	-	-	1.85	1.1	-	4.0
Lead (Pb)	0.05	0.005	-	-	-	-	0.120	0.14	-	<0.05
Mercury(Hg)[9]	0.005	0.05	-	-	-	-	<0.05	0.06	-	-
Calcium (Ca)		0.05	16.9	14.5	12.7	16.8	20.60	18.51	20.7	4.26
Arsenic (As)	0.05	0.008	-	-	-	-	<0.008	-	-	<0.008
Magnesium (Mg)		0.01	5.3	5.22	4.82	6.10	6.10	64.16	6.88	6.12
Aluminium(Al)		0.05	-	<0.05	0.06	0.05	<0.05	<0.05	0.28	0.24
Silicon (Si)		1.0	-	-	-	-	4.60	7.75	-	3.0
Chloride (Cl)	250	5.0	7.2	8.71	7.28	6.83	<5.00	<5.00	8.99	<5.00
Potassium (K)		0.14	14.8	20.7	19.4	19.8	18.1	19.95	22.0	21.7
Chromium (Cr)		0.009	-	-	-	-	<0.009	0.022	-	-
Manganese(Mn)		0.001	-	<0.001	0.002	<0.001	0.115	0.013	0.025	0.135
Iron (Fe)		0.002	-	<0.002	0.058	<0.002	0.390	0.09	0.222	3.9
Nickel (Ni)		0.006	-	<0.006	0.007	<0.006	<0.006	<0.006	0.006	-
Zinc (Zn)		0.002	-	<0.002	0.490	<0.002	0.039	<0.002	0.003	0.087
Copper (Cu)		0.001	-	0.008	0.035	<0.001	0.024	<0.001	0.004	<0.001

6.9.3 Water Monitoring

As discussed in the introduction a water monitoring program was initiated. The usual approach to a sampling program is to monitor water inlets and outlets from the project area. In this case, water is taken from Lake Naivasha, but there are no surface outlets to monitor discharge from the project. Reinjection is being used during the current phase of the project cycle and will also occur during the long-term commissioned phase. The

[8] *Eburru pumping station water intake.*

[9] Concentration values in µg/l (ppb).

reinjected fluid will also be below the main perched aquifers so that groundwater contamination of water drawn from wells will also not occur. This means that monitoring is restricted to the water intake to the project (ie Lake Naivasha).

The monitoring at the water intake in Lake Naivasha, has been initiated mainly out of concern for the health of the employees at the KPC housing estate. Factors such as pH greatly affect the efficiency of water treatment. The other reason was that there did not seem to be any systematic sampling in operation by the Ministry of Water and Development. The initial results to date (Table 6.9.2) show that the coliform count is highly variable. The initial sample was probably left too long before being analyzed so that the bacteria had multiplied before being counted. This is a common concern and the second sample is thought to be more realistic. The fact that both samples are at or in excess of the health limit, is an important result when considering the general health of people around the lake and particularly KPC staff. The results emphasise that periodic sampling is needed and just as importantly that the treatment facilities are carefully maintained. The fluctuation in pH highlights the need for monitoring.

6.9.4 Water Disposal

Water disposal is required during all phases of the project cycle. During the current development phase, there are only two wells still to be drilled but there are about a dozen to be tested. The wells are expected to average 3 MWe each and produce about 5 cumecs of waste water every minute. This means, over a medium term discharge of two months, about 400 000 cumecs will need disposal. The original practise of disposal into gullies and natural drainage lines has led to serious erosion as described in an earlier section.

Recently, KPC has initiated a program of piping all brine from wells being tested into a collection pond adjacent to well M1 and then gravity reinjected to OW-R1 adjacent to X2 campsite. This alleviates the problem of water erosion as well as avoids encouraging wildlife from drinking the brine. A similar activity has been initiated for drilling waste-water which can contain toxic compounds (e.g. caustic soda) and bentonite (making the water extremely turbid). The waste-water is being ponded adjacent to well M1 and then piped to a reinjection well. Such actions minimise the environmental concerns.

During the commissioning phase of a steam gathering system, a "steamblow" is required to clear the new pipelines of debris before they are used to transmit steam. A large volume of steam is necessary to completely scrub the line and usually several wells will be opened concurrently and directed down the line. The end of the pipeline is open to the atmosphere and can be environmentally damaging. Care needs to be taken over the scheduling of the steam blow so that the number and the length of line to be cleaned is never so great at one time that it causes problems of fluid disposal.

The chosen disposal method of the geothermal brine during the long term commissioned phase is deep reinjection. By reinjecting the waste water at a depth approximately equal to the production reservoir, there is little possibility of surface or groundwater pollution. The main problem with reinjection is that the waste water contains high levels of dissolved silica and calcium and as the fluid cools, the substances polymerize and precipitate (scale) on to the pipes which gradually block-up. In order to minimize the possibility of scaling there will be a large "conditioning pond" before the "cold" water is pumped for reinjection. The pond will also be the collection point for brine from the separator stations.

6.10 SOCIO-ECONOMICS

6.10.1 Introduction

This section reports the results of the socio-economic baseline studies. It provides information on the relationship of the project area to the administrative boundaries, baseline data on population size, Hell's Gate National Park, economic structure and labour, employment, community infrastructure, transport, Maasai and other issues, which will assist in determining how the project will affect the social component of the environment.

6.10.2 Location

Administrative Boundaries

The geothermal project area of 7 km^2 lies within Naivasha Location (**Figure 6.10.1**) which is within the Naivasha Division, which in turn falls within the Nakuru District. The current administrative boundaries are shown on the map on **Figure 6.10.2**. Hell's Gate National Park's southern and western boundaries concur with the boundaries of Naivasha Location.

Impact Areas

The power station development area lies within the Hell's Gate National Park, which was gazetted in 1984, three years after the East Olkaria Power Station commenced operation. The proposed site of the North East Olkaria Power Station lies approximately 3.3 km north-northwest of the existing East Olkaria Power Station. The southern boundary of the closest flower farm (Oserian) is approximately 1.2 km to the north-northeast of the proposed power station site. The Lake is approximately 5.3 km to the north and Naivasha Town is approximately 22 km to the north-northeast.

Primary Impact Area - The primary impact area, for the purposes of the Olkaria socio-economic assessment, is the Hell's Gate National Park. This area is consistent with the anticipated envelope of potential physical impact, due to changes in air quality. In general terms, this primary area is to the south of Lake Naivasha and accessed by Moi South Lake Road.

Secondary Impact Area - This area was assumed to be the Census area mentioned above as Naivasha Location. This area includes those areas where the direct workforce and immediate suppliers of indirect labour (both for construction and operation) could reasonably be expected to commute on a daily basis (see **Figure 6.10.1**).

Town Council Boundaries

In Government publications such as the 1979 census, Naivasha Township refers to the 10 km^2 urban centre of Naivasha. However, 'Naivasha Township' is also used by Naivasha Town Council to refer to the entire area covered by the council. The boundaries of this area are identical to those of Naivasha Location, except for the Northern section. The area is 940 km^2 and includes the project area (**Figure 6.10.3**)

Within this 'Township' area, lies Hell's Gate Ward, covering most of the area likely to be affected by the project.

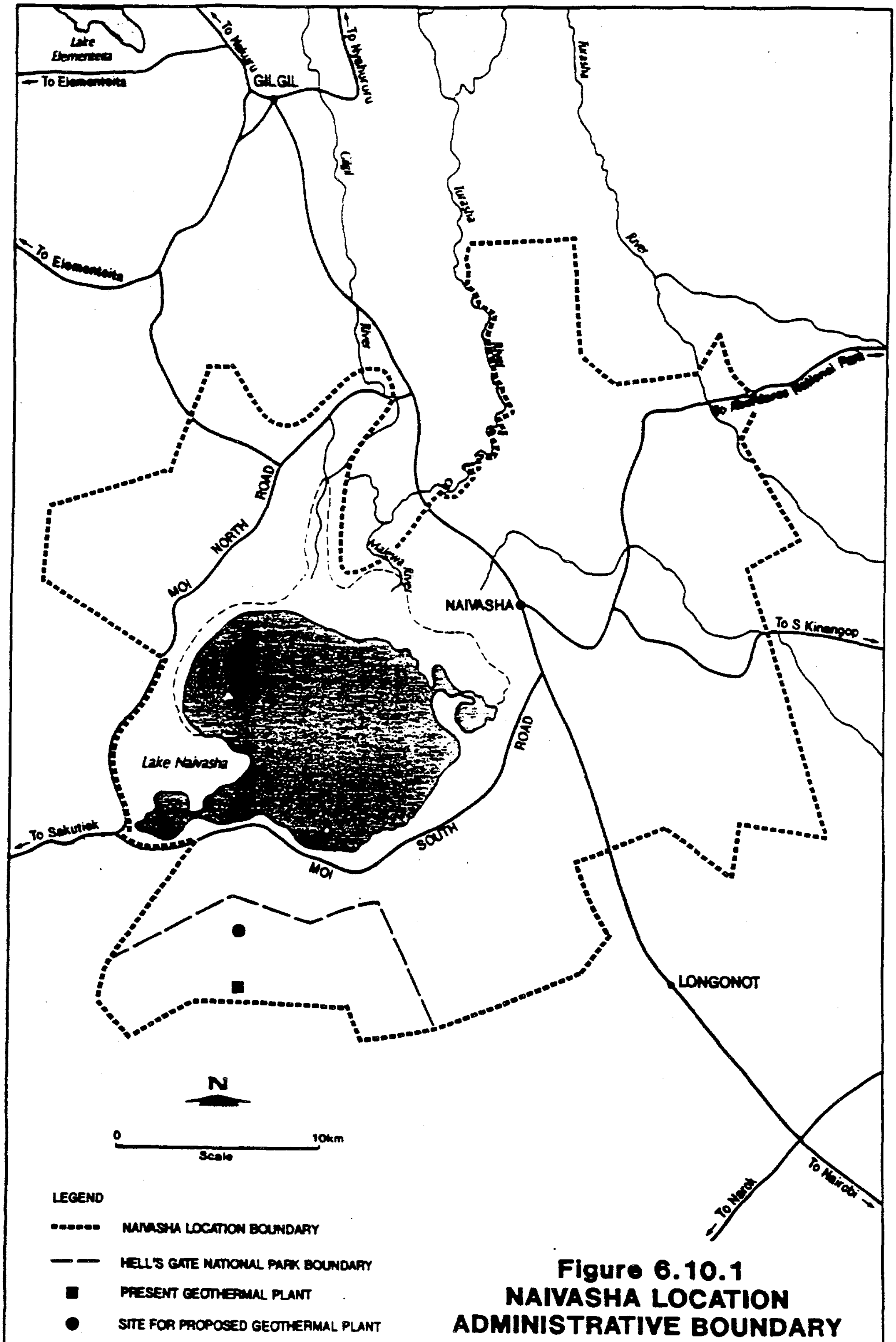


Figure 6.10.1
NAIVASHA LOCATION ADMINISTRATIVE BOUNDARY

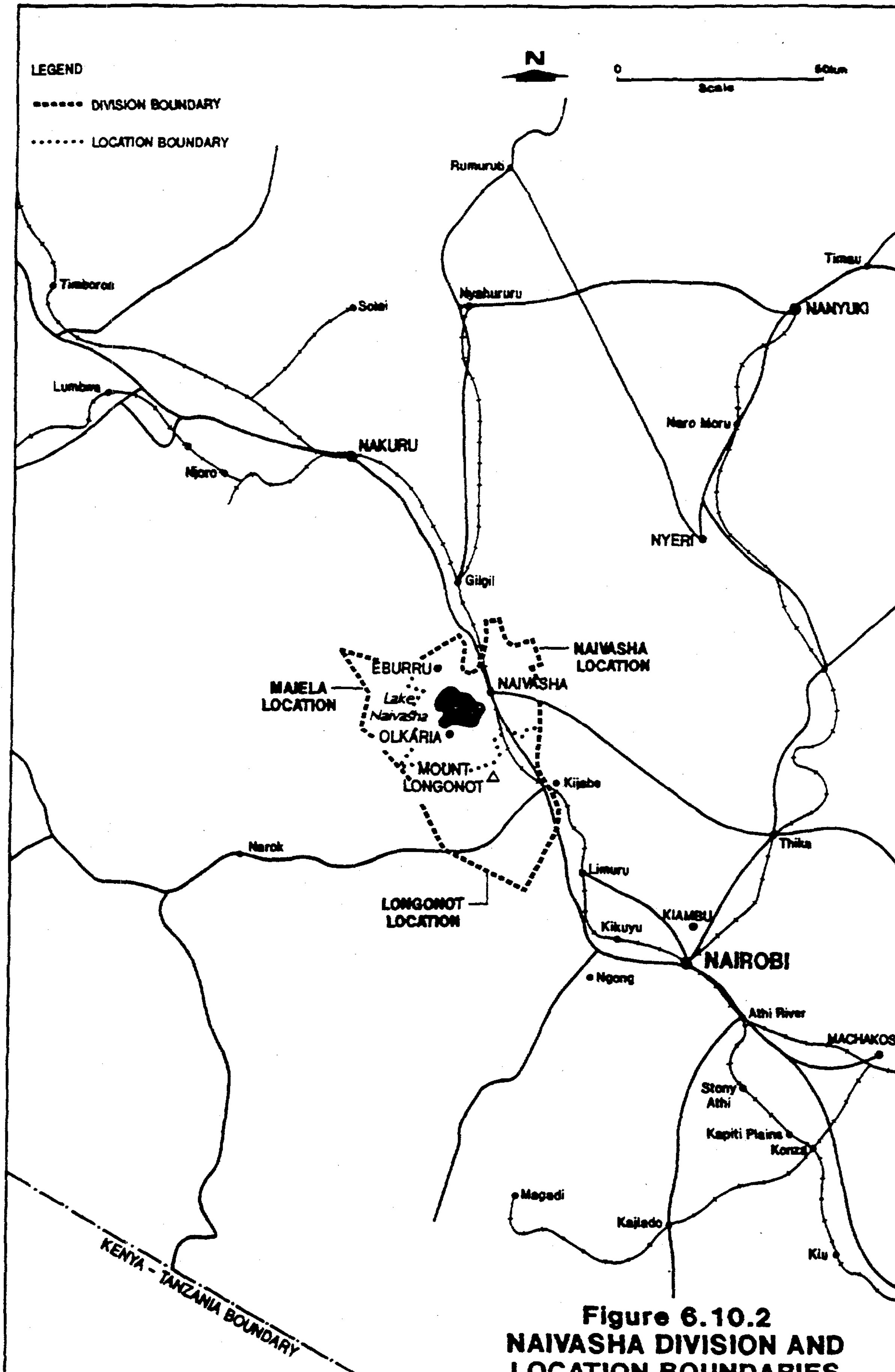


Figure 6.10.2
NAIVASHA DIVISION AND LOCATION BOUNDARIES

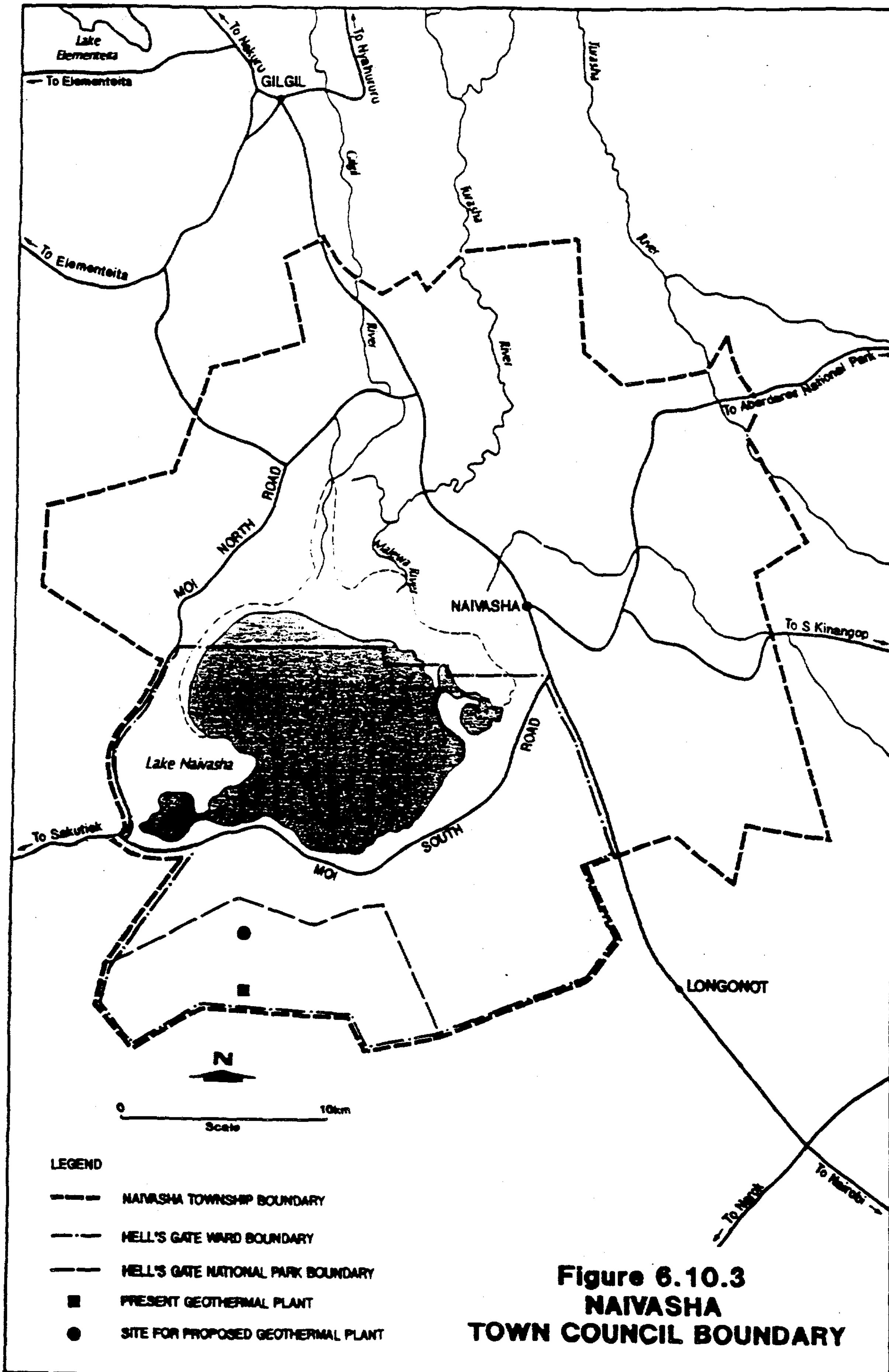


Figure 6.10.3
NAIVASHA
TOWN COUNCIL BOUNDARY

Naivasha Town
Naivasha Town lies 89 km north-northwest from Nairobi and 69 km from Nakuru Town. It is served by the main road of Trans Africa Highway and the old main road from Nairobi which now mainly serves buses and heavy trucks. The main railway line from Nairobi passes through Naivasha station.

The Town Centre, of about 25 km^2, is administered both by the Council and the Ministry of Lands.

6.10.3 Demography

Existing Population Estimate

Naivasha Division
The 1979 census gave data which are summarised in Table 6.10.1.

TABLE 6.10.1- POPULATION DATA

	Total Pop.	H/holds	km^2	Density
Naivasha Township	11 491[1]	2856	10	1,113
Naivasha Rural	38 858	9473	957	40
Total Naivasha Location	50 349	12 329	967	52
Kijabe Location	9653	2087	740	13
Gilgil Location	35 337	8221	1039	34
Total Naivasha Division	95 339	22 637	2747	34

(1) Adjusted: 12 102

Gilgil has since been removed from Naivasha Division, so the 1979 population of the current Division was 60 002.

Naivasha Town
Naivasha Town had a 1979 population of 12 102. The rate of population growth since 1979 is not accurately recorded, as the recent census was incomplete, and so current urban populations can be assessed only by reference to the Central Bureau of Statistics/UNDP forecasts of 1984 and Economic Review estimates. In the case of Naivasha, a reasonable estimate, based on the experience of other secondary towns, would be a conservative annual growth rate of around 6.5 per cent, giving a 1991 population of around 26 000.

However, it is noted that the current Nakuru District Development Plan anticipates a population of some 38 620 by 1993, as follows:

Population Projection (Min. of Econ. Plan & Dev., 1981)

	1988	1993
Naivasha Town	26 289	38 620

This suggests an annual growth rate in excess of 10 per cent, and is endorsed by the 1991 Economic Review, based on provisional figures for the 1989 census, which gives a Naivasha Town Council figure of 34 500.

Based on this figure, the current population estimate is as follows, assuming a growth rate of 7.5 per cent per annum after 1989:

1979:	12 102
1989:	34 500
1991:	40 000

Primary Impact Area South of Lake
To the south of the lake, the Town Council indicates that around 40 per cent of the 'Township' population are within Hell's Gate Ward, ie around 48 000. Hell's Gate Ward covers basically the area south of the lake. This population estimate of 48 000 is estimated to break down roughly as follows:

Sulmac	:	15 000
Oserian	:	10 000
Kongoni	:	500
KPC	:	800
Other	:	21 700
Total	:	48 000

Migration
The major factors responsible for significant population influx into the Naivasha area are listed below,

- o The buying and subsequent sub-division of former settler farms, such as Green Gordon Estate, Karati, Marorigushu, Missouri, Mukiringiri, Maiura;
- o The opening up of the Moi South Lake Road area by the Olkaria geothermal development. It is reported that there are as many as 700 people living in the Hell's Gate National Park area in around 230 shanties, and;
- o The establishment of large irrigated farms.

Summary
Based on an extrapolation of the 1979 Census and Council Sources the 1991 population to the south of the lake is 48 000. As noted above the population within Hell's Gate National Park is composed of some KPC personnel and Park Staff.

1991 Population Estimate:	
South of the Lake	48 000
Naivasha Urban	40 000
West, north and east of the Lake	62 000
Total Naivasha Division	150 000

6.10.4 Hell's Gate National Park

Background
As discussed above, the proposed power station lies, like the existing Olkaria Power Station, within the boundaries of Hell's Gate National Park. This park was gazetted several years after the geothermal development commenced and has been defined as the primary impact area for this proposal.

The key highlights of Hell's Gate National Park are as follows,

- Gazetted 2 February 1984;
- 14 km from Naivasha town;
- 115 km by road from Nairobi;
- Lies within Naivasha Division of Nakuru District, R.V. Province;
- Approximately one half of the park contains KPC geothermal developments;
- Area: 68.25 km^2 (6825 ha);
- Management is by the Department of Wildlife Conservation and Management (now Kenya Wildlife Service);
- The Government bought the land from private owners, notably Sulmac;
- Features:
  - The Njorowa Gorge
  - Fisher's and Central Towers (geological formations)
  - Flora
  - Fauna
  - Possible habitat of the Lammergeyer
  - Can alight from vehicles and walk
  - Can relieve "weekend pressure" on Nairobi National Park, and;
- Shares a warden with Mt. Longonot National Park.

Layout
There are three zones in Hell's Gate National Park as shown in **Figure 6.10.4**.

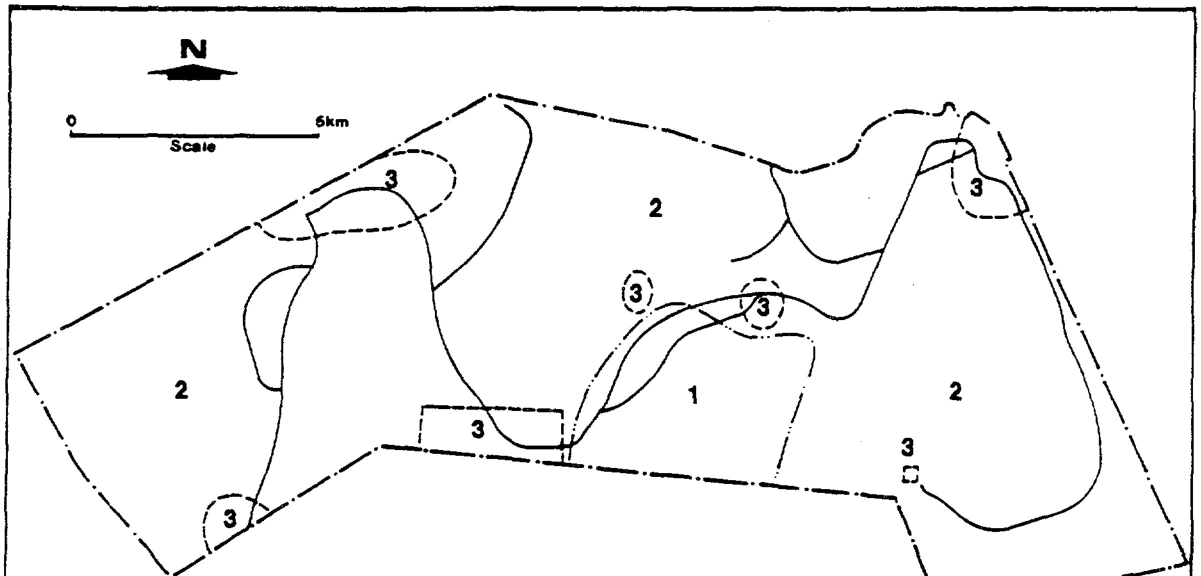


Figure 6.10.4

HELL'S GATE NATIONAL PARK SHOWING ZONING

Zone:

Preservation: 1. (14 per cent) - High Degree of Protection

Wilderness: 2. (75 per cent) - For Public access/climbing

Services: 3. (11 per cent) - Administration/Gates/Campsites etc.

The area to the north and west of the Olkaria Geothermal Plant is currently in use by the KPC for well exploration, testing and production.

Access to the park is by three gates:

- o Main Gate;
- o Olkaria Gate, and;
- o Narasha Gate (not currently used).

Adjacent Land Use
In the areas adjacent to Hell's Gate National Park, the main land uses are:

- o Livestock rearing;
- o Cultivation;
- o Human Settlement, and;
- o Infrastructure.

The inhabitants of adjacent areas move about with their livestock in search of pasture and water. In some cases they encroach into the park area.

To the north and east, the adjacent land uses are:

- o Farm Estates (flowers and food crops).

To the south and south-east,

- o Marginal Land (Privately owned)
  (Kedong Ranch Ltd, and Ngati Farmers Cooperative), and;
- o Wildlife dispersal zone.

Park Development Plan
The planning initiative for the park was set out in "Development plan for Hell's Gate and Mt. Longonot National Park" - Barrah & Jenkins (1981). The current planning document is "Management Plan 1985" (Wildlife Planning Unit), which is now the basis for an updated plan, currently being developed by the Kenya Wildlife Service.

The stated objectives are as follows:

- Conservation of unique scenic features;
- Conservation of flora;
- Conservation of fauna (including birdlife);
- Soil Conservation;
- Provision of wilderness enjoyment opportunities, and;
- Provision of educational and research opportunities;

Other key features in the strategy are:

- Relieves pressure on Nairobi National Park;
- Forms an important link with Nairobi and Maasai Mara National Reserve on the Western Tourist Circuit;
- There had been no organised visitor survey, and;
- The pattern of visits and accommodation is not known.

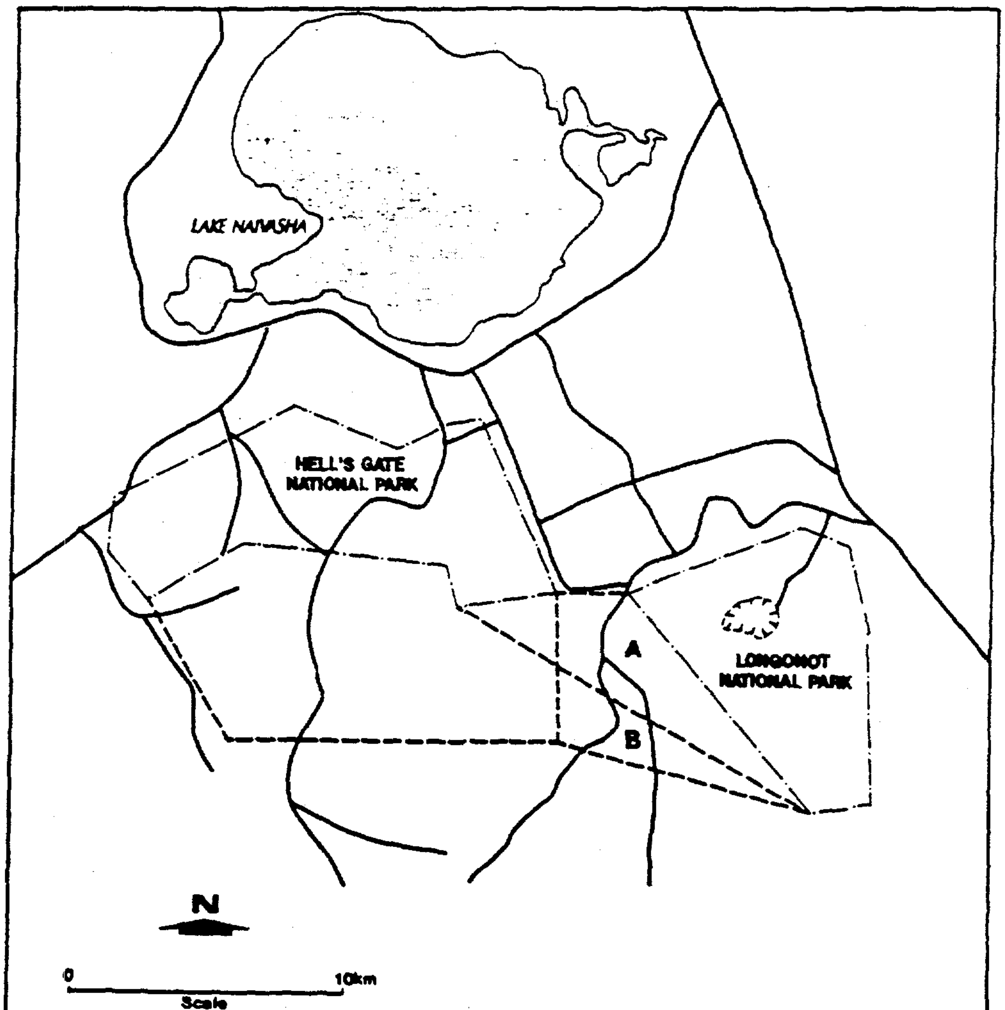
The park has some 51 km of boundaries, of which 41 km are not clearly marked or fenced. The plan is to acquire additional areas south and east of the park, as shown on the map below. It is planned to extend the present park as shown in **Figure 6.10.5**.

- The 850 ha east of the gorge is known as the "Amphitheatre". The large tracts of land south of the park contain the gorge, and will be used as a wildlife dispersal zone. They have little value for ranching. The acquisition plan will open up access from the main Narok Road to the lake, and will be complimentary to Mt.Suswa National Park.

Co-existence with Geothermal Development
The western half of the park is incorporated in a number of blocks of land gazetted for geothermal exploration and development, a project which commenced many years before the area was gazetted as a National Park.

The management plan expresses some concern about possible:

- Pollution;
- Effluent disposal;
- Emissions, and;
- Odour.



LEGEND

- PARK BOUNDARY
- ROAD
- PROPOSED EXTENSION
- A PROPOSED CORRIDOR

Figure 6.10.5

HELL'S GATE/LONGONOT NATIONAL PARKS PROPOSED CORRIDORS

The plan notes that spatial expansion of the Olkaria geothermal area could be a potential threat to the survival of the park. It proposes that the Wildlife Conservation and Management Department should control further exploration. It notes that the park has been committed to tourism development, and "cannot be overrun by any other development needs"

A suggestion appears in the Management Plan:

o "Review of the park area versus geothermal development, with a view of laying little emphasis on developing the park area under geothermal exploration for conservation and touristic purposes, and placing more emphasis on Mt. Longonot National Park, on the Longonot - Hell's Gate corridor, and the expansion area. A re-definition of Hell's Gate/Mt. Longonot Park's boundary may be necessary."

It is clear from several meetings with Kenya Wildlife Services (KWS) that a land use plan is now required covering both geothermal, tourism and wildlife.

Such a master plan is under discussion but is not complete. The present plan does not fully take into account the plans and aspirations of both the KWS and the Ministry of Energy. The implications of co-existence have not yet been identified, and neither have guidelines for the management of such co-existence yet been agreed upon.

6.10.5 Regional Economic Structure & Labour

Naivasha Town

The economic structure of Naivasha town is shown in **Table 6.10.2**. There has been a steady increase in agricultural employment. The other industry which has shown an increase in importance is trade & catering, which is probably related to the growth of the tourist industry. Employment in the energy related industry has gradually declined within the township.

TABLE 6.10.2 - WAGE EMPLOYMENT BY INDUSTRY

	1984	1985	1986	1987	1988
Agriculture	349	216	453	480	769
Mining	-	-	-	-	-
Manufacturing	580	236	611	590	350
Elect. & Water	107	108	115	98	80
Construction	4	82	403	394	42
Trade & Catering	313	373	515	569	590
Trans & Commun.	42	49	41	40	64
Finance etc	59	63	669	70	66
Community	2370	2498	3000	2834	2847
TOTAL	**3824**	**3976**	**5207**	**5075**	**4808**

(Source: Statistical Abstract)

Earnings
Total earnings in the urban area are reported in Table 6.10.3.

TABLE 6.10.3 - TOTAL & AVERAGE EARNINGS NAIVASHA TOWN

	Total Earnings L,000 annum	Average Earnings per Capita (Shs/Month)
1984	2 793 700	1218
1985	3 257 400	1365
1986	3 640 400	1165
1987	4 725 200	1552

Primary Impact Area South of the Lake
No published statistics are available on employment in Naivasha location outside of the urban area.

The number of employees in Agriculture in Naivasha Division as a whole is estimated by the local authority at around 30 000. Statistics gathered from Town Council officials and interviews with local employers in the farms around the lake are reported in Table 6.10.4.

TABLE 6.10.4- ESTIMATE OF EMPLOYMENT NUMBERS IN MAJOR ENTERPRISES (INCLUDING CASUAL LABOUR) IN HELL'S GATE WARD

Sulmac	3000
Oserian	2300
ADC	1000
KPC	250
Longonot Horticultural	300
Goldsmith Seeds	250
Aberdare Estates	60
Mbegu Farm	60
Indu Farm	180
Lake Naivasha Vineyards	30
Hotel (Various)	200
Other Farms and Ranches	1000
TOTAL	8630

Source: Local Council & Employers

6.10.6 Commercial Sector

Leading businesses in Naivasha Division are as follows:

(a) Pan African Vegetables and Foods (Production of dehydrated vegetables, mainly for the export market);

(b) Economic Housing Group (Production of prefabricated houses);

(c) Kenya Co-operative Creameries (Handles all aspects of milk production);

(d) Kenya Commercial Bank;

(e) Pharmaceutical & Horticultural Inputs Ltd (manufacturers);

(f) Njowang'a Motors Garage;

(g) Naivasha Farm inputs Ltd (animal feeds);

(h) Donleah Ltd (Hardware supplies);

(i) Njonge Glass Mart;

(j) Ng'anga General Hardware, and;

(k) Alert Agencies (Hardware).

6.10.7 Agriculture

Ranching
The largest ranch partly within Hell's Gate Ward is Kongoni, with a population of around 500. A leading dairy farm, it irrigates for the growing of cattle fodder. Some tourism facilities are available. The ranch has 3300 acres of wheat.

Flower Farming
The leading flower farms are:

- **Sulmac**
  Sulmac employs around 3000 seasonal, casual and permanent staff, and has an estimated population of 15-20 000. Sulmac grows carnations, and;

- **Oserian**
  Oserian employs around 2600 and has a population of up to 10 10 000.

Other Farms
There is a large number of farms, including horticultural businesses, which have developed around the lake, particularly on the southern side, as may be judged by the

following lists

Developments on Moi South Lake Road
(showing the distance in kilometres from the junction)

ABERDARE FARM	1/8
ACACIA HOTEL	1
BOFFAR FARM	1
JACAN FARM	1
CALDER FARM	1
DANHILL FARM	2
LAKE CROP FARM	2
HORTITEC FARM	2
ARMITAGE FARM	2
MBEGU FARM	3
PINO FARM	3
CLAUSE FARM	3
INDU FARM	3
CARECTUS MARKET	3
LAKE NAIVASHA COUNTRY CLUB	3
DOLER FARM	4
LAKE NAIVASHA HOTEL	5
SANCTUARY FARM	6
MIAKA FARM	7
MILIGARE	7
NIL LTD	8
LAKE NAIVASHA VINEYARD	8
FLAMINGO FARM	8
LONGONOT PRIMARY SCHOOL	9
LONGONOT MARKET	9
SAFARILAND HOTEL	9
LONGONOT HORTICULTURE	12
YMCA	14
ELSA GATE	14
OSERIAN STAFF HOUSES	14
SULMAC COMPANY	16
SUSWA WATER SUPPLY	16
SULMAC HOSPITAL	16
FISHERMAN'S CAMP HOSTEL	18
SHINGRI-LA FARM	18
GOLD SMITH SEED COMPANY	18
LAKE SIDE FARM	19
KPLC OLKARIA	20
KPLC STAFF HOUSES	20
OSERIAN FARM	21
OSERIAN DEVELOPMENT COMPANY LTD	21

6.10.8 Tourism and Catering

Tourism facilities are centred principally around the southern boundary of the Lake, accessed by the Moi South Lake Road.

Principal attractions are:

- The Lake itself together with Crescent Island, Hippo Point, Crater Lake, and the accompanying flora and fauna, particularly the bird life, and;

- Hell's Gate National Park, its principal features being the Njorowa Gorge, Fisher's and Central Towers, flora and fauna.

Recreational activities are: fishing, sailing, sight-seeing,bird watching, game watching and camping, walking and climbing.

Tourist facilities on the Lake are:

South Side: (from Naivasha)

o	5 km	Naivasha Hotel;
o	9 km	Safariland Hotel;
o	-	Crescent Island Tented Camp;
o	14 km	YMCA;
o	18 km	Fisherman's Camp, and;
o	20 km	Elsamere.

North Side:

o	11 km	Korongo Farm Camp;

Other facilities on the Moi South Lake Road, are:

- Acacia Barbecue (restaurant), and
- Green Park Meat Annex (restaurant).

In the town are:

- Belle Inn, and;
- Mt. Longonot Lodge;

6.10.9 Community Infrastructure

The secondary impact area of Naivasha Location may be affected by the construction, operational and induced population impacts of the proposed Olkaria development. Consequently this sub-section briefly describes existing community infrastructure in the recognised 'township area'.

The Local Authority indicated there is great pressure on existing resources and activities in Naivasha Division.

Education and Training
Current facilities within the Town Council area are shown in Table 6.10.5.

TABLE 6.10.5 - EDUCATION FACILITIES

	Public	Private	Total
Secondary Schools	3	1	4
Primary Schools	n/a	n/a	45
Nursery Schools	27	16	43

Source: Council Sources

The above data include the Rainbow pre-Primary School with a capacity of 60 pupils. Sulmac and Oserian both have large Primary Schools.

Education officials are of the opinion, that there is a shortage of secondary school capacity in the Town Council area. Particular attention was also drawn in the LADP (1986) to the shortage of nursery schools, due to the rapid increase in population.

While the number of places in schools were not immediately available, it is clear that with a population of around 15 000 in the township , of which 50 per cent may be assumed to be under the age of 14 years, there is a severe shortage of facilities.

Currently Naivasha has the following trade & tertiary institutions:

- 1 Secretarial college;
- 5 Village polytechnics;
- A dairy training school;
- Animal and Husbandry Research Institute;
- National Youth Service, and;
- Wildlife and Fisheries Training Institute;

Health Services
Current facilities are:

- 1 District Hospital (2 doctors);
- 3 Health Centres (public), and;
- 3 Health Centres (private).

Approximately seven private doctors operate private clinics.

The facilities are considered locally to be inadequate for the existing population. A need has been identified for an extension of Naivasha General Hospital, particularly the casualty department, and for health centres at four new locations.

Sulmac, Olkaria and Oserian have their own health centres.

Housing
There is generally considered to be a shortage of housing in the urban area. The majority of housing has been privately developed, or as site and service schemes.

Public
The largest developments of public housing are the Council houses, located mainly in Soloni ward.

The Council has a total of 465 housing units broken down as follows:-

Phase 1	-	10 units at 100/= per month
Phase II	-	197 units; of which
		154 units at 150/= per month 43 units at 100/= per month
Phase IV	-	118 units of which
		40 units at 100/= per month 40 units at 85/= per month 38 units at 150/= per month
Phase V	-	96 units at 120/= per month
Phase VI	-	30 units at 500/= per month
Phase VII	-	16 units at 600/= per month

There are also "standard" houses. These are good public houses developed by the council but let to private individuals. There are 9 units with varying rent levels.

Recently a new scheme of 75 units, under a tenant purchase scheme, was completed by the National Housing Corporation in collaboration with USAID.

The Council has a total of 465 housing units.

Private
Most private houses belong to investors who own 1-3 plots, which they develop. Most investors do not live in the houses but hand them over to private estate agents for letting.

One private estate agent interviewed, suggested that of the self-contained houses, approx:

- o 5 per cent are one bed-roomed;
- o 75 per cent are two bed-roomed, and;
- o 20 per cent are three bed-roomed.

The principal residential estates and information about their capacities and monthly charges are listed in **Table 6.10.6.**

TABLE 6.10.6- RESIDENTIAL ACCOMMODATION

Estate	Capacity (Families)	Rental Charges (Kshs/month)
'Industrial' estate	50	1800-2200
Site and Services	200	1500-1800
Kabati	300	150-1800
Kihoto	150-200	150-300
Commercial buildings used for residences	500	300-600

Water Supplies

The town is about three kilometres from the shores of Lake Naivasha. Although it is a fresh water lake, it is unsuitable for human consumption.

The residents around Naivasha get water from the Malewa and Marati rivers. The town has three bore-holes which have reportedly proved inadequate to cope with the growth rate of the population. Tap water for human and animal consumption is a problem, as the water is inadequately treated and sewage overflow/outfall goes into the lake.

There are four public boreholes with a total maximum capacity of about 150 m^3 per hour. These are shown on the map overleaf.

Capacities

Borehole-A - 90. m^3.h
Borehole-B - 35. m^3.h
Borehole-C - 15. m^3.h
Borehole-D - 7.5 m^3/h
TOTAL 147.5 m^3/h

Standard consumption rates are not available for Naivasha, but taking a number of 60 litres per day per person, with an output off 70 per cent of peak capacity, this would provide for a population of around 40 000.

However, not all of these boreholes are in good working condition.

The Council has also recently dug two new boreholes (1991) each with a capacity of 30 m^3/h. One of the three old boreholes still needs a new pump for it to be fully operational. The council plans to install a new pump with a capacity of 34 m^3/h.

Recreation Facilities

Stadium
Naivasha Town Council has a stadium located between the main Trans Africa Highway and the Community Hall. This stadium has a capacity of about 60 000 people. The stadium is not strategically located, resulting in loss of revenue (through gate collection), because people can easily watch matches from the flyover to the prison.

Community Hall
There is a small community hall, located next to the stadium which has a capacity of about 100 people seated. It lacks any facilities such a conference room and places for indoor games.

Public Parks
There are several open areas in Naivasha but none is designated as a public park. The Council is planning to establish public parks with flower gardens and seating facilities.

6.10.10 Transport

Detailed traffic counts were carried out on Moi South Lake Road and Moi North Lake Road from 6.00 am to 6.00 pm, Thursday to Sunday. There is very little traffic on these roads after dark.

These are the two roads which may potentially be affected by the construction phase of the project. However the effect on the Moi North Lake Road is likely to be minor.

Moi South Lake Road

Public Transport - Buses

Two buses operate on this route.

Each has a capacity of about 62 passengers. They charge 4/= per trip from Naivasha town, the junction, and 20/= from the junction of Moi South Lake Road to Olkaria

Passengers on this route mainly catch their buses at the main bus park in town, opposite KGGCU or in some cases at the junction of the Moi South Lake Road.

The maximum number of buses travelling to Naivasha recorded in any one day was four. These travel only between 6.00 am and 9.00 a.m., and between 12.00 noon and 3.00 p.m.

The pattern from Naivasha is similar, with up to three buses per day between 9.00 a.m and 6.00 p.m.

This means a carrying capacity of 120-240 people per day in each direction, which is very low compared to the number of people employed in these areas.

Matatus

Most of the matatus operating on this route are the pick-up type with a capacity of about 16 passengers. They charge 5/= from town to the junction of Moi South Lake Road and 20/= from the junction to Olkaria.

Matatus are considerably more frequent than buses. The average number of matatus per day is 30 in each direction between 6.00 am to 6.00 pm, i.e. an average interval of around 25 minutes.

Traffic Volume

The total vehicular traffic, both to and from Naivasha is reported in **Table 6.10.7.**

TABLE 6.10.7- TRAFFIC VOLUMES MOI SOUTH LAKE ROAD - DAILY AVERAGE VEHICLES 6.00 AM TO 6.00 PM

Type	Number	No/h Average	Interval
Matatus and Buses	68	6	11 mins
Private Vehicles	353	29	2 mins
Commercial Vehicles	111	9	6 mins
Tourist Vehicles	37	3	19 mins
KPLC	26	2	28 mins
Motor Cycles	13	1	55 mins
Bicycles	271	23	3 mins

Source: Field Survey 1991

By far the heaviest traffic is in the private vehicle category. Within this category the degree of variation during the days reported is shown **Table 6.10.8.**

TABLE 6.10.8 - TOTAL PRIVATE VEHICLES (FROM AND TO NAIVASHA)

	6.00-9.00	9.00-12.00	12.00-3.00	3.00-6.00	Daily Total
Thursday	47	87	50	63	247
Friday	16	124	130	136	406
Saturday	41	67	93	89	290
Sunday	32	110	139	186	467
Daily Average	34	97	103	119	353

Moi North Lake Road Traffic Volume

Public Transport - Buses

No buses operate on Moi North Road.

Matatus

Interviewees reported that three matatus operate on this route but the consultants recorded a maximum of two on all days, except Sunday. Typically, there are two matatus per day in each direction. They travel from Naivasha early in the morning and return in the afternoon. This means a carrying capacity of 32 people per day in each direction. It is clear that many local people depend on getting lifts with private transport, lorries and tractors.

The matatus charge 7/= from Naivasha to the junction of Moi North Lake Road, then 23/= to Ndabibi.

The total vehicular traffic, both to and from Naivasha, was as reported in **Table 6.10.9.**

TABLE 6.10.9- DAILY AVERAGE VEHICLES 6.00 AM TO 6.00 PM MOI NORTH LAKE ROAD

Type	Number	Vehicles/h Average	Interval
Matatus & Buses	4	0.4	180 mins
Private vehicles	33	2.7	22 mins
Commercial vehicles	21	1.8	34 mins
Tourist vehicles	3	0.3	240 mins
KPLC	-	-	-
Motor Cycles	3	0.3	240 mins
Bicycles	11	0.9	65 mins

Most of the vehicular traffic is in the private and commercial categories. Within these categories the degree of variation during the day is as reported in **Table 6.10.10.**

TABLE 6.10.10- TOTAL PRIVATE VEHICLES (TO & FROM NAIVASHA) MOI NORTH LAKE ROAD

	6.00-9.00	9.00-12.00	12.00-3.00	3.00-6.00	Daily Total
Thursday	6	7	5	2	20
Friday	3	9	9	10	31
Saturday	7	14	15	13	49
Sunday	3	6	10	12	31
Daily Average	5	9	10	9	33

TABLE 6.10.11- MOI NORTH LAKE ROAD - TOTAL COMMERCIAL VEHICLES (FROM AND TO NAIVASHA)

	6.00-9.00	9.00-12.00	12.00-3.00	3.00-6.00	Daily Total
Thursday	10	7	4	3	24
Friday	7	5	7	6	25
Saturday	5	1	7	7	20
Sunday	4	1	7	3	15
Daily average	6	4	6	5	21

Road Maintenance and Upgrading

The Trans Africa Highway passes through Naivasha, north of the town. This connects Naivasha with both Nairobi and Western Kenya. The Old Naivasha Longonot - Nairobi road is still used by heavy commercial vehicles and a limited number of tourists, and is in poor condition. The Moi South and North Lake Roads were until recently only rough tracks, but in 1991 a new tarmacked highway was completed from the Old Naivasha road to Olkaria.

The following projects are set out in the current Development Plan:

- o Road CBB: Rehabilitate 39.5 km from Central/Rift Boundary to junction of A104 at Naivasha

  KL3950 000 (GOK);

- o Rehabilitation of 23.3 km of road from District boundary/Nyandarua to Naivasha and to Moi South Lake Road

  KL116 000 (GOK);

- o Gravelling Road D445: 9.4 km from junction D323 to Maiella centre: (W. Germany: L35 250) (KFW);

- o Gravelling Road D394: 9.7 Km from junction Fisium to CBB Longonot.

  (KFU: KL36 375);

- o Travelling E443 7.0 km from CBB Maai Maahiu Kijabe, and;

- o Bridge Maai Mahiu - Narok road B3.

Of most significance to the project was the recent upgrading of the main access road into the project area from Naivasha.

6.10.11 Perceptions and Attitudes Towards the Existing Project

The principal socio-economic impact of the existing geothermal project, indeed the entire geothermal program, has been its major contribution to the opening up of the area south of the lake to rapid development, culminating in the building of a major tarmac road from Olkaria to the old Naivasha-Longonot road. In terms of employees, its payroll of around 2-300 represents only a tiny fraction of the total number of employees south of the lake, estimated at over 8000. In terms of pressure on amenities in Naivasha township, the impact has been minimal, as KPC provides housing and, like the flower farms, provides basic facilities such as a clinic.

A critical issue to resolve during the next phase of studies will be the resource management question concerning the multiple use of Hell's Gate National Park. It would appear from the attitudes expressed to date that there is a need for compromise between the KPC , tourism and conservation interests.

The following section summarises attitudes towards the existing power development, both from the local community and foreign tourist perspective.

Local Community

Local people interviewed both in Naivasha Town and around the Park exhibited a generally favourable and positive attitude towards the geothermal project, citing the greatly improved access to the area, and its beneficial effect on tourism and bed occupancy, and on the local economy in general.

Where doubts and concerns were expressed, they related generally to:

- o Possible pollution, including health hazards;
- o The level of the lake, and;
- o Driving standard of KPC employees.

Some of the negative comments made, may be judged by the following selection of responses. The impact assessment report will address these perceptions in relation to the new project.

Mr.___ broached the subject on the effects of the project on tourism around Hell's Gate National Park and Lake Naivasha. He expressed deep concern that the project will kill tourism in the area.

> "Olkaria steam breaks down principally hydrogen sulphide. The only known nullifier is Ammonia, a highly inflammable gas plus salts of sulphuric acid which affects humans, animals and plants".

> "Irritating cough, long term effect. (cause hardening of lungs). Acid rain is corrosive and can cause lung fibrosis and action must be taken."

Fisherman:

> "Bad smell like "choo". After getting used you do not smell, fish started declining in 1987".
>
> "Extremely concerned about water from holes; decent drainage is required instead of flooding land; information is required about wind drift, noise and smell pollution."

Poaching will increase.

"Govt. experimental farm should be developed near the station to determine whether the effluent affects flowers."

"Vegetation destroyed lake too long to revegetate. Our 'exotic tourism' will be affected. Moi-North South road will increase robbery and burglary in this area."

> "We are worried about the disappearance of lake. The lake has gone far down. Even when the lake fluctuation cycle is considered, there are far too many people abstracting water from the lake. It may disappear altogether".
>
> "We are afraid tourists who are concerned about health and pollution may be driven away by OGDP. The matter should be handled with care because people may take advantage of the special problem in our environment"
>
> "Crime will increase due to easy communication".

Tourist Perceptions - Tourists in the Park
A four-day survey was conducted of all tourists leaving Hell's Gate National Park though the Main Gate, in order to establish attitudes towards the existing geothermal station. A total of 230 tourists were interviewed.

They entered the park as follows:

o	Main Gate	83%
o	Olkaria Gate	17%.

Those who entered the Olkaria Gate will inevitably have passed through the geothermal development area, and some tourists who entered the main Gate also enter the geothermal area, from the east. Altogether, some 25 per cent of visitors had entered the area utilised by KPC. (57 tourists).

Those who entered the geothermal area answered as follows:

	Yes	No
o Did you get out of your vehicle there?	20%	80%
o Did you look at any part of the geothermal project?	12%	90%
o Do you consider the geothermal project offensive?	0%	100%.

The majority of visitors, who saw something of the geothermal development, were neither offended nor overwhelmingly interested in the development.

The 75 per cent who did not enter the geothermal area, i.e stayed within the eastern half of the park, answered as follows:

	Yes	No
o Were you aware of the power station?	72%	28%
o Could you see it?	57%	43%
o Could you hear it?	10%	90%
o Could you smell it?	16%	84%

Clearly the visual sighting was the most frequent cause of awareness of the power station, most tourists neither smelling nor hearing it.

All the interviewees were asked if they thought that a geothermal project could be a tourist attraction, and 77 per cent answered "Yes".

Eighty-two per cent of tourists said that they would visit Hell's Gate National Park again.

The broad conclusion is that most tourists do not enter the geothermal area, although they are generally aware of the power station. It was apparent that most tourists have no idea whether or not they are allowed to enter the area, but they do consider that such a project could be a tourist attraction.

Tourists at the Lake Hotels

A survey was conducted covering 240 interviewees at Safariland Hotel and 241 at Lake Naivasha Hotel. The results are reported separately because there were differences between the type of tourist frequenting those two hotels. The differences relate to their knowledge about Kenya and the background to their visit: Safariland tends to be visited by guests with local connections, experience of Kenya or special interests. Lake Naivasha Hotel, on the other hand, represents the package tourist often on his or her first trip to Kenya, with little local knowledge.

Safariland

Seventy per cent of Safariland visitors were foreign tourists; 29 per cent were local tourists.

The foreign tourists responded as follows:

	Yes	No	Don't know
o Have you heard of Hell's Gate National Park?	74%	26%	
o Are you planning to visit HGNP?	57%	43%	
o Have you ever visited HGNP?	21%	79%	
o Are you aware that there is a geothermal power station in the park?	40%	60%	
o Are you planning to visit the power station?	38%	62%	
o Do you think a geothermal power project can be a tourist attraction?	86%	2%	13%
o Do you think a geothermal power station is:			
- Smelly?	34%	16%	50%
- Ugly?	9%	35%	57%
- Noisy?	57%	9%	34%

Lake Naivasha Hotel

Ninety-six per cent of visitors were foreign tourists;
Four per cent were local tourists.

The foreign tourists responded as follows:

	Yes	No	Don't know
o Have you heard of HGNP?	17%	84%	
o Are you planning to visit HGNP?	7%	93%	
o Have you ever visited HGNP?	2%	98%	
o Are you aware that there is a geothermal power station in the park?	0%	100%	
o Are you planning to visit the power station?	0%	100%	
o Do you think a geothermal power project can be a tourist attraction?	30%	14%	56%
o Do you think a geothermal power station is:			
- Smelly?	6%	31%	63%
- Ugly?	9%	33%	58%
- Noisy?	42%	14%	44%

To date, there is no evidence that the presence of a geothermal power station is putting foreign tourists off from visiting the National Park. Indeed, the relatively low number of visitors to the park is more likely to be related to ignorance about the park's existence, rather than the presence of a geothermal power station. In the impact assessment phase, it will be important to establish if the proposed location and the considerably increased presence of power generation facilities will affect foreign tourist perceptions of their Park experience. The issue of local tourism will also be examined.

6.10.12 Maasai

Background

Before the Maasai lived in the south of Kenya, they are thought to have grazed their cattle around Lake Turkana in the north. In the eighteenth century they are thought to have moved to the fertile plains of the Rift Valley. By 1800, the land used by the Maasai had spread to the south into today's Tanzania.

In 1910-11 the Maasai were forced to live in a smaller reserve, the approximate boundaries of which are shown in **Figure 6.10.6**. This reduced "living" area was one of a number of problems faced by the Maasai. Other problems included death of live stock from rinderpest and serious epidemics of smallpox and cholera. Gradual encroachment by other communities into traditional Maasai grazing lands continued to take place. In the 1940s, land was lost to the commercial sector and to wildlife reserves. Government policies through the 1970s and 1980s have kept the existing Maasai lands intact. However the reduced area of land and increasing population have necessitated a trend from the traditional pastoral life to a more settled existence.

Maasai land in Kenya is presently administered from two District Centres, Kadjiado and Narok (see **Figure 6.10.6**) (**Sharmon, 1979**). The district closest to the project area is Narok and the south western boundary of the Hell's Gate National Park runs within a few kilometres of the Narok District boundary. In 1979 there were 118 000 Maasai in the Narok District, giving an average population density of seven Maasai per square kilometre (Source: 1979 Census).

Earlier Narok was treated as a closed district, but it has now been settled by people from other parts of the Rift Valley, Nyanza and Central Province, who have introduced more conventional farming. The estimated composition of the population of Narok District (**Were and Olenja 1986**) is as follows:

o	Maasai	57% (including 0.73% Okiek, a group related to the Maasai)
o	Kalenjin	28%
o	Kikuyu	8%
o	Kisii	2%
o	Other	5%
	Total	**100%.**

There have been a number of factors that have changed the pattern of traditional pastoralism of the Maasai in Narok (**Kituyi 1990**). These are listed below.

- Large companies such as Kenya Breweries and East African industries have introduced large-scale farming of barley and rapeseed on leased land.

- Other high potential areas have been developed as farms.

- Individual and group ranches have been introduced by the government following independence with the objective of improving live stock production and ensuring land rights for the Maasai.

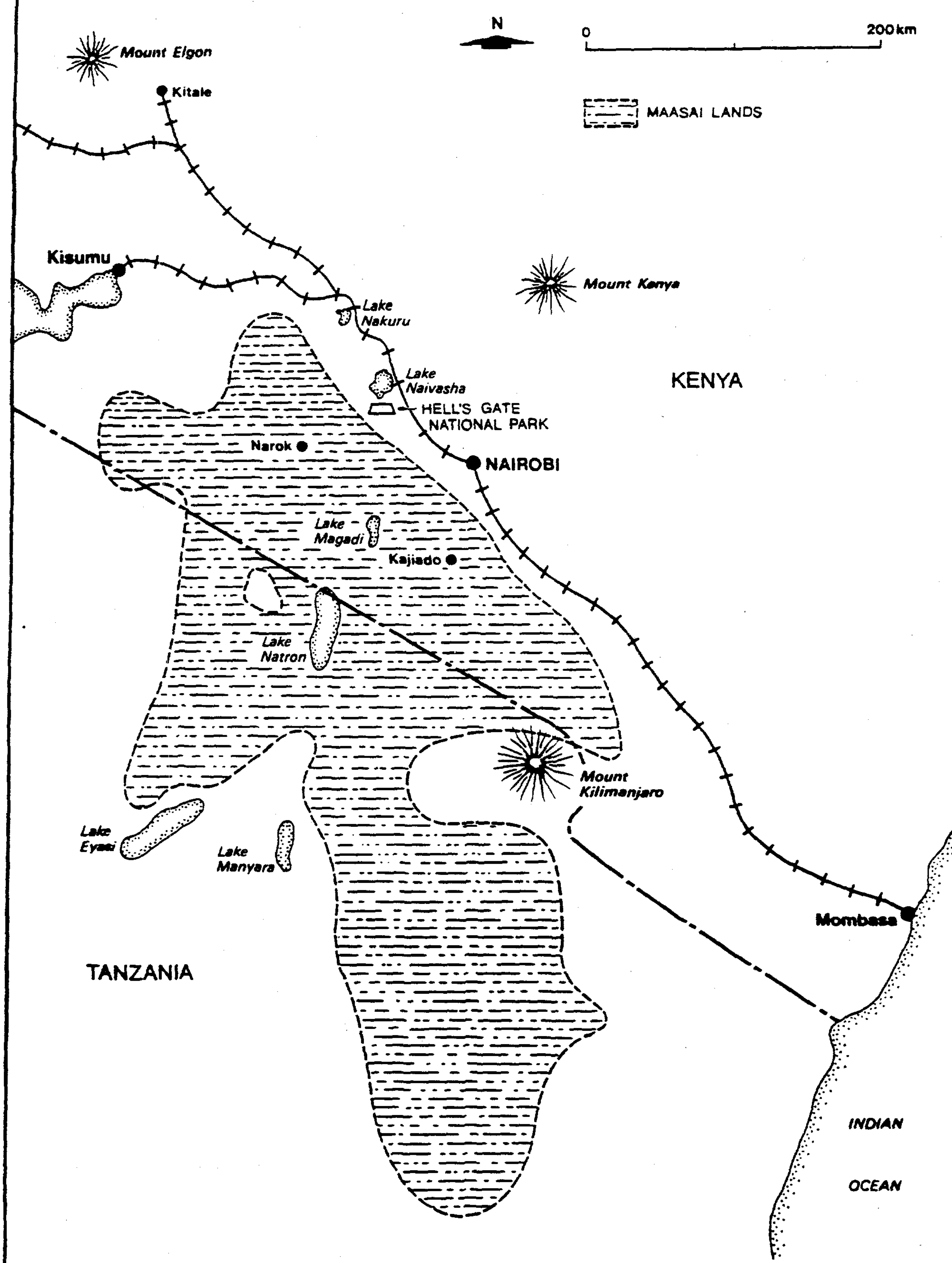


Figure 6.10.6

MAASAI LANDS IN KENYA AND TANZANIA SINCE EARLY TWENTIETH CENTURY

These progressive developments and acquisition of land by permanent immigrants, has forced some Maasai away from well-watered areas to the north and west of the district.

Base-line Data and Relationship with the Project

The area affected by the present geothermal development exploiting the East Olkaria and the proposed development in the North East field is confined almost wholly within the Hell's Gate National Park, which is within the Nakuru District and therefore outside Narok District. KPC has developed a close relationship with Maasai close to the park and power development areas. They have assisted in the provision of reliable water supplies and in solving other community problems. In addition, the upgrading (tarmacking) of the Moi South Lake Road assists the Maasai as it does all people in the area. Maasai leaders are also represented on the Hell's Gate National Park Management Committee and thus have an opportunity to interact with KWS. The impact of the project on the Maasai is considered in **Section 7.8**.

Prior to gazettal of Hell's Gate National Park in 1984 and for some period after, Maasai settlements were established on land now defined as the park. There do not appear to be written records of how many people resided in the park or who they were. The EA team has undertaken a series of interviews to determine the extent of the occupation. The survey was undertaken by interviewing the leaders of two Maasai settlements on the boundary of the park. Following information from these interviews further interviews were held with Maasai who had formerly resided in the park and were presently living in the area between the southern boundary of the park and Suswa. All interviews were conducted with the assistance a KPC employee, who provided assistance in communication.

A summary of the notes made during the interviews of two leaders of the settlements closest to the park are set out below. The locations of these two settlements are marked as "Silas" and "Peter" on **Figure 6.10.7**. It should be noted in all estimates of the population of Maasai involved, the estimates of the number of children associated with "families" are estimates only.

Baba Peter/Mama Peter - 19 December 1991 (afternoon)

This "family" occupies the closest manyatta to the park and is one of four within 1000 m of each other. The interview was with Baba Peter and Mama Peter. At the time of the interview, the "family" had six members and one visitor from Suswa. They graze 400 cattle and 400+ sheep/goats. They have lived at the site for approximately 20 years. They have children (number not revealed) all of whom were born in the "village". The oldest is 13.

They take water from several sources including the lake and the pipeline running from the lake to Suswa. The tap on the pipeline is one kilometre from the manyatta. Their biggest problem is water. The pipeline cannot always supply enough water. Their livestock graze an ill-defined area of the "undeveloped" land to the south. They cannot graze in the park which is to the north.

The mother of the family (Mama Peter) considers the next biggest problem, after water, is lack of educational facilities for her children. Next problem is security of livestock from predators (lion/leopard).

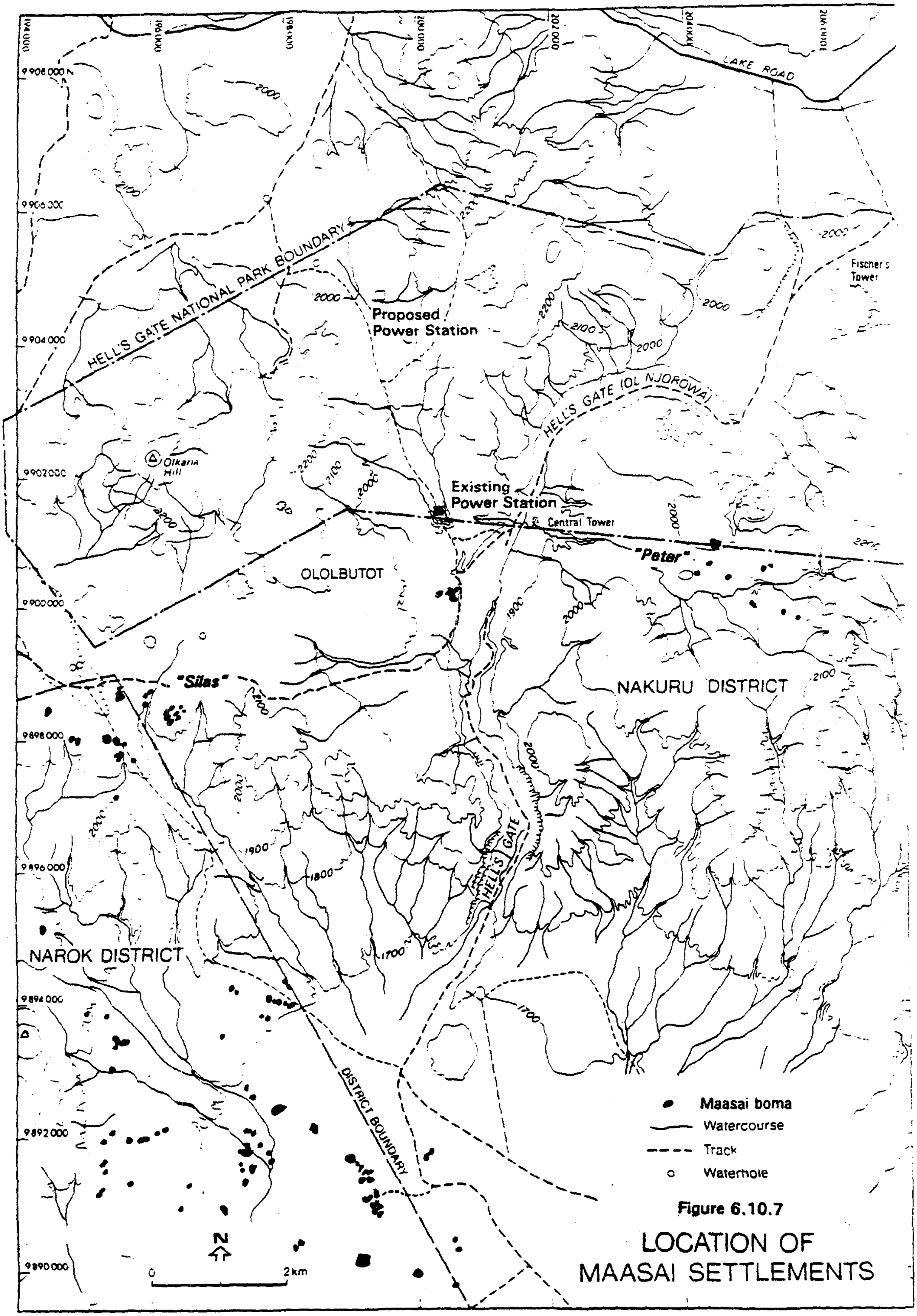


Figure 6.10.7

LOCATION OF MAASAI SETTLEMENTS

They make frequent journeys to the Sulmac and Naivasha shops. They will shop maybe twice a week or seven times per month. They get money from selling livestock.

They have strong social links with other Maasai in the Suswa area to the south.

At this stage the total number of Maasai in this area would appear to be approximately 20-30.

Silas Suntia and Catherine Suntai also in attendance Nkoitiko and one other man and some children - 21 December 1991 (morning).
Silas is the head man of his manyatta. He speaks English and has been educated at a secondary school in Ngong. He keeps a diary of major events and his business dealing and so would appear to be a reliable source of information concerning recent history, in particular the timing of events. He commenced residence in Hell's Gate in 1984. Previously he at lived at "Suswa" and prior to that he had worked for Magadi Soda.

In September, 1987, he was given four days verbal notice to vacate the park. At 11.30 am on the 16 September, 1987, he was made to leave as part of KWS's policy for managing the park. From KWS's point of view the Maasai settlements in the park are not legal and there is a clear incompatibility between the KWS land use of the area as a game park and the Maasai use for grazing. He was given no compensation or assistance in moving. He relocated to the Narasha entrance to the park[10], but had to sleep without shelter until new huts could be built. (Clearly this is some resistance to being moved). He says approximately 15 "families" were moved from the park at this time. In another part of the interview, he estimated that ten manyattas were moved and that each manyatta would hold approximately 30 people including children. This means approximately 300 people were moved.

He currently owns 200 goats/sheep and 40 cattle. Shopping is done at Maiella shops (approximately 10 km) twice per week. They take water from local creeks in the wet season, or from a KPC water tank when river water is not available. His plans for the future are to grow wheat/barley near Suswa where he has some land.

Table 6.10.12 provides information on the "families" of Maasai who occupied Hell's Gate National Park. These people now reside outside the park, mostly on the land between the southern boundary of the park and Suswa. From the table it is estimated that the total population of Maasai residing in the park was 64 adults. If each wife had on average four children the total population of the park would have been approximately 240.

Because the existing and proposed power stations are almost totally within the park, the impact of the power station on the Maasai will be negligible.

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[10] The Narasha entrance to the park, although marked on some maps, is not a formal entrance to the park. It is not manned by KWS and the access from the this area to other parts of the park is impossible except with four-wheel drive.

TABLE 6.10.12 FAMILY NAMES OF MAASAI OCCUPIERS OF HELL'S GATE NATIONAL PARK

Family name	Family structure	Number of adults (Total wives)
Kiraison	Family 1 (3 wives)	4
Reson	Family 1 (5 wives) Family 2 (6 wives) Family 3 (4 wives)	18
Nkamasiai	Family 1 (2 wives) Family 2 (2 wives) Family 3 (2 wives) Family 4 (1 wife) Family 5 (1 wife)	13
Nairenyu	Family 1 (3 wives) Family 2 (1 wife) Family 3 (1 wife) Family 4 (1 wife) One single	11
Sencho	Family 1 (3 wives) Family 2 (1 wife) Family 3 (1 wife) One single	9
Ngueta	Family 1 (4 wives)	5
Meshuko	Family 1 (3 wives)	4
Total		64 (44)

6.10.13 Olkaria Archaeology

An archaeological survey (carried out in conjunction with the National Museum) has been completed in the project area and the complete results are reported as **Appendix 6.10** to this report.

There are no registered archaeological sites likely to be affected by the project. The nearest sites (listed in **Appendix 6.10**) are all too far from the project to be affected either by interference, damage or changed or impeded access.

7. Environmental Assessment

7.1 FLORA

Introduction

This section describes the predicted impact on flora of the drilling, construction and operational activities at the proposed North East Olkaria Site. In addition it presents the results of studies of the impact of the existing power station on natural vegetation and on flowers which are grown commercially in the area.

A problem encountered with many impact assessments is that judgements have to be made without any analogous developments in similar situations. This is not the case at Olkaria, where the current geothermal power station provides a strong indication of the likely extent and magnitude of impacts on the vegetation for the North East Olkaria development. The vegetation map shows no observed differences in the various vegetation types (communities) between the possibly affected catchment containing the existing station and the North East Olkaria development catchment. Although the different community types were "ground-truthed" their distribution was identified from aerial photographs. This limits comments on development impact to "visible" community changes. The concern that emissions from the existing station may affect vegetation in more subtle ways led to two further studies being carried out. The first was to compare quantitative data on species diversity and abundance between the possibly affected area (ie adjacent to the existing station) to that of a relatively remote and unaffected area in another catchment. The second study related to concern over the close proximity of the commercial flower growers. This involved the growing of commercial flower species at differing distances from the cooling towers. Further details and discussion of both studies are given in **Sections 7.1.2** and **7.1.3**.

7.1.1 Olkaria North East Site

Impacts During Construction Phase

The opening up of the North East Olkaria Site for drilling will involve the construction of a road and the clearing of the actual site for a well. This will result in the removal of the original vegetation, however in the case of the road which will be only five metres wide on average, the impact on vegetation is likely to be minimal.

Of greater significance is the effect of clearing the drilling site where natural vegetation covering an area of approximately half an acre will be completely removed. Although natural revegetation has taken place in other areas where sites have been cleared, it is basically with opportunistic species of ruderal habitats which colonise sites after disturbance. Revegetation of this type begins with annual weeds such as the grasses Digitaria velutina, Chloris pycnothrix, Chloris virgata, Setaria pumila along with herbaceous species such as Datura stramonium, Solanum incanum and the biennial shrub Nicostania glauca.

There are two remedies to prevent this type of revegetation. Firstly, the site cleared for well drilling should be kept to a minimum as far as practicable to ensure minimum disturbance of natural vegetation. Secondly, perennial species which are indigenous to the area should be introduced immediately, preferably stoloniferous grasses in the form of runners, for example Cynodon dactylon and Cynodon niemfuensis which are referred to as Star grass. Chloris gayana, known as Rhodes grass, is also suitable and may be introduced by seed or cuttings.

Natural revegetation takes time and exposes the site to the possible adverse effects of erosion. Steps should be taken at the outset to prevent this. Woody plants such as Acacia xanthophigea, Dodonea angustifolia, Olea europaea, Euclea divinorum, Acacia seyal, Acacia gerrandil, Grewia similis and Trema guineensis could be introduced into cleared sites to stabilise the soil as well as forming part of the process of replacing indigenous vegetation. All of the above species of grasses and woody plants occur in the area and establishment should not be difficult, particularly as an adequate water supply should be available.

Sump ponds are other areas which need stabilisation once they have been constructed. The sides should be re-seeded with the same grasses recommended for the padsites. Kikuyu grass (botanically referred to as Pennisetum clandestinumlis) can also be used to stabilise the piles of soil surrounding these ponds to reduce the possibility of erosion. This grass will thrive in an area with deep soil deposition and is easily introduced through stolons.

Impacts of Atmospheric Emissions

It is difficult to assess precisely the impact of hydrogen sulphide emissions on vegetation although the predicted ground-level concentrations (see **Section 7.4**) are such that there are unlikely to be major adverse effects. It is recommended however that monitoring of potential long-term effects on natural vegetation be carried out in the area. To this end a study was undertaken to compare species diversity and abundance in affected and unaffected areas. Details of this study are presented in **Section 7.1.2**

A program to assess the possible impacts on the commercial flower farms in the area is being carried out in the form of a flower growing trial and is discussed in detail in **Section 7.1.3**. This will be a continuing program and in addition it is recommended that there should be several small "flower gardens", possibly in moveable containers scattered throughout the site, particularly on high ground, where hydrogen sulphide concentrations are predicted to be greatest.

Effects of Fire

It is evident that fire has been playing a role in maintaining the proportions of Acacia - Tarchonanthus - and grasses in most of the area where these occur. Tarchonanthus comphoratus is a fire-tolerant species with a tendency to sprout back after a burn. Themeda triandra is another species which has evolved successfully with fire in east Africa rangelands, where burning tends to increase range biomass production under this particular grass.

The overall effect of fire on these communities would be to perpetuate those species that are fire-tolerant to the detriment of others which are susceptible to destruction by fire. There are several factors, however, that influence fire in rangelands, such as the season, availability of fuels, prevailing winds and so on, which are beyond the scope of this report. It is noteworthy that prolonged incidence of fire in a range area like Olkaria would eventually introduce more open plant communities with reduced dense bushland. Thus

Tarchonanthus - Themeda - Acacia- Setaria/Digitaria associations would have a tendency to predominate in rather open bushed grasslands should repeated incidences of fire occur.

One of the problems associated with the presence of developments such as the Olkaria power station in a park area is that the natural cycle of bushfires may be disturbed. It will be important to continue to monitor the ecology of the flora and if necessary take appropriate action, such as controlled burning. This should be left entirely in the control of KWS, but the Environment Unit of KPC should be fully informed.

Impacts of Brine Release

The release of brine into ponds from the existing power station has influenced the growth of Typha and Cyperus as the main wetland plants able to resist the high levels of concentrated salts. This type of vegetation seems to be tolerant to the brine, but at the periphery of the ponds, Acacia xantholpholea should be introduced rather than Eucalyptus species. The pepper tree Schinus molle normally has a shallow root system and in volcanic soils this type of rooting is unlikely to support the growth of large trees for a long period of time. There are suitable indigenous trees such as Olea europeas ssp africana, the African olive, which would certainly do well in this environment. Various species of Ficus could also do well in this area and are fairly easy to establish.

It is predictable that the vegetation of gullies and luggas is likely to be adversely affected by brine if these are used as drainage channels. Normally these drainage areas do not get water at regular intervals throughout the year, only during the rainy season. Having brine trickle constantly throughout the year would certainly introduce changes in species composition. Sedges are likely to invade the channels, but the steep slopes are not likely to be affected, since the level of brine is fairly low. Silt depositions in the channels tends to form dry season grazing areas with Pennisetum, Setaria and a host of palatable herbaceous species, which will certainly disappear with the introduction of brine.

The release of brine into drainage channels should therefore be discouraged and as much as possible the brine should be held in the drainage ponds closest to the source. The more environmentally acceptable way of discharging brine would be to deliver it in concrete piping to a central pond, ensuring that it does not come into contact with vegetation or wildlife and even domestic livestock. Ideally, and this is the intention at Olkaria, the brine should be reintroduced into the ground, through deep wells which are unlikely to produce steam.

7.1.2 Natural Vegetation Trials

To assess the likely impacts of the proposed power station on the abundance and diversity of natural flora, a study was carried out comparing areas which would be likely to be affected by the existing power station with more remote areas where the power station should have no impact.

The presence or absence, or marked change in relative abundance, of certain species of known environmental tolerances and preferences have been used as indicators of habitat conditions. Species may be of indicator value either, because they are very intolerant of degraded conditions, and therefore first to disappear following disturbance, or because they are unusually tolerant of degraded conditions and survive, where others will not. Species of greatest indicator value are those that are:

1. Sufficiently widespread in most sites within the habitat type;

2. Sufficiently narrow in environmental tolerance to a particular stress or so that changes in the species' relative abundance reliably indicate particular habitat conditions;

3. Sufficiently short generation time so that population changes due to the changing environmental conditions can occur rapidly, and;

4. Sufficiently abundant so that fluctuations in population numbers are substantial in magnitude with changing levels of environmental stress.

The key point is that species responses/tolerances have to be known. There is generally a lack of such specific information for the species found at Olkaria.

The use of lichens as morphological indicators of air pollution is now well developed (**Hawksworth 1976, de Wit 1976, Denison 1973**). One of the best-tested generalisations is that fruticose lichens (with branched structures well above the surface) are more susceptible to sulphur dioxide damage than foliose lichens (whose leaf like thallus lies nearly flat on surfaces) and that both are more susceptible than crustose lichens (which embed the tissue in the cracks of bark, soil and rocks). In areas not burnt, numerous lichen species were present on both Acacia drepanolobium and Tarchonanthus camphoratus trees. All three of the diagnostic growth forms were found at Olkaria which suggests atmospheric pollution is not severe. Further investigation and comment was limited by the lack of suitable habitat not affected by the fire. This parameter remains as a possibility for future monitoring.

Another approach was used in which detailed studies were made of species diversity and abundance in different plots. The same vegetation type was studied both close to the existing power station and over two kilometres away in the North East Olkaria development catchment in an area near X2-Camp. All of the sites were classed as the same type of bushland vegetation (type "B" on the vegetation map).

Four plots, each of a hectare, were studied. Within each plot, the different plant species were recorded (**Table 7.1.1**).

The list of species present in each plot can be used as presence-absence data to measure the similarity between the sample plots. Similarity measurements based on such binary data are the simplest type, but fail to provide some measure of the relative importance of the species in the community. The latter limitation is discussed further during the discussion of the results.

The basic data for calculating binary (or association) coefficients is a 2 X 2 table (Krebs, 1989):

		Sample A	
		# Present	# Absent
Sample B	# Present	*a*	*b*
	# Absent	*c*	*d*

Where: *a* = Number of species in sample A and sample B (joint occurrences)
b = Number of species in sample B but not in sample A
c = Number of species in sample A but not in sample B
d = Number of species absent in both samples (zero-zero matches).

There is considerable disagreement in the literature about whether *d* is a biologically meaningful number. However in this study, the absence of certain species in the pair of plots being analysed but present in the other sample plots, was thought to be relevant. Consequently, a simple matching coefficient (*S*) that makes use of both negative matches as well as positive matches was used:

$$S = (a + d)/(a + b + c + d)$$

The similarity values (*S*) range from 0 (totally dissimilar) to 1 (identical).

The calculated similarity values for the four plots are given in **Table 7.1.2**. The results show that the pairs of sites closest to each other are the most similar, that is those close to the existing station (a and b) and those nearer X2-Camp (c and d). The similarity between the areas adjacent to the existing station and that of X2 camp was lower. This type of result could be argued as indicative of a difference in species composition between the two areas brought about by the effect of the current station. However, such statements are clearly invalid because the diversity of species present was in fact greater adjacent to the existing station than at the relatively remote site near X2-Camp (**Table 7.1.1**).

The classification of the two areas as the same class of vegetation based on aerial photographs but obviously different when compared in terms of species composition, was of concern. The probable reason was, as mentioned earlier, that relatively few species were abundant in the areas and the rare or uncommon species were biasing the similarity results (i.e. being based on diversity rather than any abundance measure). This point can be seen when only the dominant types of vegetation in the areas are compared. To do this, the forbs and succulent species were deleted from **Table 7.1.1** and only the shrub and grass species were compared in terms of similarity using the same method described before. The results in **Table 7.1.3** show an increase in similarity between the different sites, particularly between the pairs of sites adjacent and remote from the existing power station. The results confirm that the small and not very abundant species (primarily forbs) were the reason for the relatively poor similarity figures between the two areas.

Based on the above results, there would not seem any indication that vegetation diversity had been affected by the existing station. Although classified as one type of vegetation, there are pronounced differences in species composition between the different locations. These differences, however, are not due to changes in dominant (abundant) species but small and relatively uncommon forbs and succulents.

The existing station has been operating for over a decade. After this length of time, the chronic effects could have caused a reduction in abundance of certain species (especially annuals) or a failure to re-establish resulting in a greater proportion of bare soil (ie increased erosion potential). A survey of 20 subplots showed that the proportion of bare soil was no greater than that found at the remote sites near X2 camp (Table 7.1.4). Also, the greater species diversity is an indication that the sites were unlikely to be devegetated.

7.1.3 Flower Trials

Introduction
The primary objective of the flower trial was to investigate the effect (if any) of the existing power stations's cooling tower plume on flowers grown in the vicinity for commercial purposes.

Two sites were selected in the prevailing downwind direction from the gas ejectors and cooling towers. The first site, referred to as the lower site was situated 600 m from the towers, while the second (upper) trial site was 1.2 km away. The purpose of selecting sites at different distances from the towers was to assess both the effects of air pollution, in particular hydrogen sulphide, from the cooling tower emissions on flower growth and also any gradient in plant susceptibility.

The species and varieties planted out in each of the two trial areas were as follows:

1. Ornithogolum arabicum (arabicum)
2. Limonum sinuata (statice) var. blue
3. Limonum sinuata (statice) var. white
4. Dianthus caryophyllus (carnations) var. ferore
5. Dianthus caryophyllus (carnations) var. bonita
6. Dianthus caryophyllus (carnations) var. rony.

Each variety was planted in beds (1 x 10 m) at a density of 32 plants per m^2 and the beds replicated four times at each site **(Figure 7.1.1 and 7.1.2)**. The trials were set out in a randomised block design and the planting out date for each bed is also shown in the figures.

A weekly schedule of fertiliser and fungicide/insecticide spraying was followed as recommended by the Oserian Estate. Considerable effort was made to reproduce the standard practices and procedures normally followed by the Oserian Estate for their commercial plots.

In general the damaging effect of a toxic substance can be broadly correlated with dosage, that is the combination of exposure concentration and exposure time. However, the physiological mechanism of acute toxicity (high concentration over a short time period) may differ from that of chronic toxicity (low concentration over a long period). In the

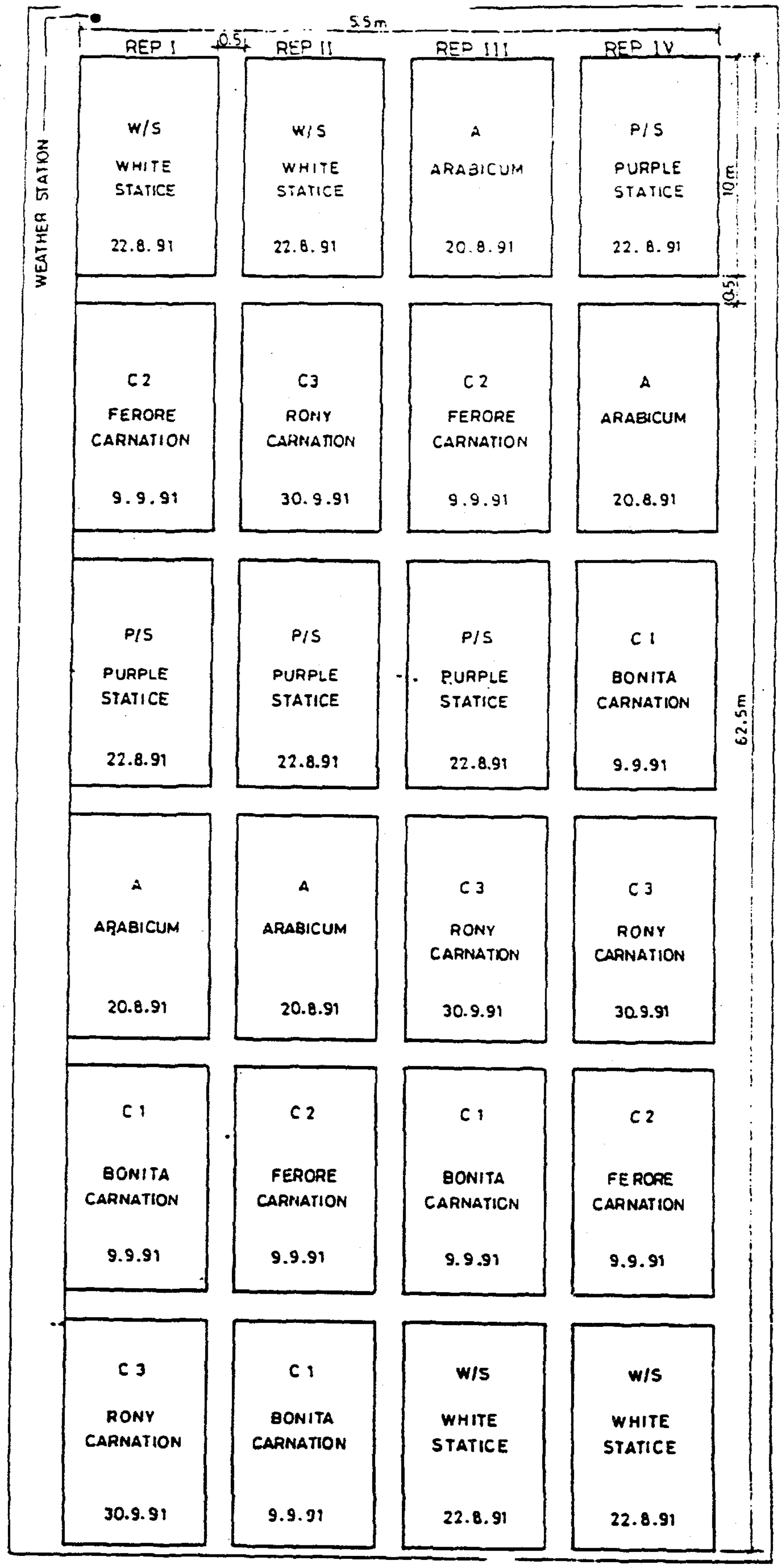

Figure 7.1.1

Layout of Flower Trial Plot I Barrier Gate

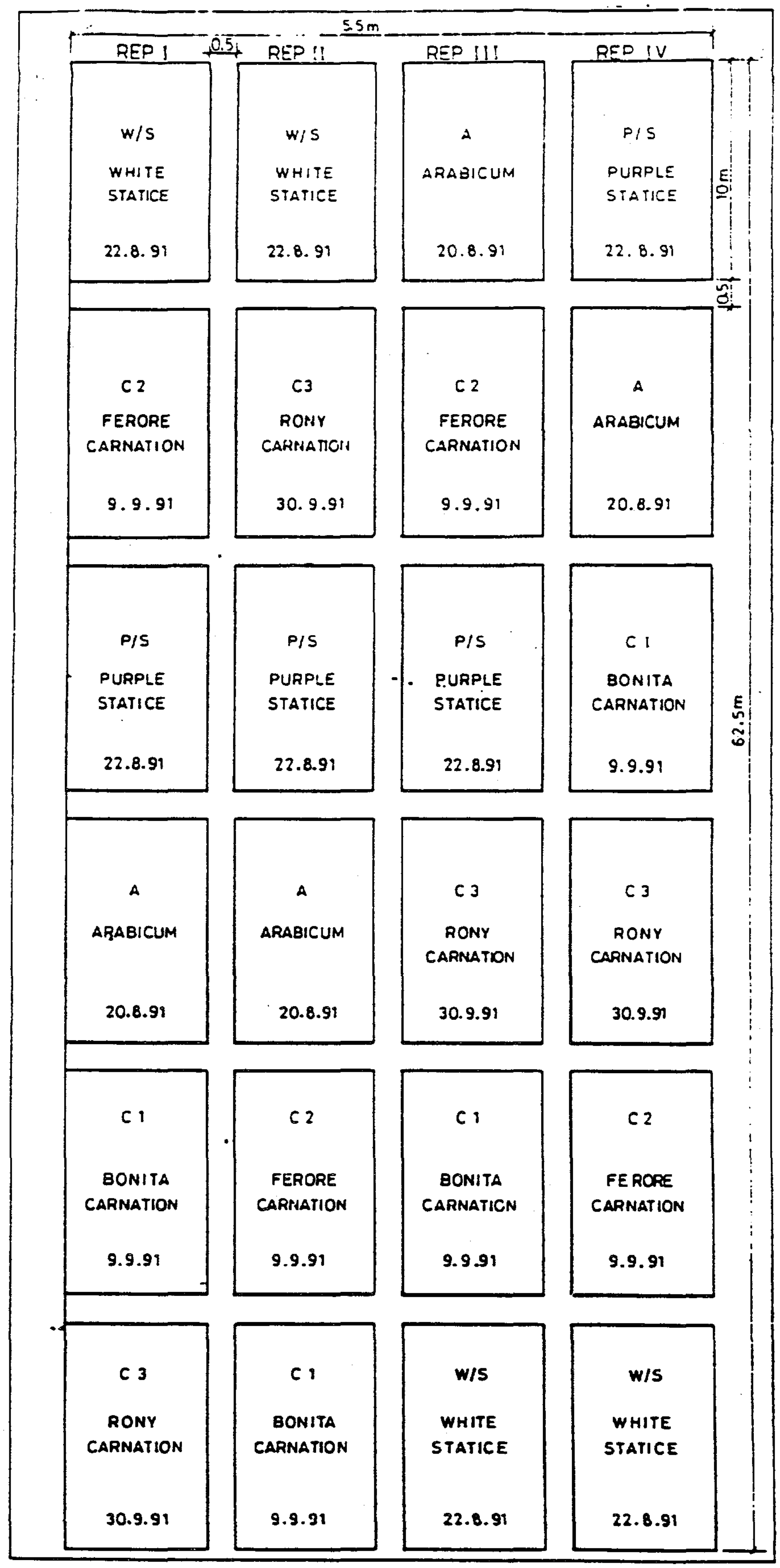

Figure 7.1.2

Layout of Flower Trial Plot II Corner

present situation, the ground-level concentrations of hydrogen sulphide at the trial sites are such that chronic, rather than acute effects, are likely to be observed.

Chronic exposure of plants to low concentrations of pollutants can cause progressive leaf chlorosis and premature senescence, symptoms which can be difficult to recognise in the presence of other environmental stresses. In contrast, high concentrations generally cause visible lesions as a consequence of the death, drying out and bleaching of localised areas of leaf tissue. In some cases, the causative agent can be identified from the characteristic injuries it induces; for example sulphur-dioxide generally causes chlorosis between the veins of a leaf. Examination of leaf material by a hand-lens failed to show any obvious injury though there was leaf "tip burn" in the arabicum. Such injury can be caused by atmospheric pollutants (ie hydrogen fluoride (HF)), but was thought more likely to result from soil chemical concentrations.

In practice, there are no widely applicable concentration thresholds for the appearance of visible symptoms because of interactions between pollutants and environmental factors and the great variation between species and populations in their resistance to damage. Furthermore, combinations of pollutants will act to give different thresholds and symptoms.

In soils with rather low levels of sulphur, the fumigation of plants by sulphur-dioxide has acted as a fertiliser, giving stimulation rather than a reduction in growth. Similarly, sulphur-dioxide can also improve dry matter production by controlling plant diseases (i.e. acting as a fungicide).

A factor to be remembered is that plants photosynthesise during the day. At night the stomata, through which most gases enter or leave the plant, are closed resulting in a reduced susceptibility to pollutant molecules. Therefore the daily dispersion pattern from the power station may be of greater importance to the surrounding vegetation than the nocturnal.

Results

The plant species arabicum (Ornithogolum arabicum) has shown distinctive leaf "tip burn" and bacterial pathogen attack (Erwinia spp). It is distinctly more pronounced at the site closest to the station, however early documentation and identification of the symptoms did not reveal whether the Erwinia was the primary cause of the damage or a secondary factor following initial damage from other causes. In an attempt to identify the cause of the damage, a series of chemical analyses of soil and tissue samples was undertaken comprising the following:

- 18 tissue analyses, 6 for each plant species
- 6 soil analyses, 3 from each site taken at the top, middle and bottom sections of the beds.

The results of these are presented in **Tables 7.1.5 to 7.1.8**

It is possible that the observed "tip burn" in the arabicum species is due to boron toxicity rather than the effects of hydrogen sulphide. This could enhance the likelihood of fungal attack by Fusarium and/or Pithium spp. on the roots or lower stem. The soil analyses

TABLE 7.1.1- SPECIES OCCURRENCE IN FOUR ONE HECTARE PLOTS.

Species	Category[1]	Plots[2] 1	2	3	4	Total
Acacia drepanolobium	Shr	x	x	x	-	3+
Aerva lanata	F	-	x	-	-	1
Aloe sp	Su	-	-	x	-	1
Aristida adoensis	G	x	x	x	-	3+
A. keniensis	G	x	x	-	-	2-
Bulbine abyssinica	F	-	-	x	-	1
Cassia mimosoides	F	x	x	-	-	2-
Chenopodium carinabum	F	x	-	-	-	1
Chloris gayana	G	x	x	x	-	3+
C. virgata	G	-	-	x	-	1
Commelina africana	F	x	x	-	x	3+
Conyza aegyptiacn	F	-	-	-	x	1
Crotalaria agatiflora	F	-	-	-	x	1
C. balbi	F	x	x	-	-	2-
C. barneiri	F	x	x	-	-	2-
C. incana	F	x	-	-	-	1
Cucumis sp	F	x	-	-	-	1
Cycnium tubulosum	F	x	x	-	-	2-
Cymbopogon nardus	G	x	x	x	-	3+
Cynodon dactylon	G	-	x	x	x	3+
Cyphostema oroddo	F	x	-	-	-	1
Digitaria milanjiana	G	x	x	x	x	4*
Enneapogon sp	G	-	-	x	-	1
Eragrostis minor	G	x	-	-	-	1
E. tenuifolia	G	x	-	-	x	1
Erucastrum arabica	F	-	-	-	-	1
Euphorbia incaquilatera	F	x	-	-	-	1
E. kibwezensis	T	-	-	-	x	1
Felicia abyssinica	F	x	x	x	x	4*
Fuerstia africana	F	-	-	x	x	2-
Harpachne schimpori	G	x	x	x	x	4*
Helichrysum glumaceum	F	x	x	-	-	2-
Hibiscus aponeurus	F	x	-	-	-	1
Hyparrhenia hirta	G	x	-	-	x	2-
H. papillipes	G	x	x	-	-	2-
Indigofera tanganyikensis	F	x	x	-	-	2-
I. volkensii	F	x	x	-	x	3+
Justicia flava	F	x	x	x	x	4*
Kalanchoe sp	Su	-	-	x	-	1
Kohautia caespitosa	F	x	x	-	-	4*
Leonotis nepetaefolin	F	x	-	-	-	1
Leucus glabrata	F	-	-	x	-	1
Mariscus amantopus	G	x	x	x	x	4*
Melhania velutina	F	x	-	-	-	1

Species	Category[1]	Plots[2] 1	2	3	4	Total
Nicotiana glauca	Shr	-	-	x	-	1
Ocimum suave	Shr	x	-	-	x	2-
Opuntia vulgaris	Su	-	-	x	-	1
Plectranthus caninus	F	x	-	x	x	3+
P. zatarhendi	F	-	-	-	x	1
Polygala sphenoptera	F	x	x	x	-	3+
Psiadia arabica	Shr	-	-	x	x	2-
Rhus natalensis	Shr	x	-	x	-	2-
Rhynchelytrum repens	G	x	-	-	-	1
Rhynchosia minima	F	x	x	-	-	2-
Satureja biflora	F	x	x	-	-	2-
Setaria sphacelata	G	x	-	-	-	1
Sida cuneifolia	F	-	-	x	x	2-
Solanum incanum	F	-	x	x	-	2-
Spermacoce sphaenostigma	F	x	x	-	-	2-
Tarchonanthus camphoratus	Shr	x	x	x	x	4*
Themeda triandra	G	x	x	x	x	4*
Tribulus terrestris	F	x	-	-	-	1
Tragus berteronianus	G	-	-	-	x	1
Zornia setosa	F	-	x	-	-	1
	Total	43	30	27	22	122

Footnote:

1 Key: F = Forbs; Shr = Shrubs; G = Graminoides (grasses and sedges); Su = Succulents

2 Key: x = present; - = absent

* = Dominant
\+ = Co-dominant
\- = Occasional

TABLE 7.1.2- SIMILARITY COEFFICIENTS DERIVED FROM ALL SPECIES BETWEEN THE FOUR VEGETATION SAMPLE PLOTS (BASED ON EQ.1).

	Plot A	Plot B	Plot C
Plot A			
Plot B	66%		
Plot C	34%	55%	
Plot D	38%	52%	59%

Average = 51%

TABLE 7.1.3- SIMILARITY COEFFICIENTS DERIVED FROM ONLY SHRUBS AND GRASSES BETWEEN THE FOUR VEGETATION SAMPLE PLOTS (BASED ON EQ.1).

	Plot A	Plot B	Plot C
Plot A			
Plot B	71%		
Plot C	50%	71%	
Plot D	42%	54%	50%

Average = 56%

TABLE 7.1.4 COVER ESTIMATE BY SPECIES IN FOUR 100 x 100 m PLOTS.

Species/type	Category[1]	Plot 1		Plot 2		Plot 3		Plot 4	
		Mean % Cover	% Freq.	Mean % Cover	% Freq.	Mean % Cover	% Freq.	Mean % Cover	% Freq.
Rocks and pebbles		1.17	60	0.48	40	5.94	65	1.93	50
Mineral soil		43.75	100	60.88	100	48.00	100	51.63	100
Overall vascular cover		53.00	100	32.77	200	23.75	100	30.25	100
Hyparrhenia hirta	G	9.78	60	-	-	-	-	-	-
Chloris gayana	F	3.30	40	1.50	5	-	-	-	-
Themeda triandra	G	4.30	50	15.75	90	9.03	45	17.78	85
Cymbopogon pospischilla	G	12.05	50	3.75	15	-	-	-	-
Digitaria milanziana	G	5.25	50	6.90	95	5.48	85	0.18	10
Zornia setosa	F	0.15	5	-	-	-	-	-	-
Mariscus macrocarpus	G	0.30	10	0.60	20	-	-	-	-
Euphorbia cuneata	F	0.03	5	-	-	-	-	-	-
Rhynchosia minima	F	0.03	5	0.03	5	-	-	-	-
Justicia flava	F	0.38	5	-	-	-	-	-	-
Tribulus terrestris	F	0.15	5	-	-	-	-	-	-
Setaria sphacelata	G	10.75	50	-	-	-	-	-	-
Kohautia aspera	F	-	-	0.48	10	-	-	-	-
Indogofera bogdanii	F	-	-	0.75	20	-	-	-	-
Crotalaria vallicola	F	-	-	0.70	20	-	-	-	-
Cynodon dactylon	G	-	-	1.88	10	1.50	15	1.43	20
Indigofera brevicalyx	F	-	-	0.03	5	-	-	-	-
Cassia mimosoides	F	-	-	0.15	5	-	-	-	-
Aristida adscensioni	G	-	-	0.38	5	-	-	-	-

Cover Estimate by Species in Four Plots (cont)									
		Plot 1		Plot 2		Plot 3		Plot 4	
Species/Type	**Category**	**Mean % Cover**	**% Freq.**	**Mean % Cover**	**% Freq.**	**Mean % Cover**	**% Freq.**	**Mean % Cover**	**% Freq.**
Polygala sphenoptera	F	-	-	0.13	5	-	-	8.03	55
Aristida adoensis	G	-	-	0.32	5	-	-	0.75	10
Chloris virgata	G	-	-	-	-	6.03	35	-	-
Fuerstia africana	F	-	-	-	-	0.45	15	0.38	5
Dichanthium insculptum	?	-	-	-	-	1.13	10	-	-
Cycnium tubulosum	F	-	-	-	-	0.15	5	-	-
Felicia abyssinica	F	-	-	-	-	1.25	35	0.38	10
Harpachne schimperi	G	-	-	-	-	0.33	15	-	-
Aristida adoensis	G	-	-	-	-	0.45	15	-	-
Plectranthus caninus	F	-	-	-	-	0.30	10	-	-
Commelina reptans	F	-	-	-	-	0.03	5	-	-
Psiadia arabica	SW	-	-	-	-	-	-	0.30	10

TABLE 7.1.5 SOIL ANALYSES - (mg/l)

	LLD	Upper Trial			Lower Trial		
		Top	Middle	Bottom	Top	Middle	Bottom
pH	-	6.1	6.0	6.1	7.4	7.7	7.2
Conductivity	-	3.3	2.9	2.6	4.0	3.3	2.9
Nitrate-N	-	147	179	143	225	154	133
Ammonium-N	-	185	120	120	181	94	107
Phosphorus	0.02	28	27	27	44	40	33
Potassium	0.1	334	419	400	530	484	457
Magnesium	0.02	117	124	109	97	75	72
Sulphur	0.01	266	159	152	254	229	184
Calcium	0.005	600	615	528	768	610	524
Sodium	0.02	105	104	106	424	555	352
Chloride	-	81	78	69	99	78	70
Manganese	0.001	5.2	3.6	2.8	5.6	2.3	2.0
Boron	0.003	18.4	14.2	11.6	18.5	23.2	10.0
Copper	0.001	6.5	9.5	6.7	2.2	1.1	0.9
Iron	0.002	115	112	105	51	39	61
Zinc	0.002	22	22	18	10	9	16
Molybdenum	0.002	0.13	0.16	0.12	0.07	0.07	0.13
Aluminium	0.005	6.5	7.9	10.5	4.8	5.6	4.6

TABLE 7.1.6- PLANT TISSUES ANALYSES: ARABICUM - (mg/l)

	LLD	Upper Trial			Lower Trial		
		Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
pH	-	5.5	6.0		5.3	5.7	5.4
Conductivity	-	7.3	7.3		7.0	6.1	6.1
Nitrate-N	-	340	246		266	308	346
Ammonium-N	-	18	30		38	23	41
Phosphorus	0.02	29	51		46	16	34
Potassium	0.1	1413	1952		1046	641	915
Magnesium	0.02	71	86		34	24	36
Sulphur	0.01	14	23		13	9	14
Calcium	0.005	399	438		340	227	277
Sodium	0.02	21	38		41	18	28
Chloride	-	879	673		747	1036	1164
Manganese	0.001	0.4	0.7		0.4	0.3	0.3
Boron	0.003	3.17	5.46		3.05	1.92	2.02
Copper	0.001	19.92	14.68		10.2	8.35	10.61
Iron	0.002	0.6	1.3		0.6	0.4	0.6
Zinc	0.002	0.7	1.0		1.0	0.8	0.9
Molybdenum	0.002	0.04	0.04		0.04	0.04	0.04
Aluminium	0.005	0.63	0.73		0.57	0.50	0.50

TABLE 7.1.7 PLANT TISSUES ANALYSES: CARNATION - (mg/l)

	LLD	Upper Trial			Lower Trial		
		Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
pH	-	6.2	6.3	6.2	6.0	6.0	6.3
Conductivity	-	12.0	10.3	11.7	12.0	10.7	14.4
Nitrate-N	-	585	284	474	430	405	539
Ammonium-N	-	32	24	24	27	24	37
Phosphorus	0.02	472	453	348	533	574	403
Potassium	0.1	4008	3722	3894	3798	3696	3326
Magnesium	0.02	400	342	391	300	271	296
Sulphur	0.01	253	217	243	250	257	243
Calcium	0.005	477	519	647	398	472	478
Sodium	0.02	220	115	193	587	212	1613
Chloride	-	1253	885	1405	933	757	1199
Manganese	0.001	11.9	21.4	14.6	9.3	21.6	17.3
Boron	0.003	19.17	23.78	25.52	43.32	21.06	60.52
Copper	0.001	0.48	0.37	0.40	0.38	0.27	0.32
Iron	0.002	16.2	28.7	16.5	3.1	5.2	7.1
Zinc	0.002	8.9	6.6	6.0	6.3	7.3	6.8
Molybdenum	0.002	0.10	0.13	0.10	0.12	0.10	0.14
Aluminium	0.005	10.16	16.90	9.38	1.84	4.20	6.55

TABLE 7.1.8- PLANT TISSUES ANALYSES: STATICA - (mg/l)

	LLD	Upper Trial			Lower Trial		
		Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
pH	-	6.5	6.3	6.8	6.0	5.2	5.1
Conductivity	-	18.2	16.4	17.4	17.2	18.5	17.9
Nitrate-N	-	1476	1082	1457	1028	904	703
Ammonium-N	-	194	210	233	315	436	416
Phosphorus	0.02	242	193	206	502	354	454
Potassium	0.1	5260	4534	4690	4194	4638	4738
Magnesium	0.02	746	687	837	647	555	652
Sulphur	0.01	623	577	579	570	550	620
Calcium	0.005	354	437	432	561	516	479
Sodium	0.02	533	594	522	989	1124	1004
Chloride	-	1900	1952	1673	1888	1828	2019
Manganese	0.001	3.7	4.9	4.4	4.6	5.0	5.3
Boron	0.003	1.97	3.81	2.61	9.52	12.91	4.77
Copper	0.001	0.41	1.11	1.00	1.14	0.19	0.43
Iron	0.002	4.2	3.0	2.8	2.7	2.6	2.1
Zinc	0.002	5.2	6.3	5.3	9.2	8.9	10.1
Molybdenum	0.002	0.15	0.20	0.17	0.37	0.17	0.38
Aluminium	0.002	2.27	1.97	1.87	2.51	2.76	2.44

show high boron concentrations and also a large degree of variation in concentration within the trial area, particularly at the site closer to the power station. There is also a marked difference in pH between the sites, with an average pH of 7.4 at the site closer to the power station (lower site) and an average pH of 6.1 at the more distant (upper) site. This may also be a contributing factor in leaf damage.

Several other soil chemical concentrations differ noticeably between the two trial sites including, phosphorus, sodium, copper, iron and zinc. Such differences confound the issue of whether atmospheric contaminants are contributing to the toxicity observed at the trial site closest to the plant.

It is difficult to predict which plants will be most susceptible to air pollution damage. There are a number of morphological features of arabicum which make it likely to be resistant to air pollution effects. In particular, the leaves have a large smooth surface area and an undissected leaf margin which would result in laminar flow over the leaf, leaving a relatively thick area of still air between the leaf surface and the potentially polluted air flowing over the leaf. Thus the rate at which the arabicum leaf would be brought into contact with air pollutants could be less than plants with a rougher leaf surface. The leaves are also glossy, indicating the presence of cuticular wax which coats the leaf surface and can act to exclude airborne pollutants. The greater susceptibility of lichens to air pollution damage relative to higher plants is likely to be due to their lack of waxy cuticle. In addition young plants which are cuticle thin and senescent plants which may have cracked cuticles have been shown to be susceptible to pollution.

Carnations on the other hand have quite different morphological features, including hairy leaves which could create localised turbulence as air flows over the foliage. This mechanism could bring the pores of the leaves (stomata) which absorb gases into greater contact with air pollutants than the smoother arabicum leaves. Leaf hairs (trichoma) could also aid in the entrapment of particulate matter and moisture which may contain sulphate particles or other air pollutants. However it is possible that the hairs could act as filters which ultimately reduce the amount of pollutants absorbed. Carnations studied in the trial areas showed no obvious symptoms of any leaf damage. Similarly, no leaf damage was observed for the statice plants.

It was considered unlikely that the observed leaf "tip burn" in the arabicum was due to atmospheric emissions. Differences in soil composition between the two trial sites were judged to be more significant factors, although the responsible elements and mechanism of action have not been determined. While the difference in soil composition at the site closer to the power station may be related to its proximity to the plant, this will have no bearing on the commercial flower farms in the area, the closest of which is 1.2 km from the proposed power station. In any event the disposal method for hydrogen sulphide emissions from the proposed power station will result in much lower ground-level concentration than those arising from the existing power station. The additional impact of the proposed power station will therefore be low and certainly much lower than if the existing power station were to be duplicated. In addition the commercial flower farms will experience lower concentrations of hydrogen sulphide than either of the trial sites.

7.1.4 Summary of Recommended Management and Monitoring Procedures

The major visible impact of the proposed Olkaria power station on flora is the clearing of natural vegetation for drilling sites and plant. In addition the release of brine into ponds and drainage channels such as gullies has already affected the balance of vegetation in these areas. Other more subtle long-term effects are less obvious and need to be carefully monitored. These include the effect of atmospheric emissions on natural vegetation and commercial flowers and the potential effect of the development on the balance of the ecology through disruption of the normal patterns of grazing and the natural cycles of bushfires. Initial studies indicate that these impacts are likely to be minor but the studies should be continued to confirm that this is the case.

The following management and monitoring strategies are recommended.

1. Keeping the area of natural vegetation cleared to a minimum.

2. Deep reinjection of brine and drilling water to avoid potential toxic effect on flora.

3. Cleared areas should be quickly rehabilitated with appropriate indigenous flora to prevent the growth of opportunistic species.

4. Monitoring of the abundance and diversity of natural vegetation should continue. If necessary, appropriate action should be taken by KWS such as controlled grazing and burning of park areas. The Environmental Unit of KPC should be made fully aware of all such activities.

5. The potential effect on local flower farms should be monitored with the flower trials continued for a total of two years. If the Oserian Estate wish to extend the trials longer than this they should be given access to the plots.

7.2 SOILS

It is inevitable with a development of the type of the North East Olkaria Project that some impact on soils will take place. However, if appropriate and timely erosion control techniques are used, these can be kept to a minimum and the problems which have developed as a result of the existing operations, can be avoided. Most of the issues have already been discussed in **Section 6.3** in relation to the existing development.

The following mitigating measures are recommended for the proposed development.

Construction Phase
Some disturbance of the soil will inevitably occur during the construction phase but this can be minimised by revegetating the disturbed area as soon as possible so that soil erosion does not occur. As discussed in **Section 6.3**, native grasses such as Star grass should be planted as quickly as possible. It is pertinent to note that vegetation that is attractive as animals as a source of food should be avoided in the first instance when attempts are made at revegetation. Even strong fencing around areas being revegetated has proved insufficient protection against the larger herbivore such as buffalo. To avoid problems of this sort it is suggested that less palatable plants such as the Tarconanthus Camphoratis-Oleleshua, which is native and widespread in the area should be used.

Operational Phase
Care will have to be taken to attend to erosion problems as they arise and not allow the level of erosion that has occurred in the past. The proposed method of disposal of well water and brine by deep reinjection will eliminate flow of surface waters and therefore development of the deep gullies, which are characteristic of the type of erosion problem that has occurred in the past.

Runoff from roads has the potential to cause erosion problems, however if the road surfaces are properly maintained and runoff can be diverted at regular intervals to avoid build up of water, erosion problems will be minimised.

It is recommended that effectiveness of the erosion control measures be monitored. Soil conditions should be reviewed, at monthly intervals during construction and at yearly intervals during operation, by a soils expert. Finally, it is recommended that KPC nominate an officer to take reponsibility for the day to day control of all activities that could lead to soil erosion. The officer should be briefed by a soils expert as to the nature of risks and should be provided with sufficient authority to direct contractors concerning day to day activities that could lead to erosion.

7.3 FAUNA

Introduction
This section deals with the impacts on fauna of the existing power station and those of the proposed North East Olkaria well during the development, operational and abandonment phases. The main areas of concern are the loss of habitat from a variety of causes; the potentially toxic effect of brine used for drinking water, the death of animals through road accidents and the conflicts caused by the presence of human settlements within the park.

7.3.1 Impact of Existing Power Station

Loss of habitat
The area of habitat within Hell's Gate National Park is already restricted. The park is relatively small and wildlife density for most species is above that of most other parks. In addition, extensive areas within the park are rocky, steep and inaccessible to most large mammals. Much of the areas outside the park boundaries, which formerly provided dispersal zones, have been taken over by intensive agriculture or ranching farms.

The physical facilities for the existing East Olkaria power station, which include the power station buildings, roads, steam pipes and the well-heads, result in a minor reduction in the area available as wildlife habitat. These facilities have then been enclosed by a wire-mesh perimeter fence which surrounds the entire original steam field. Some new make-up wells are beyond the perimeter fence. The perimeter fence serves little purpose and is an impediment to the movement of wildlife, preventing grazing animals from using the space between the wellheads and around the power station. In the case of fire, local extinction of enclosed species could occur. This impact is restricted to medium to small sized mammals that cannot pass through the wire-mesh. Most larger mammals would have left the area during construction as a result of human harassment. Very large animals such as buffalo are capable of breaking down fences and would not be trapped.

This impact can be for the new power station can be mitigated by erecting fences only around selected facilities that need to be isolated from human interference or those which may be dangerous to animal (for example switchyards). Animals could then make use of the area between the individually fenced areas thus minimising the area converted from wildlife use to producing electricity.

Drilling Water and Brine

Current Station
The quality and availability of surface water is critical to wildlife species such as zebra and kongoni which must drink daily or every other day. The brine from the current station is used by these species and also by buffaloes which break the wire-mesh fence. However, the level of chemicals in the brine, particularly fluoride, may constitute a health risk, even though by world standards the brine is not particularly toxic. Grazing animals may be affected by fluorosis which affects hoofs, bones and teeth. However the level of fluoride in the natural drinking water, for example Lake Naivasha, is high.

North East Olkaria
Currently, drilling water and brine is held in fenced ponds. However, the maintenance of the fences is very poor and animals have access to and therefore drink the water. An example of this problem is the pond adjacent to M1 which is broken in many places. The composition of drinking water can alter reproductive physiology and the consequent changes in the breeding success rate may influence the overall survival of the species.

Measures should be taken to avoid this problem including game-proof fencing of the ponds, the disposal of drilling water and brine outside the park, and the reinjection of drilling water and brine.

Open drains for brine and drilling water
The drains have an insignificant impact on large mammals, however they act as barriers that prevent movement of small mammals, with relatively small home ranges. This problem can be overcome by the use of covered drainage and if this is not possible having the open drainage running along already established roads and other infrastructure.

Steam Pipes
The elevated steam pipes in the existing power station interfere with movement routes of animals in addition to taking over space that would otherwise provide extra habitat. The pipes also have a negative visual impact which reduces the natural appearance of the area. The impact can be reversed by having the pipes underground with permanent cover that can allow revegetation or a cover of removable concrete slabs to facilitate repairs in case of breakages.

Roads and traffic
High speeds of vehicles to and from the other power station cause accidents that kill wild animals. The only way to avoid this is to reduce the speed limit on these roads. This will be difficult to enforce unless speed humps are introduced at appropriate points along the route.

7.3.2 Impact of North East Olkaria Development Phase

Roads and Padsites
The main negative impacts resulting from the construction of access roads and padsites

are loss of habitat, the blocking of migration routes and initiation of soil erosion, leading to further habitat loss.

Although not geographically continuous, the development would cause segmentation of the already limited habitat resulting in the isolation of animals to smaller areas. This situation, in the long term, can lead to habitat overuse, destruction and inbreeding of the confined species. Roads also cause high mortality of wildlife, particularly if there is vehicular movement at night.

These impacts can be reduced if the roads and padsites take up the minimum area possible once the required equipment is in place. At the padsites, rehabilitation (revegetation) should be initiated by planting indigenous species. The steep slopes of most padsites should also be terraced to increase the rate of revegetation and to decrease soil erosion.

Once revegetation is in place it should be monitored on a regular basis. Permanent plots in representative padsites should be set up and monitored for vegetation growth (cover, richness, rate of growth of woody species) and utilisation by wildlife both in space and times.

Sump Ponds
The main impact of the sump ponds is the loss of habitat, although this would be of limited extent. Poisoning of animals may occur if they have access to and drink the brine and drilling water. The areas adjacent to the ponds may also change in vegetation type, structure and microclimate resulting in further habitat alteration and possible loss.

Periodic examination of avifauna is recommended to detect any pathological defects that may arise from toxic levels of chemicals in water and vegetation.

Well Drilling and Testing
The main impact of the drilling and testing activities is the water and brine which contain toxic levels of some chemicals. Noise may also keep the animals from preferred habitats.

Reinjection of the water and brine, game fencing to keep animals from using the drilling water and brine will minimise this impact.

Construction of Station, Office and Estate
The negative impacts include the following:

- loss of habitat and disturbance of the substrate leading to erosion and further habitat loss;

- noise from equipment and people, dust which covers forage making it unsuitable for consumption by animals;

- human harassment of animals, and;

- blockage of normal diurnal and seasonal movement of animals.

The proposed location (PS-A) has several animal trails that cross the road and are frequently used by buffalo, zebra and kongoni. No matter where the power station is located, this would be the case. The disturbance although a negative impact is not unacceptable.

Disturbance of the habitat should be kept to a minimum in terms of areas used and design of the physical facilities. During construction, sites should be fenced in, so that no further habitat is lost. The labour force should be kept to the minimum size possible. Areas adjacent to the proposed site for the station should be identified for providing alternative trails or movement routes for animals. If too steep, some landscaping may be considered. The distribution, abundance and movement of animals should be monitored.

Power Transmission Corridor
The impact of the power transmission corridor is likely to be negligible, because generally the vegetation in this area is low and because there will be minimal disturbance to vegetation.

Production Steam Pipeline
The main impact of the steam pipeline will be the prevention of the already established free movement of animals. Because the pipe cuts across most of the Olkaria North East, this impact is of considerable magnitude and extent.

The adverse impacts can be reduced by ensuring that the siting of the pipe does not cut across major animal movement routes. The pipe can also be designed in such a way that it is underground totally or only in areas where it crosses a major animals' trail. The latter alternatives would provide corridors for gullies that form major routes for animals when moving from low flat plains to higher elevations of their home ranges. The movement of animals can be facilitated further by creating corridors to surrounding ranches or acquiring the ranches to be part of the park.

It is important that animal distribution density and movement patterns are monitored.

Waste Disposal
Garbage from equipment, construction material and domestic sources can cause significant impacts. Garbage can be eaten by wild animals making them change natural feeding habits. Garbage can also poison animals and increase conflicts because of more contacts with people. Inadequate care can make the impact very extensive in the immediate environs of human habitation and construction sites.

To minimise this impact, it is essential that there is total observation of park laws which prevent any form of littering. The impact will also be reduced by the collection and disposal of waste to areas outside the park. It is recommended that in the longterm, there is no human settlement within the park.

Revegetation
This will have positive impacts if local indigenous species of plants are used.

Exotic species
The influx of construction teams and outside workforces into an area, can result in the introduction of exotic plants and animals. In the case of exotic animal species, the impact can be significant with domestic dogs and cats preying on wildlife and together with poultry, transmitting diseases to local species. This impact can be avoided by ensuring that domestic animals are not allowed into the park as required by park regulations and by-laws.

Exotic plant species from outside the park (including those from overseas, that might come commercially or accidentally with equipment) can have negative impacts on the local species and overall ecology of the park. Normally such species flourish, excluding the local species, because exotic species do not have the competitors that would normally exist if they were growing in their native habitat.

Measures to avoid these impacts include the fumigation of equipment from overseas. The labour force should not be allowed to grow ornamental plants, or any type of crop or plant outside their houses. Any exotic species entering the park and germinating accidentally should be uprooted.

The construction site and associated human settlements should be monitored for exotic animal and plant species.

Labour Workforce
The main impacts of the labour workforce on the local environment include;

- direct killing of animals for food, through conflicts or accidentally;
- noise and animal harassment;
- use of wood for fuel and other purposes;
- indirect negative impact on tourism, and;
- waste disposal.

The impacts can be managed by keeping the labour force to a minimum size by allowing only individual workers (and not their families) to reside in the park. As discussed earlier, it is recommended that in the longterm there is no human settlement within the park. The number of people at the construction site should be monitored regularly at Olkaria Gate and in the employment records. Workers behaviour and attitudes towards wildlife should be monitored with the aim of teaching them how to reduce human wildlife conflict. Night activities should be banned to allow animals to have access to areas and resources inaccessible during the day, because of human presence and construction activities.

Fencing
The major impact of fencing is the restriction of animal movements. The amount of fencing will be kept to the minimum possible. It should also be close to the construction so that large areas which are not needed are not enclosed and therefore inaccessible to animals.

Fencing should not be required around existing human settlements, provided people comply with park regulations. This would have the additional benefit that grass lawns in these areas could be a source of forage for wildlife.

Fire
Bush fires are difficult to put out in steep, rocky and rugged terrain like Hell's Gate. The fire destroys habitat and kills small vertebrates and invertebrates. The fire also alters the microclimate. The extent and magnitude of the damage is determined by the amount and degree of dryness of fuel material. Fires can be caused by deliberate actions, carelessness

or by accident.

Construction workers should be informed on the dangers and implication of bush fires, how they can be prevented and put out.

Temporary and permanent firebreaks should be erected where construction activities are likely to cause fire. Surveillance and warning systems should be established especially during high fire risk periods. In addition, fire-fighting equipment should be in place to help in fighting fires before they consume extensive areas.

Fire when properly, used creates an appropriate mosaic of open grassland and bushed habitats that in turn are occupied by corresponding fauna. Prescribed burning and monitoring programmes should be initiated to control accumulation of fuel, active growth of quality grass layer and increase richness of plant and animal species.

7.3.3 Impacts During Operation Phase

Road Surfacing

The main impact of road surfacing is loss of habitat. In addition, tar roads do not allow infiltration of rainwater and instead the water gathers into large volumes that can cause erosion or collect on lower grounds into temporary ponds. The ponds can have a positive impact by attracting waterbirds and other animals, adding to the attractions in the park. If the ponds carry water for extended periods, new plant association can form with species such as A. Xanthophloea, Cyperus spp and Papyrus spp.

Runoff water from the roads in steeper areas should be gathered in drains and directed to holding ponds or a central area for use by animals and for improving the rate of revegetation. The ponds should preferably be located in areas which have been impacted on negatively and which are undergoing rehabilitation.

Vegetation composition and use of the area adjacent to the roads by wild animals should be monitored.

Waste Disposal

Impacts, mitigation measures and required monitoring are similar to those of waste disposal during construction phase.

Revegetation

Impacts will be positive provided that local indigenous species of plants are used.

Fire Risk and Exotic Species

Impacts, mitigation measures and required monitoring are similar to those during the construction phase.

Labour Force

Impacts are similar to those encountered during the construction phase. The presence of a workforce within the park can give rise to problems of fire, noise and animal harassment, waste and sewage dumping, turning animals to garbage feeders, poaching of wildlife and removal of dead resources such as wood for fuel and human and wildlife injuries or death.

Mitigation and monitoring programmes are the same as those for the construction phase.

All necessary actions should be taken to reduce human-wildlife contacts and conflicts. In addition no shopping or trade should be allowed inside the park.

Separators and Cooling Tower Emissions
There is no evidence of any impact on fauna.

Traffic
Impacts of traffic on fauna include the following:

- accidents that kill large and small mammals and birds;
- fire caused directly or through people in vehicles;
- off-road driving also destroys the habitat and disturbs the normal behaviour of animals, and;
- vehicles cause noise and dust and also contribute (although to a lesser extent) to littering.

Impacts can be reduced by the introduction of speed limits and prohibition of off-road driving. Avoidance of the use of heavy vehicles also reduces negative vehicular impact.

The density of off-road tracks and the number of vehicles should be kept to a minimum. Adherence to park regulations should be actively enforced.

7.3.4. Abandonment Phase

Structure Removal and Road Clearing
The main negative impacts during the abandonment phase are the loss of habitat associated with leaving abandoned plant, equipment and buildings without any attempt at rehabilitation. Unplanned, careless and disorganised removal of physical facilities can cause further loss of habitat. Once the structures are removed the sites can be left to undergo succession, or be rehabilitated to achieve average status with the neighbouring area. An additional problem is the abandoned wells (holes) which can be a wildlife and human hazard.

Negative impacts can be reduced by consideration in the planning stage of the design of some of the physical facilities and roads with the aim of transfering them to tourism and wildlife viewing circuits once the project is abandoned. Most of the buildings should be semi-permanent so that they can be easily removed with little disruption. Professional removal of plant and building will also ensure that no further loss of habitat and unnecessary disturbance of wild animals which may have learnt ways of living alongside the project during its operation period. After the removal of plant, revegetation should be encouraged to increase the rate of recovery.

7.3.5 Summary of Recommended Management and Monitoring Procedures

The following is a summary of the management and monitoring procedures recommended to protect wildlife from the negative impacts of the development.

1. Game-proof fencing of the holding ponds to prevent poisoning of wildlife.

2. Deep reinjection of drilling water and brine.

3. Location of drains and pipelines so that they do not form barriers for small animals.

4. Introduction of speed humps to reduce animal deaths from excessive vehicle speeds.

5. Minimising the area taken up by roads, padsites and plant to reduce loss of habitat. Vegetated gullies are important refuges for animals and these should not be interfered with during any stage of the project cycle.

6. Training of workers regarding park regulations particularly with regard to interaction with animals and littering. KPC should ensure that poaching does not occur and personnel found interfering with wildlife should be dismissed

7. Adequate facilities for waste disposal.

8. Bans on the introduction by the workforce of exotic animals (such as domestic dogs and cats) and exotic plants (apart from indoor plants).

9. Cleared areas should be rehabilitated with indigenous vegetation as soon as possible to restore habitat.

10. In general, fencing should be kept to a minimum to avoid loss of habitat. Care should be taken to ensure that there are no small animals trapped inside fenced areas.

11. Animal numbers, movements and distribution should be monitored. This should be done either independently by KPC or in liaison with KWS. KPC's Environmental Unit should actively participate in these studies and should be made aware of the findings of these studies and the management decisions which are made as a result of these findings.

12. Vehicle movements within the park should be monitored.

13. It is considered desirable that in the longterm there are no human settlements within the park.

14. KPC have three senior members of staff on the Hell's Gate National Park Management Committee. The personnel are the Geothermal Development Manager, the Geothermal Scientific Superintendent and the Environmental Scientist. An excellent working relationship has been established and there is an effective mechanism by which KWS can influence KPC's activities on a day-to-day basis and in the longer-term. This Further a committee known as the Wildlife Conservation/Geothermal Exploration and Development Committee has been formed to monitor the development of the geothermal resource and the Hell's Gate National Park. This committee will focus on longer-term strategic issues.

7.4 AIR QUALITY

This section describes the predicted impact of the proposed North East Olkaria Power Station on air quality. The impacts are considered in conjunction with the impacts of the existing power station as these effects will be cumulative. The approach to air quality assessment which has been adopted in this study has been to use a dispersion model to estimate ground level concentration of hydrogen sulphide. This was identified in **Section 6.6** as the only air emission likely to have significant local impact.

The proposed development will have no impact on the local climate, however geothermal power stations emit methane and carbon dioxide which are both greenhouse gases. The power station will have no significant effect on the climate of the area. Carbon dioxide emissions from the existing and proposed power stations generating 109 MWe for a year are estimated to be 87 200 tonnes. An equivalent amount of electrical energy delivered by a coal-fired power station, with 37 per cent efficiency burning black coal with calorific value of 23 MJ/kg and carbon content of 65 per cent, would result in the emission of approximately eleven times as much (964 027 tonnes) of carbon dioxide. Nevertheless, the quantities of these gases emitted will be substantially less than from a fuel-burning power station of a similar capacity. The amount of methane emitted is estimated to be 119 tonnes per year for the two power stations generating 109 MWe for one year. This emission will have no measurable environmental effect. In addition the extent of the environmental impact will be considerably less than for a coal-fired power station as there are no associated mining activities apart from the drilling of the wells.

7.4.1 Approach Used in Modelling Analysis

The Dispersion Model
Dispersion modelling has been used to assess the potential air quality impacts due to operation of the power station. The model used is known as AUSPLUME. It is a model developed by the Victorian Environment Protection Authority (VEPA) for use in licensing of stationary sources. It was developed originally from the United States Environmental Protection Agency's ISC-ST model but has been modified progressively to incorporate improvements in dispersion modelling practice as these are made available by the modelling community. Its principal features, relevant to the present study are listed below:

- Provides predictions for any user specified averaging period from three minutes to 60 minutes and 1, 2, 3, 4, 6, 8, 12, 24 hours; 7 days, 90 days (running averages), 3 months, or the full period of the meteorological data file;

- Includes the effects of building-wakes following procedures as set out by **Huber and Snyder (1976)** and **Huber (1977)** and **Bowers et al. (1979)**;

- Takes account of the transformation of a pollutant with time using an exponential decay with time, and;

- Takes account of the effect of terrain on ground-level concentrations using the procedures developed by **Egan (1975)**.

The model includes many other features that are not listed above because they were not used in the application of the model in the present study. A full description of the model is provided in the user's manual (VEPA, 1986). This document is held by KPC Limited.

Application of Dispersion Model

The model has been used to predict ground-level concentrations of hydrogen sulphide over a regularly spaced rectangular grid of points (29 by 39) covering an area 14 km (east-west) by 18.667 km (north-south). The grid spacing used was 333.3 m and the southwest corner of the grid was at 192 000E and 9897 000N on the Longonot (1:50 000) topographical map, East Africa (Kenya) Series Y731 (DOS 423) Sheet 133/4 Edition 7 (DOS 1975). To take account of the effects of terrain, each grid point had an elevation associated with it which was read from 1:10 000 topographical maps when possible and from 1:50 000 maps when the area was not covered by the 1:10 000 scale map. Dispersion modelling simulations were undertaken for 1-hour, 24-hour and 1-year averaging periods. Three cases were simulated:

- o Case 1 simulating dispersion of hydrogen sulphide assuming emissions take place from the existing East Olkaria Power Station operating alone (existing situation);
- o Case 2 simulating the dispersion, assuming emissions take place from the North East Power Station alone, and;
- o Case 3 simulating the dispersion of hydrogen sulphide, assuming emissions take place from the East Olkaria Power Station and from the North East Power Stations at the same time (proposed situation).

Oxidation of Hydrogen Sulphide

In the atmosphere, hydrogen sulphide is oxidised to water and oxides of sulphur. The principal reactions are:

$$OH + H_2S < \text{-------} > HS + H_2O \qquad (1)$$

$$HS + O_2 < \text{-------} > SO + OH \qquad (2)$$

$$SO + O_2 < \text{-------} > \text{Sulphur oxides} \qquad (3)$$

Cox and Sheppard (1980) and **Cox and Sandalls (1974)** provide further information on these reactions and provide data that allow the average removal rate of hydrogen sulphide to be calculated. Using average figures, namely a reaction rate $5x10^{-12}$ cm^3/s **(Cox and Sheppard 1980)** for Equation 1 and an average hydroxyl concentration of $3x10^6$ $molecules/m^3$ **(Cox and Sandalls, 1974)** it is possible to estimate an average value for the removal rate of hydrogen sulphide. This was estimated to be approximately 5 per cent per hour, which has the equivalent exponential decay of $1.425x10^{-5}$ s^{-1}, when used in the AUSPLUME model.

Model runs with and without the decay, showed very little difference over the grid. This is not surprising, since plume travel distances within the grid are typically less than 16 km. Even in light wind conditions, it is unlikely that wind speeds of less than 1.0 m/s would be encountered at the effective height of the plume and therefore travel times are unlikely to be much greater than four to five hours. This would give rise to depletion of hydrogen sulphide in the plume of between 20 and 23 per cent, that is 20 to 23 per cent of the hydrogen sulphide in the plume will have been transformed by the time the plume has travelled 16 km or so. While this is not a particularly significant depletion it has been taken into account in the modelling, as it is believed to be more realistic than not including it.

7.4.2 Emissions

The dispersion model also requires data on emissions from the power stations. Table 7.4.1 lists the required emissions data for the East and North East Power Stations if they both operate at their maximum power levels and the hydrogen sulphide emission levels are as high as they are ever likely to be. The emission figures are based on approximately 4.7 per cent of the non-condensable gases being hydrogen sulphide.

TABLE 7.4.1- EMISSION PARAMETERS USED TO MODEL DISPERSION FROM EXISTING 45 MWe EAST OLKARIA POWER STATION AND THE PROPOSED 64 MWe NORTH EAST POWER STATION

	East Olkaria	North East Olkaria
Height of emission point above grade (m)	19	20
Exit velocity (m/s)	20.0	10.6
Exit temperature (K)	375	315
Diameter of discharge point at tip (m)	0.2	8
Mass emission rate of hydrogen sulphide for each of three emission points for East Olkaria and for each of six emission points for North East Olkaria (g/s)	4.46	3.01

7.4.3 Comparison of Plume Rise at East Olkaria and North East Olkaria Power Stations

From the point of view of dispersion modelling and from the resulting impacts, there is an important difference between the existing and proposed power stations. The difference is due to the way in which the waste hydrogen sulphide is disposed of in the two power stations.

The North East Power Station will discharge the non-condensable hydrogen sulphide in the cooling tower plume, whereas the East Olkaria Power Station discharges the hydrogen sulphide through three pairs of gas ejectors located on the main power station building. The cooling tower plumes have a substantial plume rise compared with the plume rise from the gas ejectors. Table 7.4.2 shows the effective height of the plume (that is the plume rise plus the height of the emission point) from the two sources under a range of wind speeds under stable atmospheric (Pasquill-Gifford F-class) conditions. These are the stability conditions when plume rise would be expected to be at its lowest.

The table shows that under low wind speed conditions, the plume rise for the proposed power station is between three and four times higher than the plume height from the existing power station. This leads to substantially lower predicted ground-level concentrations. Plate 3 in Section 2 shows plumes of condensing water vapour from the cooling towers and the gas ejectors of the East Olkaria Power Station. The plate confirms that the plume rise from the cooling towers is substantially higher than that from the ejectors.

7.4.4 Assessment of Impacts

7.4.4.1 Impacts in the Development and Construction Period

Drilling of wells has very little effect on air quality except for minor emissions of exhaust fumes from diesel engines and the generation of dust from vehicles travelling on unsealed roads. In the Olkaria environment, the impacts are unlikely to ever reach unacceptable levels and need no special controls.

TABLE 7.4.2 - EFFECTIVE FINAL PLUME HEIGHT[1] FOR EAST OLKARIA AND NORTH EAST OLKARIA POWER STATIONS UNDER RANGE OF WIND SPEEDS FOR STABLE CONDITIONS - (m)

	Wind speed m/s				
	1	2	3	4	5
East Olkaria	27	23	22	21	21
North East Olkaria	115	95	86	80	76

Testing of wells does have the potential to damage vegetation close to the well by allowing hot steam to "burn" plants and allowing hot brine and silica in solution to come into contact with nearby plants. This can destroy plants. However the vegetation will recover and the effect is temporary and confined to the proximity (a few tens of metres) of the well. Well-testing also has the potential to cause odour impacts if undertaken close to residential or work areas. Some wells at North East Olkaria have affected both vegetation and the quality of the air with respect to odours. However, given the temporary nature of these impacts, it is considered that these are acceptable provided adequate buffer zones are maintained. For some wells the impacts at X2-Camp may not have been acceptable initially and the well development program was modified.

Construction work will involve the generation of dust as site works are undertaken and as vehicles travel on unsealed roads. This has the potential to affect air quality at X2-Camp and water carts should be used to minimise dust from construction activities. With these simple controls in place, air quality impacts will be maintained at acceptable levels.

[1] The effective plume heights shown in the table have been calculated using AUSPLUME's Brigg's (1975) plume rise equations including building wake and downwash effects if applicable. The nominated wind speed in the table refers to the speed that would apply at 10 m.

7.4.4.2 Reliability of Model Predictions

The basis of the impact assessment for the operational phase of the development is a comparison of predicted ground-level concentrations with various criteria relating to either health or nuisance effects.

Inaccuracies may arise in the modelling for the following reasons:

- o the meteorological data may be inaccurate or not representative of the area being studied;
- o the emissions data may be inaccurate;
- o the dispersion model may not faithfully simulate the physical processes[2] associated with the dispersion, and;
- o the model may not faithfully simulate the chemical process involved in removing the pollutant from the plume.

In the present study, considerable efforts have been made to ensure that representative and reliable input information has been used. Where uncertainties apply, it is believed that conservative approaches have been adopted. That is assumptions have been adopted that will exaggerate impacts rather than understate them, while at the same time preserving realism in the assessment.

In impact assessment for green-field projects, dispersion models are used directly and there is no opportunity to check the accuracy of the model. For the present study there is a limited opportunity to compare the measured concentrations near the existing East Olkaria Power Station, with predicted concentrations. This comparison is of limited value because the two power stations have substantially different emission characteristics (see discussion on plume rise below) and further, the range of concentration measurements is small and confined to an area close to the power station where concentrations are expected to be high. Nevertheless it is interesting to compare the predicted ground-level concentration under the dispersion conditions that gave rise to highest concentrations reported in **Table 6.6.2**.

If the hydrogen sulphide concentration measurements presented in **Table 6.6.2** are reviewed, it will be seen that the highest measured concentration was 1.25 ppm (1.52 mg/m^3). This occurred on 27 December, 1991, with light winds, (2 to 3 m/s) blowing from approximately 18° east of north, at a site approximately 160 m from the central gas ejector. From the time of day and the cloud cover at the time, it can be determined that the prevailing atmospheric stability would have been Class-D. Under these conditions, the dispersion model predicts that the 1-minute average ground-level concentration would be 1.71, 1.45 and 1.26 ppm for 2, 2.5 and 3 m/s wind speeds respectively. The model therefore appears to have a tendency to predict concentrations that are higher than measured by between 1 and 40 per cent. Readers are cautioned against assuming that the results of this "test" would apply under all dispersion conditions

[2] These include the equations that account for plume rise, the effects of terrain, the effects of building-wake turbulence as well as the dispersion process.

It should be noted that the scientific community would generally expect model predictions obtained using an advanced gaussian dispersion model (of the AUSPLUME class) with good quality meteorological to "be accurate to within a factor of two".

7.4.4.3 Impact Assessment (Predicted Maximum Concentrations)[3]

Impacts have been assessed by comparing the air quality criteria discussed in **Section 6.6** with predicted concentrations for 1-hour, 24-hour and 1-year averaging periods for three cases, one with the existing East Olkaria Power Station operating alone (existing situation), the second with the proposed North East Power Station operating alone and the third with the two power stations operating together (proposed situation).

It will be clear that predicted concentrations are too low to give rise to effects on health. Also concentrations are too low to affect vegetation. However, it is predicted that there will be detectable odours due to emissions of hydrogen sulphide over a wide area. The impact of odours depends not only on the intensity of the odour but also on the frequency with which the odour occurs. For this reason we analyse impacts in two different ways. Firstly, consider contours of the predicted maximum 1-hour, 24-hour and the annual average concentrations. For the 1-hour and 24-hour predictions, the contours do not reflect the dispersion pattern for a particular hour or 24-hour period but rather are a composite drawn from the highest predicted 1-hour or 24-hour concentrations that occur for each receptor throughout the year.

These contour plots show that the power stations will not comply with the strictest criteria for the protection against nuisance impacts, at least not in all areas. Given this, the contour diagrams are not particularly helpful in assessment of impact because they do not provide any information on how frequently odours may be detected. To provide this information, cumulative frequency plots have been calculated for selected residential areas. These show how frequently a particular value of hydrogen sulphide concentration would be expected to be exceeded in a twelve month period. These are more useful for assessing air quality at a particular location, than the contours of the maximum predicted concentrations.

The predicted ground-level concentrations for the combined operation of East Olkaria and North East Olkaria are shown in **Figures 7.4.1** to **7.4.3**. Predicted ground-level concentrations for the separate power stations are pesented in **Appendix 7.4**.

An interesting factor apparent from a comparison of the predictions for the East Olkaria Power Station (**Figures 1, 2 and 3, Appendix 7.4**) with the equivalent figures for the North East stations operating alone (**Figures 4, 5 and 6, Appendix 7.4**) is that the ground-level concentrations due to the North East Power Station are much lower than those from the East Olkaria Power Station. The introduction of the North East Power Station makes very little difference to ground-level concentrations, although the North East Power Station will have over 40 per cent greater generating capacity than the existing East Olkaria station. The reason for this was discussed in **Section 6.6**.

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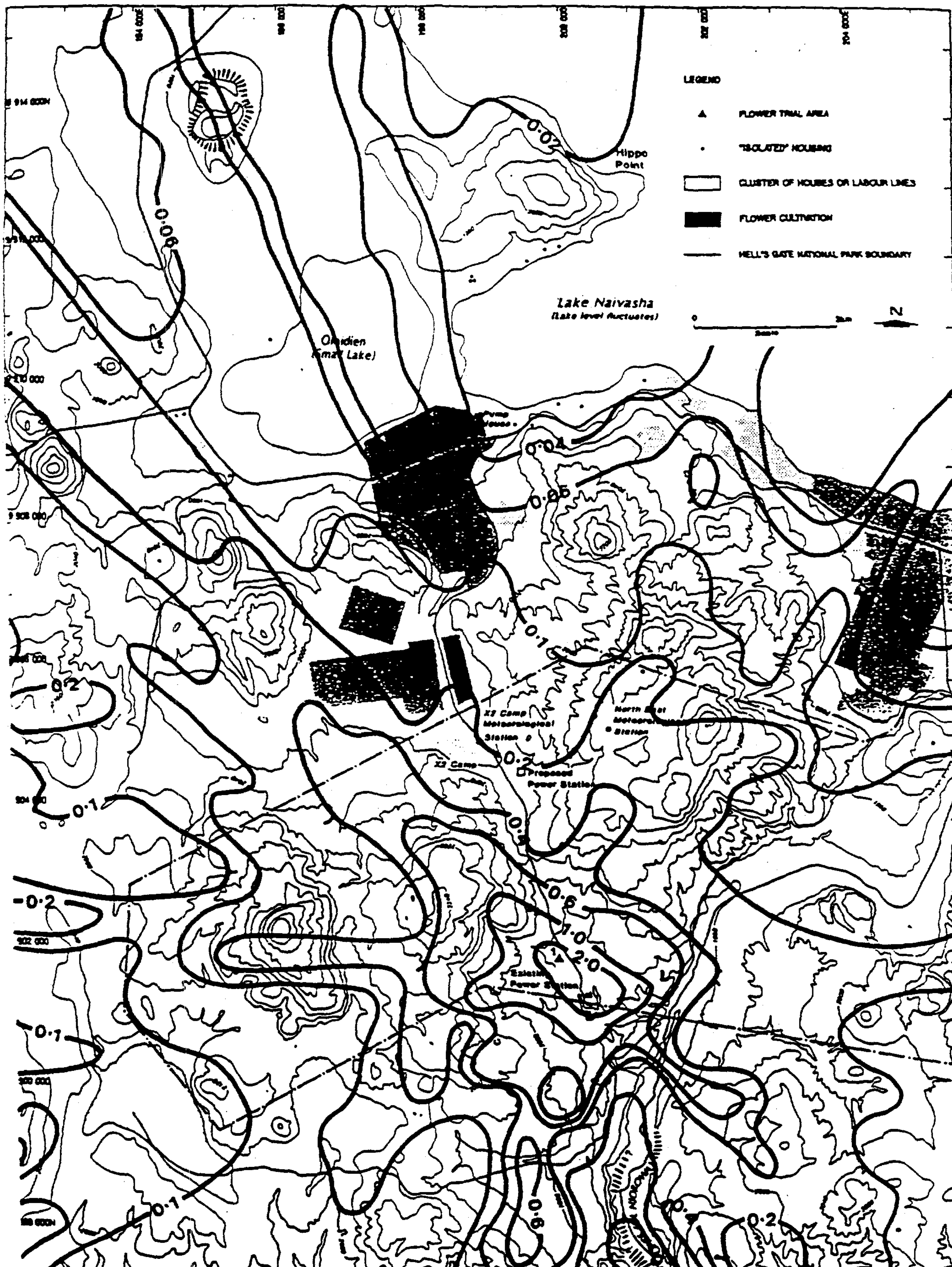
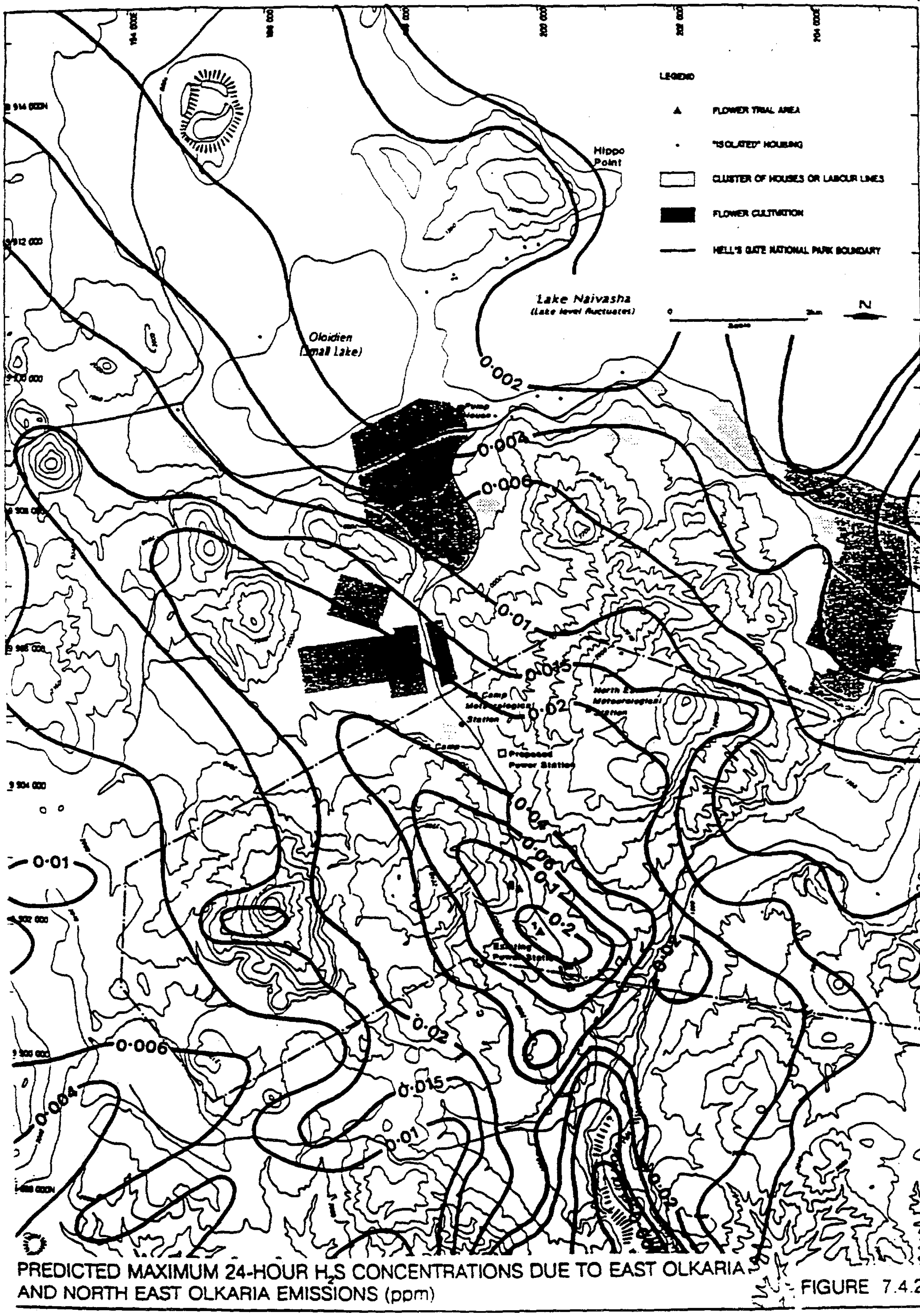
[3]In this section the air quality criteria expressed in ppm take account of the fact that the typical atmospheric pressure at Olkaria will be only 80 per cent of standard atmospheric pressure. The same adjustment has been made in converting the concentrations of hydrogen sulphide from the model predicted $\mu g/m^3$ to ppm.



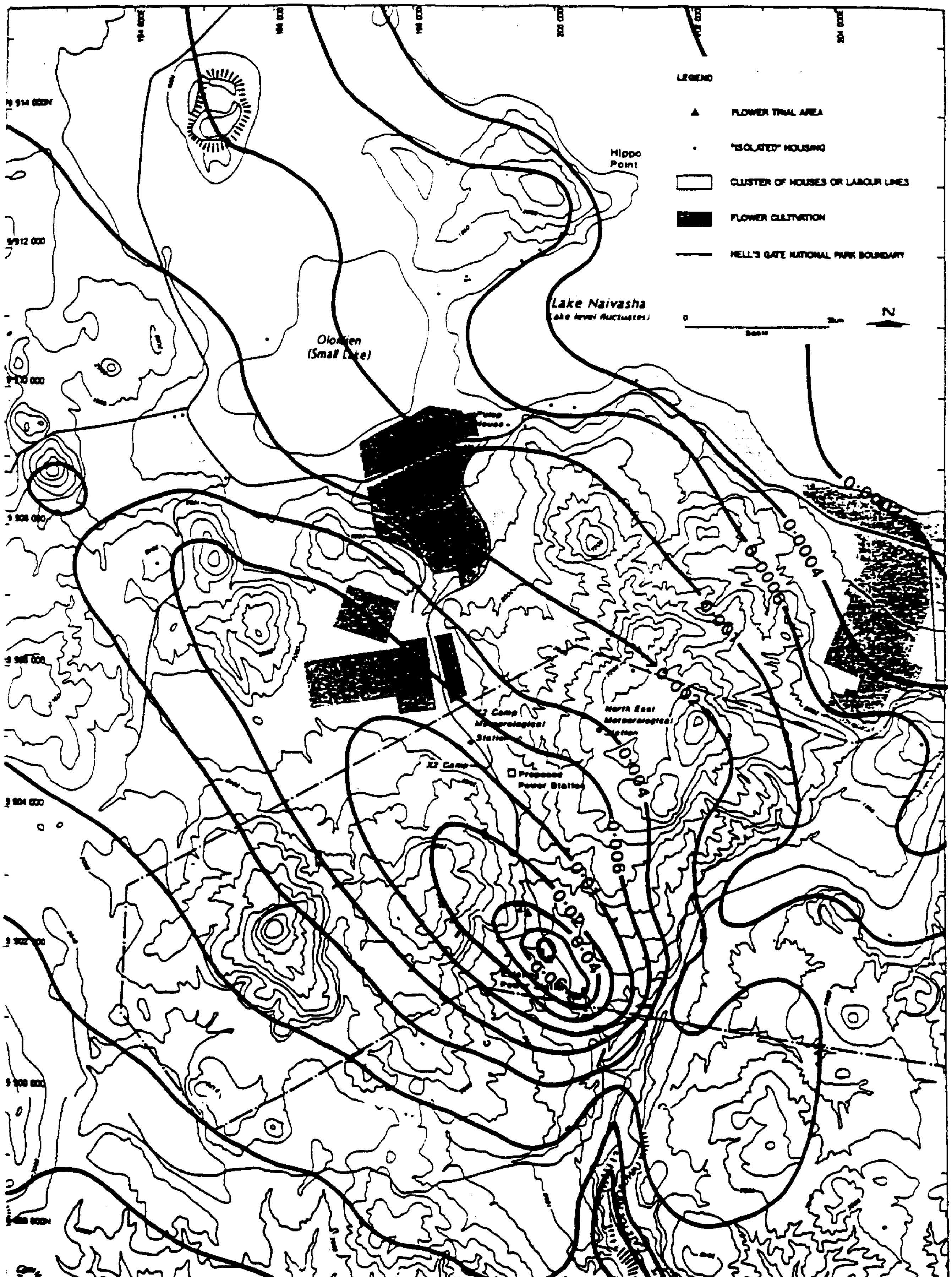
PREDICTED MAXIMUM 1-HOUR H_2S CONCENTRATIONS DUE TO EAST OLKARIA AND NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 7.4.1



PREDICTED MAXIMUM 24-HOUR H_2S CONCENTRATIONS DUE TO EAST OLKARIA AND NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 7.4.2



PREDICTED MAXIMUM 1-YEAR H_2S CONCENTRATIONS DUE TO EAST OLKARIA AND NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 7.4.3

East Olkaria Power Station
Examining the predicted ground-level concentrations in detail, it can be seen that the highest predicted concentrations occur in the immediate vicinity of the power station. Maximum 1-hour averages occur towards the north (see **Figure 1, Appendix 7.4**). The contour plotting process smooths out the highest concentrations and although the maximum contour level shown is 2.0 ppm, the maximum predicted 1-hour concentration was 6 ppm (1-hour average) and the equivalent short-term average over a few minutes or so may be a factor of 1.8 higher at 11 ppm (13.4 mg/m^3). This concentration occurred under Class-E stability, with a wind speed of 1.1 m/s from 53 degrees. It clearly relates to a condition when the emission is trapped in the building-wake turbulence, in a wind blowing along the length of the power station.

Eight-hour average concentrations would be expected to be 0.66 times the predicted maximum 1-hour concentrations and thus the very highest 8-hour average concentration expected at ground-level in the ambient air close to the power station (the fenced area) of the station, would be approximately 7 ppm. This is below the 10 ppm occupational health exposure level.

Further, from the power station it can be seen that 1-hour average concentrations and of course 30-minute averages (which would be expected to be approximately 15 per cent higher) exceed the 0.03 ppm Californian 1-hour criterion, 8 km from the East Olkaria Power Station and even further, if points on elevated terrain are considered. The WHO recommended 30-minute goal would be exceeded out to even greater distances. This makes it necessary to examine the frequency at which various concentrations will be exceeded at various residences. This is done later in this section. No threats to health are posed by the predicted concentrations.

Figure 2, Appendix 7.4, shows a maximum contour of 0.2 ppm. The maximum predicted ground-level concentration was 0.45 ppm. The recommended WHO goal is 0.125 ppm (at 80 per cent of sea-level pressure). It can be seen that this contour extends to approximately 1.8 km to the northwest of the existing Power Station. This standard is set to protect the health of humans with a safety factor of 100. No non-KPC controlled residential areas are affected. Visitors to the Hell's Gate Park may pass through the area predicted to experience 24-hour average concentrations above 0.125 ppm level but visitors are not permitted to spend 24 hours at a time in this area and the short-term exposures are not such as to pose a threat to health.

Figure 3, Appendix 7.4 shows the predicted 1-year average concentrations. Sensitive plants are reported to experience adverse impacts above a concentration of 0.1 ppm (0.125 ppm at 80 per cent of sea-level pressure). Clearly there is the potential for sensitive plants to show some affects within a few hundred metres of the East Olkaria Power Station. However, the vegetation and flower trial studies (reported elsewhere) have not revealed impacts due hydrogen sulphide. The effects on vegetation observed so far appear to be due to deliberate actions such as grass cutting, or accidental fires and accidentally introduced non-local plants, by construction equipment.

North East Olkaria[4]
Figure 4, Appendix 7.4, shows the predicted maximum 1-hour average concentrations. The pattern of contours is quite different from the case of the East Olkaria Power Station. This is because of the substantially higher plume rise that will occur with the new power station. The maximum concentrations are associated with the high ground and the maximum contour shown is 0.4 ppm. The highest predicted concentration is 1.12 ppm. No residential areas except for part of X2-Camp and some Maasia bomas on the south western and central southern boundary of Hell's Gate Park, are predicted to exceed the Californian 1-hour average 0.04 ppm level, adjusted for 80 per cent sea-level pressure. Comparison of **Figures 1** and **4, Appendix 7.4**, shows that the impact of the proposed North East Power Station is far less than from the existing East Olkaria Power Station.

Figure 5, Appendix 7.4, shows the predicted 24-hour average concentrations for the North East Power Station operating alone. No areas are predicted to be affected by 24-hour average concentrations above the WHO 24-hour goal of 0.1 ppm (0.125 ppm at 80 per cent atmospheric pressure).

Figure 6, Appendix 7.4, shows the predicted annual average hydrogen sulphide emissions due to North East Olkaria Power Station emissions. Nowhere do predicted concentrations exceed that concentration at which sensitive plants show effects.

Cumulative effects of North East Olkaria and East Olkaria Power Stations
Figure 7.4.1 shows the predicted 1-hour maximum ground-level concentrations of hydrogen sulphide. It is clear that the introduction of the North East Power Station has almost no effect on the maximum 1-hour ground level concentrations experienced. The impact assessment is the same as for the East Olkaria Power Station operating alone, except that marginally higher concentrations are experienced on the high ground to the east and southwest of the North East Power Station.

Figure 7.4.2 shows the maximum predicted 24-hour concentrations. Comparison with **Figure 2, Appendix 7.4**, shows no significant change in predicted maximum 24-hour concentrations except in the area to the east of the North East Power Station. The change in the area to the south west apparent in the predicted 1-hour concentrations does not show up in the 24-hour averages.

Figure 7.4.3 shows the predicted 1-year average hydrogen sulphide concentrations. Again the introduction of the North East Power Station is almost imperceptible except on the high ground to the east of the North East Power Station, where concentrations will approximately double (see area close to the North East Meteorological Station where concentrations increase from a low value of 0.002 to a still low value of 0.004 ppm).

7.4.4.4 Impact assessment (predicted cumulative frequency distributions)

To evaluate fully the impact of odours from the power stations, it is necessary to examine not only the maximum concentrations expected but also the frequency with which particular concentrations are expected. **Figures 7.4.4, 7.4.5 and 7.4.6** show the predictions for nine sites for the three cases; East Olkaria Power Station by itself, North East Olkaria Power Station by itself and the two operating simultaneously. The grid

[4] This case will be of minor significance because it is planned that the two power stations will operate together.

CUMULATIVE FREQUENCY DISTRIBUTION OF PREDICTED 30-MINUTE AVERAGE HYDROGEN SULPHIDE CONCENTRATIONS DUE TO EAST OLKARIA POWER STATION (USING X2 1990/91 METEOROLOGICAL DATA)

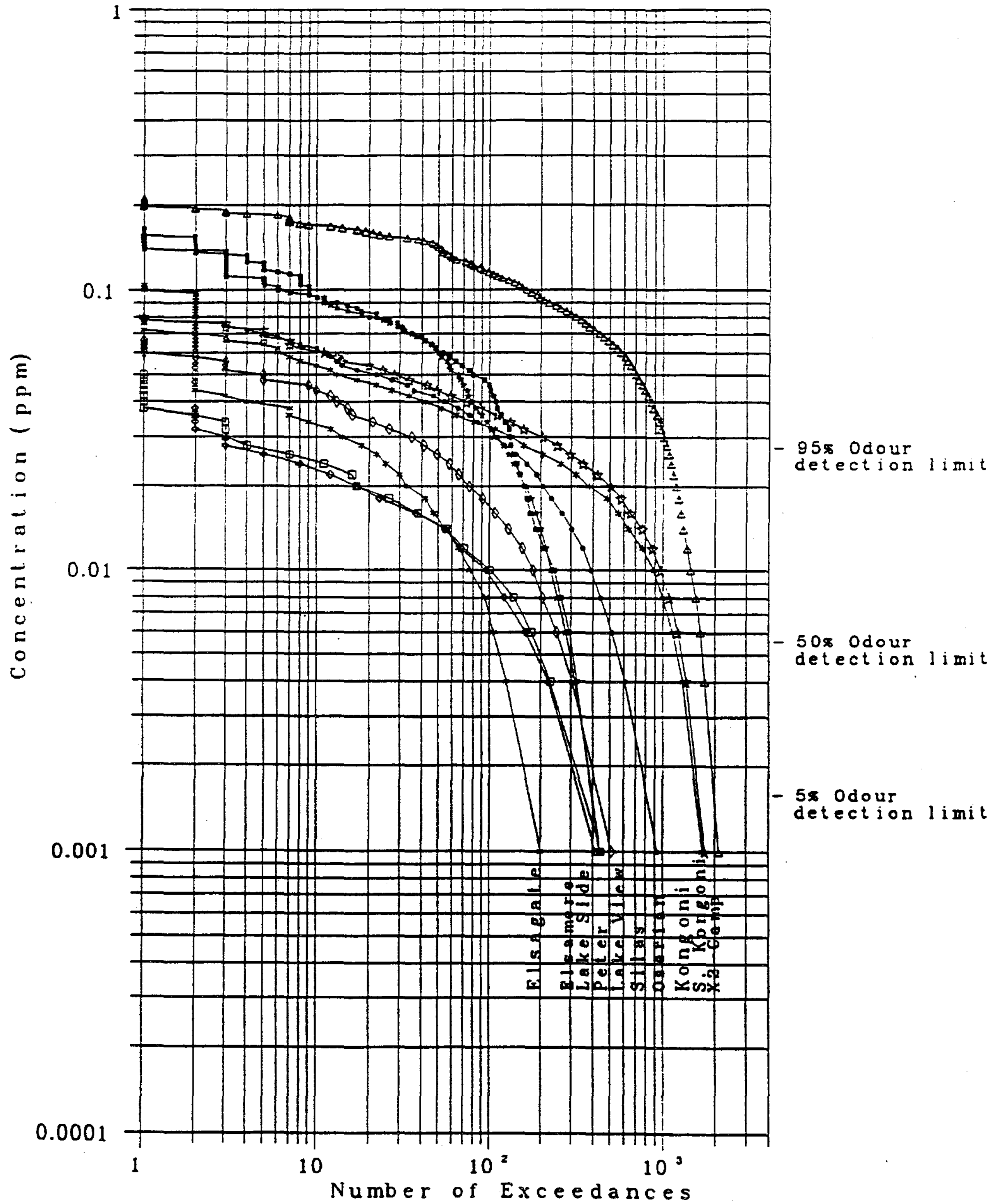


Figure 7.4.4

CUMULATIVE FREQUENCY DISTRIBUTION OF PREDICTED
30-MINUTE AVERAGE HYDROGEN SULPHIDE CONCENTRATIONS
DUE TO NORTH EAST OLKARIA POWER STATION
(USING X2 1990/91 METEOROLOGICAL DATA)

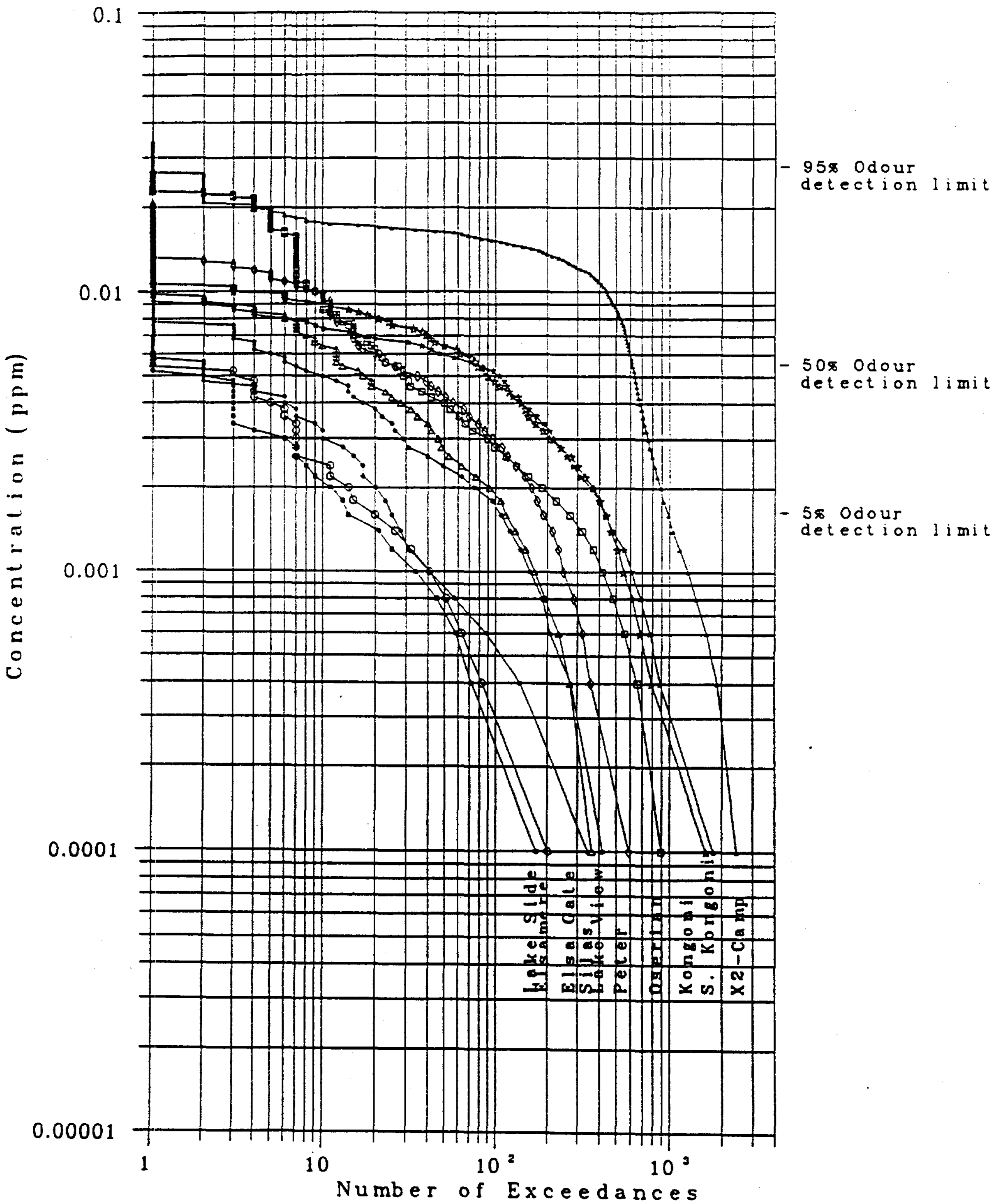


Figure 7.4.5

CUMULATIVE FREQUENCY DISTRIBUTION OF PREDICTED 30-MINUTE AVERAGE HYDROGEN SULPHIDE CONCENTRATIONS DUE TO EAST OLKARIA AND NORTH EAST OLKARIA POWER STATIONS (USING X2 1990/91 METEOROLOGICAL DATA)

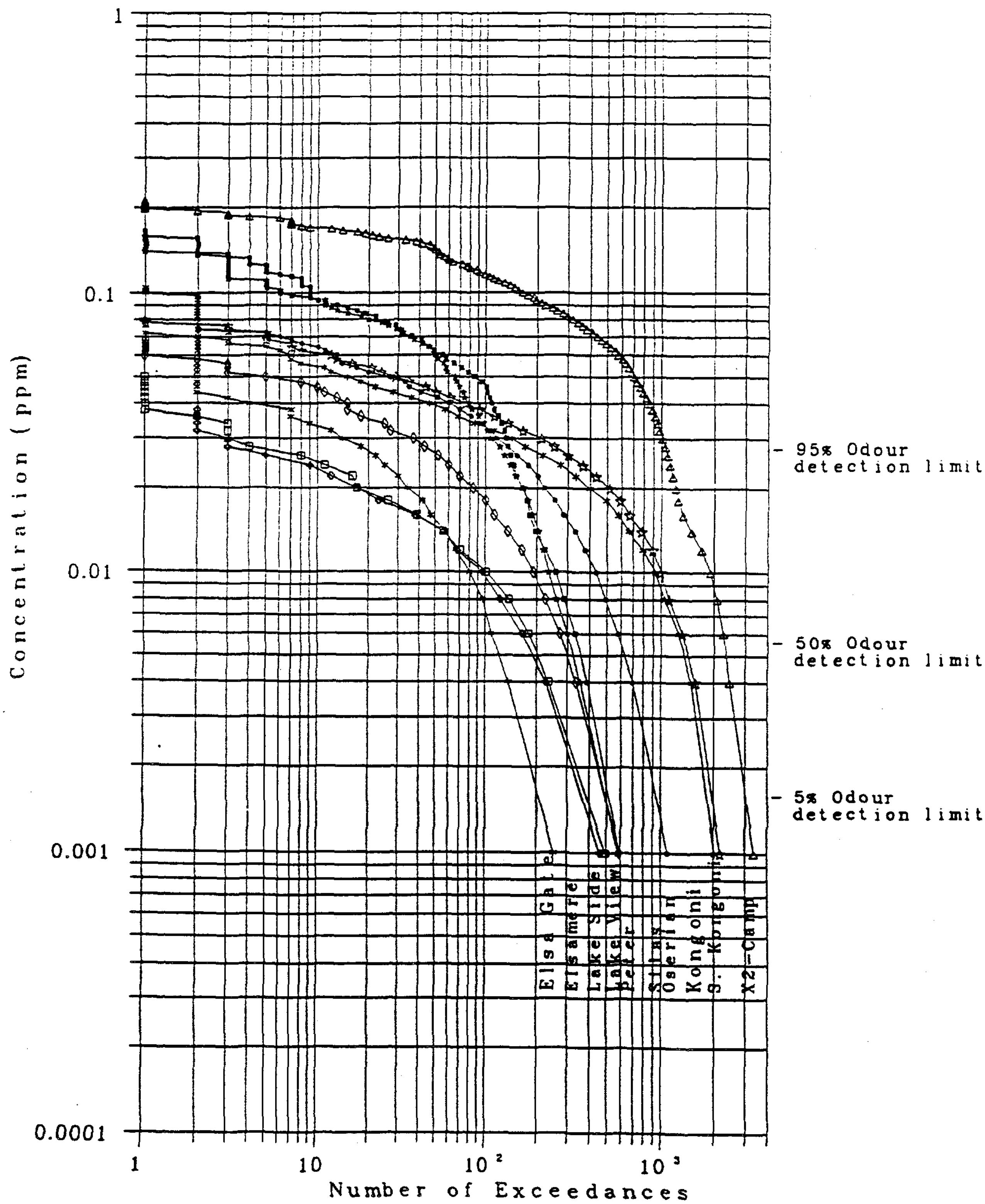


Figure: 7.4.6

coordinates and elevations of the nine sites are listed in Table 7.4.3 and the sites are also shown on Figure 6.6.1.

The discussion presented in this section will probably be the most useful method whereby local residents will be able to assess the impact of the proposed power station. It allows the existing level of impact to be compared with the future level.

TABLE 7.4.3- COORDINATES AND ELEVATIONS OF SITES FOR CUMULATIVE FREQUENCY DISTRIBUTION PLOTS

Site	East (m)	North (m)	Elevation (m above sea-level)
Elsa Gate (KWS northern entrance to Hell's Gate National Park)	207100	905900	1940
Elsamere (Conservation Centre)	201300	910200	1900
Kongoni (Ranch and Police Post)	194700	909550	1920
Lake Side (KPC housing)	201650	910000	1900
Lake View (KPC Housing)	210275	909325	2000
Oserian (labour housing)	199250	908325	2000
Peter (Maasia boma)	204700	900500	2000
Silas (Maasia boma)	196800	900000	2000
X2-Camp (KPC housing)947Y	198425	904800	2000

Figure 7.4.4 is the predicted air quality for the existing situation. The figure shows how many hours in the year a particular 30-minute concentration value will be exceeded at any of the nine locations. On the right-hand axis are marked three odour levels: the 5 per cent odour detection limit; the 50 per cent limit; and the 95 per cent limit. These are taken from data presented by Nagy (1991) following tests of human response to odour undertaken using two 9-person odour panels. The 5 per cent limit is the concentration at which the most sensitive panellist was able to just detect an odour (but not necessarily identify it), the 50 per cent limit is the concentration at which 50 per cent of the panel could just detect the odour (presumably the more sensitive members experience an odour stronger than the "just detectable") and the 95 per cent limit is the concentration at which 95 per cent of the panellists could at least detect the odour.

To use the graph, select a particular curve, for example Elsa Gate (existing situations) and read from the curve how frequently a particular 30-minute concentration is exceeded. For Elsa Gate the curve shows that the 50 per cent odour detection limit is exceeded for approximately 108 hours[5] in a year. That is if the 50 per cent-member of Nagy's odour panel spent one year at Elsa Gate continually concentrating on detecting hydrogen sulphide odours, then that person would be expected to report an odour on approximately 108 hours. That is slightly over two hours per week. The same person at X2-Camp would be expected to report a detectable odour on approximately 1654 hours per year. That is approximately 32 hours per week.

This approach to the assessment may overstate the odour impacts because it does not take into account the fact that exposure to hydrogen sulphide causes a rapid decrease in sensitivity to the odour. Nor does it take into account the decreases in sensitivity that occurs due to interference by common hydrocarbons and other odours. However, unless an odour panel was selected from residents in the area the approach seems to be the best available.

Nagy (1991) also supplies information on complaint levels from the odour panel studies. The 5 per cent complaint level is 0.0017 ppm, the 50 per cent level is 0.016 ppm and the 95 per cent level 0.247 ppm. Thus clearly even at X2-Camp, the "worst-affected" residential area, there would still be people for whom the concentration did not reach the complaint level. The 50 per cent complaint level would be exceeded on approximately 1300 hours per year. That is 25 hours per week. Again these goals probably overstate the impact because of the factors discussed above.

Figure 7.4.5 shows the predicted cumulative frequency curves for the proposed North East Power Station operating by itself. The improved disposal method, namely discharging the hydrogen sulphide in the cooling tower plume, will achieve much greater plume rise (see **Table 7.4.2**) and the consequences for ground-level concentrations of hydrogen sulphide are dramatic. The most sensitive noses at X2-Camp would be predicted to detect the smell on only 609 hours in the year (about 37 per cent of the frequency due to the existing Power Station which is substantially further away) and the least sensitive noses may never detect the odour. This operating scenario will probably never occur so the curves are only useful for determining the contribution that the North East Power Station will make.

Figure 7.4.6 shows that expected future operating case with both the East and North East Power Stations operating together. Comparing **Figure 7.4.4** and **Figure 7.4.6** is probably the best way to assess the impacts. It can be seen that the change in impact is generally small, except at X2-Camp where the 50 per cent odour detection limit is predicted to be exceeded 1654 hours/year at present and 2280 hours/year with both stations operating. This level of impact would be expected to apply also at KWS's Olkaria Gate. At the Elsa Gate entrance to Hell's Gate National Park the number of "exceedances" rises from 110 hours/year to 112 hours/year.

Table 7.4.4 summarises the number of times that the 50 per cent odour detection limit is exceeded at each of the ten sites for the three cases examined.

The operation of the North East Power Station will make very little difference to the incidence of odours in the area.

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[5] The predicted concentrations used in constructing the cumulative frequency curves are 30-minute average concentrations. Only one 30-minute average is predicted for each hour of meteorological data. Thus there are approximately 8760 predictions of half-hour concentrations in the year.

TABLE 7.4.4- PREDICTED NUMBER OF 30-MINUTE HYDROGEN SULPHIDE CONCENTRATIONS ABOVE THE 0.0058 ppm 50% ODOUR DETECTION LIMIT OVER ONE YEAR

Site	East Olkaria (alone)	North East (alone)	East Olkaria and North East Olkaria (together)
Elsa Gate	108	1	112
Elsamere	182	1	186
Kongoni	1157	72	1290
South Kongoni	1239	72	1350
Lake Side	169	1	171
Lake View	254	6	280
Oserian	526	22	589
Peter	298	22	340
Silas	283	12	306
X2-Camp (use for KWS's Olkaria Gate area)	1654	609	2280

7.4.5 Emissions of Radioactive Gases

As discussed in **Section 6.6**, the data on radon emissions presented by **Clarke et al. (1990)**, shows that the radon-222 levels in the Olkaria area were in the range 255 to 3000 counts per minute. On the assumption that the maximum level would have been 5000 cpm and the volume of the enamometer chamber was 250 ml and its efficiency was 100 per cent, then the activity of the fumarole gas would be 3.3×10^5 Bq/m^3. As discussed earlier, radon-222 levels were found to be strongly correlated with carbon dioxide concentrations and the carbon dioxide concentration that corresponded to the maximum radon-222 level was 30.6 percent.

With this information, and the predicted maximum annual average hydrogen sulphide concentrations presented in **Section 7.4.4**, it is possible to estimate the maximum ground-level radon-222 level. This can be done by noting that hydrogen sulphide has been taken to be four to five per cent of the non-condensable gas fraction of the geogas emission. This results in a maximum ground-level concentration of hydrogen sulphide of 0.08 ppm (annual average with both power stations operating). If the remainder of the geo gas emission is taken to be carbon dioxide, then it is possible to estimate the radon-222 level to be $0.08 \times 10^{-6} \times (96/4) \times (100/30.6) \times 3.3 \times 10^5$, namely 2.1 Bq/m^3. The EER radon-222 concentration will be less than this by a factor of at least two. Therefore the increase in radon-222 concentration due to emissions from both power stations is likely to be of the order of 1 Bq/m^3, at the most-affected receptor. This is one percent of the **WHO (1990)** guideline.

Thus power generation activities are not expected to have any significant effect on radiation levels at Olkaria. However, it should be noted that this conclusion is based on assumptions, which although believed to be either realistic or conservative, are nevertheless assumptions. In view of this, it is recommended that a program to measure worker exposure to radiation should be undertaken.

7.4.6 Conclusions and Recommendations

Main findings

The air quality assessment has provided a description of the local environment, a description of the project from the point of view of air quality and has reviewed data on existing air quality. It has been based on the use of the AUSPLUME computer-based dispersion model, local meteorological data and emissions data to predict ground-level concentrations of emissions. Predictions have been made for three cases: the existing situation where the East Olkaria Power Station operates by itself; the case when the proposed North East station operates by itself; and the proposed future situation when the East and North East Power Stations operate simultaneously.

Because of superior dispersion of emissions from the new power station, the introduction of the new North East Power Station will have little effect on ground-level concentrations of hydrogen sulphide.

The modelling studies show that there are no health risks due to hydrogen sulphide in the ambient air, although there is an area, extending approximately 1000 m to the north of the East Olkaria Power Station where the WHO 24-hour goal of 0.15 ppm may be exceeded under "worst-case" days. This area is fenced and access to this area is already controlled. The concentrations are well below occupational health standards.

Although no health impacts are predicted to occur, the model predicts that odours are presently detectable over wide areas. The concentrations predicted when modelling the existing situation exceed the more stringent of the internationally recognised air quality goals but comply with the less stringent goals. The introduction of the North East Power Station will make little change to the frequency or intensity of odours experienced in residential areas except at KPC's X2-Camp (and the nearby KWS's Olkaria Gate) where the incidence of odours is predicted to increase by 39 per cent.

Predicted annual average concentrations of hydrogen sulphide indicate that even sensitive individuals are unlikely to be affected by either the existing power station, or the two power stations taken together. Flower-growing trials and surveys of existing vegetation have failed to identify any air pollution effects. However, it is recommended that the vegetation monitoring program and flower growing trials should be continued for a further three years after which the need for continued monitoring should be reviewed. The new power station will cause an almost imperceptible increase in annual average ground-level concentrations at the closest point in Oserian's flower growing areas. No impacts are expected.

Thus on the basis that current air quality is acceptable, there should be no reason not to allow the operation of the North East Power Station.

Recommendations
The following recommendations are made concerning air quality issues.

- o Residents in X2-Camp are predicted to experience a significant exposure to odours. Ideally the camp should be moved to an area experiencing a lower incidence of odours. However the shortage of accommodation in the area means that it is likely that people would prefer the option of living at X2-Camp, rather than uncertain alternatives.

- o Meteorological monitoring should be continued at the X2-Camp site.

- o One and preferably two continuous hydrogen sulphide monitors (with logging equipment) should be established to monitor hydrogen sulphide concentrations at the flower trial areas to the north of the East Olkaria Power Station and at X2-Camp.

- o The cooperative flower trial studies with Oserian Development Company should be continued until such times as Oserian Development Company are satisfied that the sensitivity of their operations to hydrogen sulphide has been determined. It would be useful if these studies were to establish the threshold at which adverse effects begin to occur. This would be useful information for KPC's future planning. It is envisaged that these studies may need a further period of up to three years.

- o KPC's Environmental Unit at Olkaria should continue to develop its expertise in dispersion modelling and air quality monitoring and to make use of monitoring data to assess the performance of the dispersion model. This enhancement in expertise will require overseas training or the use of outside consultants with expertise in air quality matters, or a combination of both.

7.5 NOISE

7.5.1 Introduction

Noise impacts have been assessed using a noise prediction model to estimate noise levels that will occur in the neighbourhood of the power station and well field during the well testing phase and during operation of the power station. The predicted noise levels have been presented as contour plots showing the "maximum" predicted noise levels over the area of interest. Discussion of noise impacts expected during the construction phase is also presented. The following sections provide information on the method used to predict noise levels, the environmental noise quality goals which are appropriate for this environment and the expected impacts due to noise emissions.

7.5.2 Method of Predicting Noise Impacts

The computer-based model used in this study, has been developed for assessing the noise impacts from mining and industrial sources. The model is referred to as NOISE4. The principles by which the calculations are made, are similar to those used by most consultants and regulatory agencies undertaking similar noise impact assessment work.

The model takes into account three major factors affecting noise propagation: namely the diminution of noise level due to distance as the sound energy spreads outwards from the source; the effects that natural and artificial barriers have on the sound, and the absorption of sound energy by the atmosphere, where some of the vibrational energy of the sound is converted to heat in the atmosphere. Some sound energy is absorbed by vegeation but with elevated noise sources such as will apply for the power station this effect is expected to be minor.

The first cause of diminution of sound level due to distance (see above) is due primarily to geometric factors and is 6 dB each time the distance from the source to the receptor is doubled. The effects of natural and artificial barriers depends on the frequency of the sound and the geometry of the arrangement of the source, receptor and barrier. The estimates of the reduction in noise level due to barriers has been calculated using a procedure set out by **Harris (1979)**. The absorption of noise in the atmosphere depends primarily on the frequency of the sound and the temperature and humidity of the atmosphere. The method used to account for atmospheric absorption is again taken from **Harris (1979)** and the temperature and humidity assumed to apply was 10 °C and 90% relative humidity. This combination of temperature and humidity corresponds to low absorption and thus leads to generally conservative estimates of noise levels at distant receptors.

For the model to operate, it requires data on sound power level and the tonal composition of the emitted noises. This information has been determined by on-site measurement of noise emissions from existing East Olkaria Power Station. These have been increased appropriately by 1.3 dB to take into account the fact that the proposed North East Power Station will be a 65 MWe Power Station compared with a 48 MWe for the present East Olkaria Power Station.

Apart from noise from heavy earth-moving machinery required for site works during construction, the only significant noise sources associated with the project are the noise of wells under test; noise from the cooling tower complex; and noise from the gas ejectors located, in the East Olkaria Power Station, on the main power station building. For the North East Power Station the gas ejectors disposing of waste hydrogen sulphide will be located inside the cooling towers. Because of the shielding afforded by the walls of the cooling tower, this may well lead to lower noise emission levels than for the present power station. However, in the absence of specific performance data for this arrangement, it has been assumed that the sound power levels due to the North East Power Station gas ejectors will have the same tonal composition and be 1.3 dB noisier than the East Olkaria gas ejectors.

The model takes into account the three attenuating processes discussed above and estimates the sound level at a user-specified grid of points covering the area of interest. For the present study the grid points were spaced at 333.3 m and covered a rectangular area 14.3 km in an east-west direction and 19.0 km in a north-south direction with the southwest corner of the grid at 192 000 m East and 206 000 m North (see **Figure 2.2.3**) The calculations are repeated for each source and the resultant noise level at each grid point is determined by adding the contribution from all of the sources.

7.5.3 Environmental Noise Quality Criteria

The annoyance potential of noise in a particular environment depends on the tonal composition of the noise, whether it is impulsive or not and the level by which the noise exceeds the background level[6]. With the exception of reversing horns that may be used on heavy earth-moving equipment during site preparation works the noise emissions from the project in both the development and operational phase will be broad-band non-impulsive noises. Under these circumstances it is possible to determine environmental noise quality guidelines which can be used to protect communities against adverse noise impacts.

In the present study the goals applied by the New South Wales (Australia) Environmental Protection Authority (EPA) have been used. These are similar to the goals that are applied throughout much of the western world and from discussions at the Technical Environmental Review Committee Meetings these are appropriate for use in Kenya. The New South Wales goals are set out in the "Environmental Noise Control Manual" published by the New South Wales EPA (1985). The relevant information from the manual is set out in the paragraphs below.

The first step in determining appropriate environmental noise quality goals is to establish background noise levels in the area. Because of the well-testing program it was not possible to determine representative background noise close to the proposed power station site and measurements have been made in locations where the influence of noise emissions from wells under test was negligible. Background noise levels in remote isolated areas and in areas where noises from insects and frogs and the wind was low was between 25 and 30 dB(A). Indeed most areas experienced background levels as low as 30 dB(A) from time to time. The NSW guidelines set acceptable background noise levels for rural residences of 45 dB(A) in the day (7 am to 10 pm) and 35 dB(A) at night (10 pm to 7 am). Thus the existing noise environment should be considered as satisfactory, but because of the low background levels the potential for an intruding noise to annoy is higher than it would be in a noisier environment. The NSW guidelines consider that in such environments (that is those with low background noise levels) the intruding noise is acceptable so long as the L_{A10} level from the intruding noise is less the greater of 5 dB(A) above the existing background level, or 35 dB(A). Thus an appropriate environmental noise quality goal is that L_{A10} due to operational noise from the power station should be below 35 dB(A) at noise sensitive sites.

Experience has shown that model calculations made under the assumptions described above will under some atmospheric conditions, namely with light winds blowing towards the receptor and strong ground based inversions, underpredict noise levels at the receptor by up to 20 dB(A). This type of meteorological condition would occur under calm night time conditions with clear skies. This level of underprediction tends to occur at large distances from the noise so although noise levels are higher than predicted they are still very low and below the level at which levels would be considered to be a nuisance.

7.5.4 Predicted Noise Levels and Impact Assessment

Noise During Well-Testing

Well-testing is a noisy operation where high pressure gas (mostly steam) from the well is released to the atmosphere either through a silencer or directly to the atmosphere. Measured noise levels at Well 716, which tested at 4.5 MWe, are presented in Section

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[6] The term background noise level as used in this report refers to the noise level exceeded for 90 per cent of the period of interest. It is usually written as L_{A90}.

6.7. These show noise levels at 30 m from the well are in the range 95 to 100 dB(A). The noise is best described as a roaring noise similar to a large jet engine. Generally three wells are tested at a given time and the test period runs over three months during which time the wells discharge continuously 24 hours a day.

Two other wells, Wells 714 and 709 were tested at 7.1 and 8.5 MWe respectively and thus could be expected to be noisier than Well 716 by between 2 and 2.8 dB(A). **Figure 7.5.1** shows the predicted noise level from Well 716, operated by itself. The figure shows X2-Camp would have experienced noise levels between 45 and 50 dB(A) and the KWS Olkaria Gate area would have experienced noise levels of approximately 47 dB(A). These are above the 35 dB(A) limit and thus would not represent a satisfactory long-term condition. No other residential areas would be expected to experience noise levels above 35 dB(A) and so adverse impacts are confined to the two locations.

Taking account of the noted propensity of the modelling procedure to under-predict noise levels for distant receptors under certain meteorological conditions, (see **Section 7.5.3**) it is relevant to note that it is possible that at distant locations such as Kongoni, noise levels due to Well 716 under test would be perhaps 34 dB(A). Under quiet night time conditions, the noise would be clearly audible above the background. If the effects of an additional two hypothetical wells were to be taken into account, the noise levels would probably not be significantly increased unless the wells had similar noise emission levels. If two additional wells with the same noise emission level as Well 716 were to be tested at the same location as Well 716, then the noise level would increase by 4.8[7] dB(A).

The results of modelling show that well testing has the capacity to cause adverse noise impacts at X2-Camp and at the Olkaria Gate area. The limited duration of the well testing program mitigates the impact, nevertheless for the well testing phase of the project, adverse noise impacts will occur at these two sites.

Well testing will also affect the acoustical environment of other areas of the Hell's gate National Park. In general, in day time conditions noise from well testing in the areas of the park most used by visitors will not be noticed above background noise levels. At night time the park is not open to visitors. However the camping area (4 km ENE of East Olkaria Power Station) may be occupied by campers. Under light winds and inversion conditions, noise from the well testing is audible and may be considered by some campers to detract from the value of the camping experience. However noise levels will at all times be lower than 35 dB(A) and may equally well be considered as an interesting feature of the area. Given the limited duration of well testing this matter is not considered in further detail.

Construction Phase

The noisiest phase during construction will be when site works are being undertaken. This work, which will span approximately 9 months, will involve the use of bulldozers, graders, scrapers, front-end loaders, trucks and cranes. Work will be confined to daytime only 6 am to 5.30 pm. Noise will be clearly audible at X2-Camp (500 m NW of the site), at KWS' Olkaria Gate 1 km to the NNW) and to workers in the neighbouring flower growing areas on Oserian Developments flower growing land (1.2 km to the NNW). Given these distances and the lack of night time operations, no adverse impacts are anticipated at any

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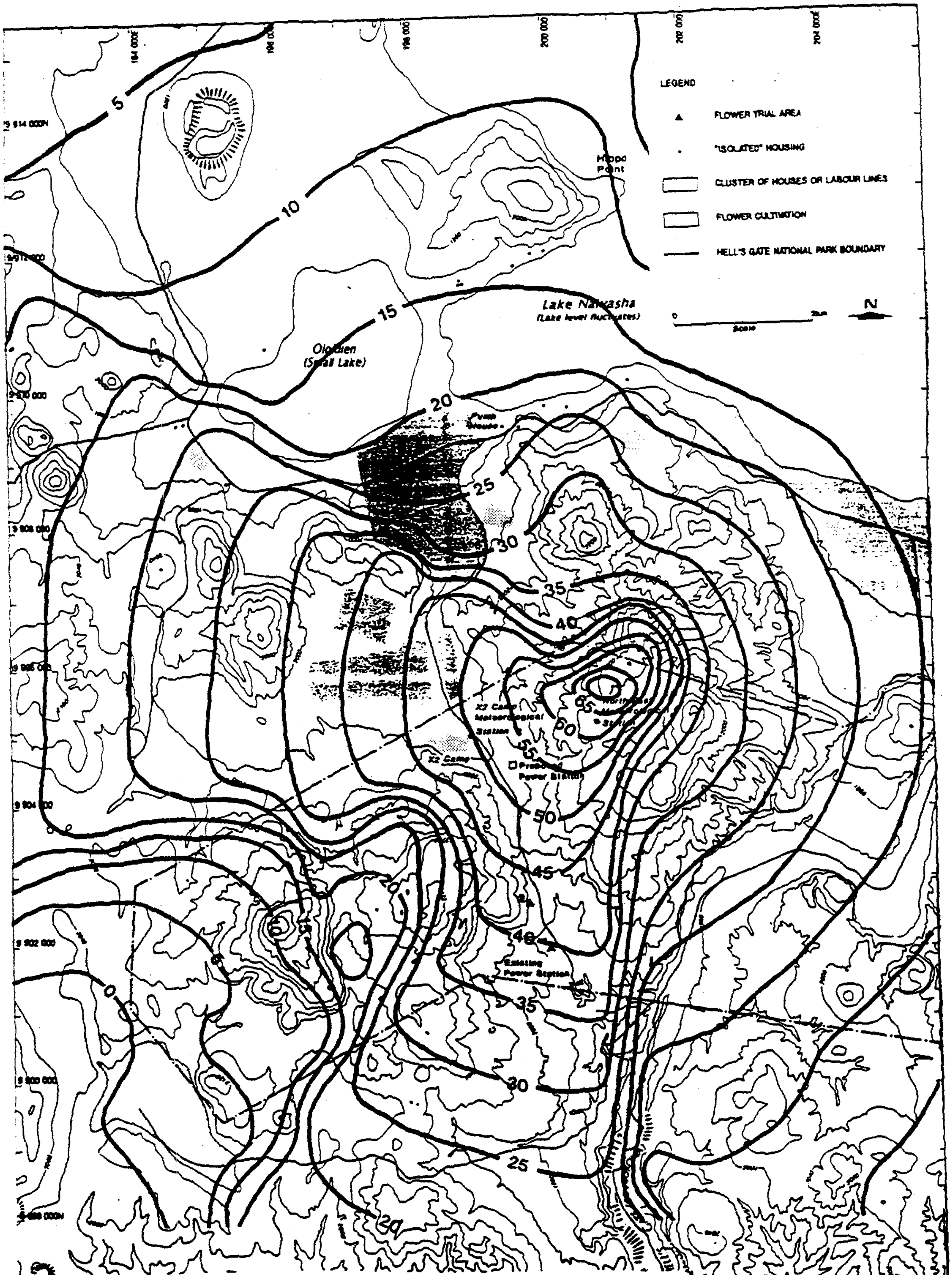
[7] The addition of noise levels follows a logarithmic rule. For example adding two identical noise levels together increases the noise level that is produced by one of the sources by 3 dB (that is $10\log_{10}(2)$). If three identical sources are added the level increases by 4.8 (that is $10\log_{10}(3)$).



PREDICTED MAXIMUM NOISE LEVELS DURING TESTING OF WELL 716 - dB(A)

Figure 7.5.1

of the locations due to construction noise.

Operational Phase Noise
Predicted noise levels due to the existing East Olkaria and proposed North East Olkaria Power Station are presented in **Figure** 7.5.2. X2-Camp is predicted to experience L_{A10} levels in the range 43 to 50 dB(A) and the Olkaria Gate area to experience a level of approximately 38 dB(A). Thus X2-Camp is expected to experience a significant impact and the Olkaria Gate area to experience a marginal impact.

Recommendations
The noise predictions are based on certain assumptions about noise emission levels from the proposed power station. It is possible that noise emission levels from the new power stations gas ejector system will be lower than assumed. However, it would appear unlikely that noise levels below the target of 35 dB(A) will be achieved. If this is verified by monitoring after commissioning of the power station, then the following recommendations apply.

1. Relocate X2-Camp to outside the 35 dB(A) contour operation noise contour; and

2. Monitor noise levels at the Olkaria Gate KWS residences and provide acoustical treatment of these residences if the measured L_{A10} levels due to the power station are above 35 dB(A) and if the affected residences request such treatment.

No other areas are expected to experience noise levels that would justify mitigating actions to be taken.

7.6 IMPACTS ON LAKE NAIVASHA

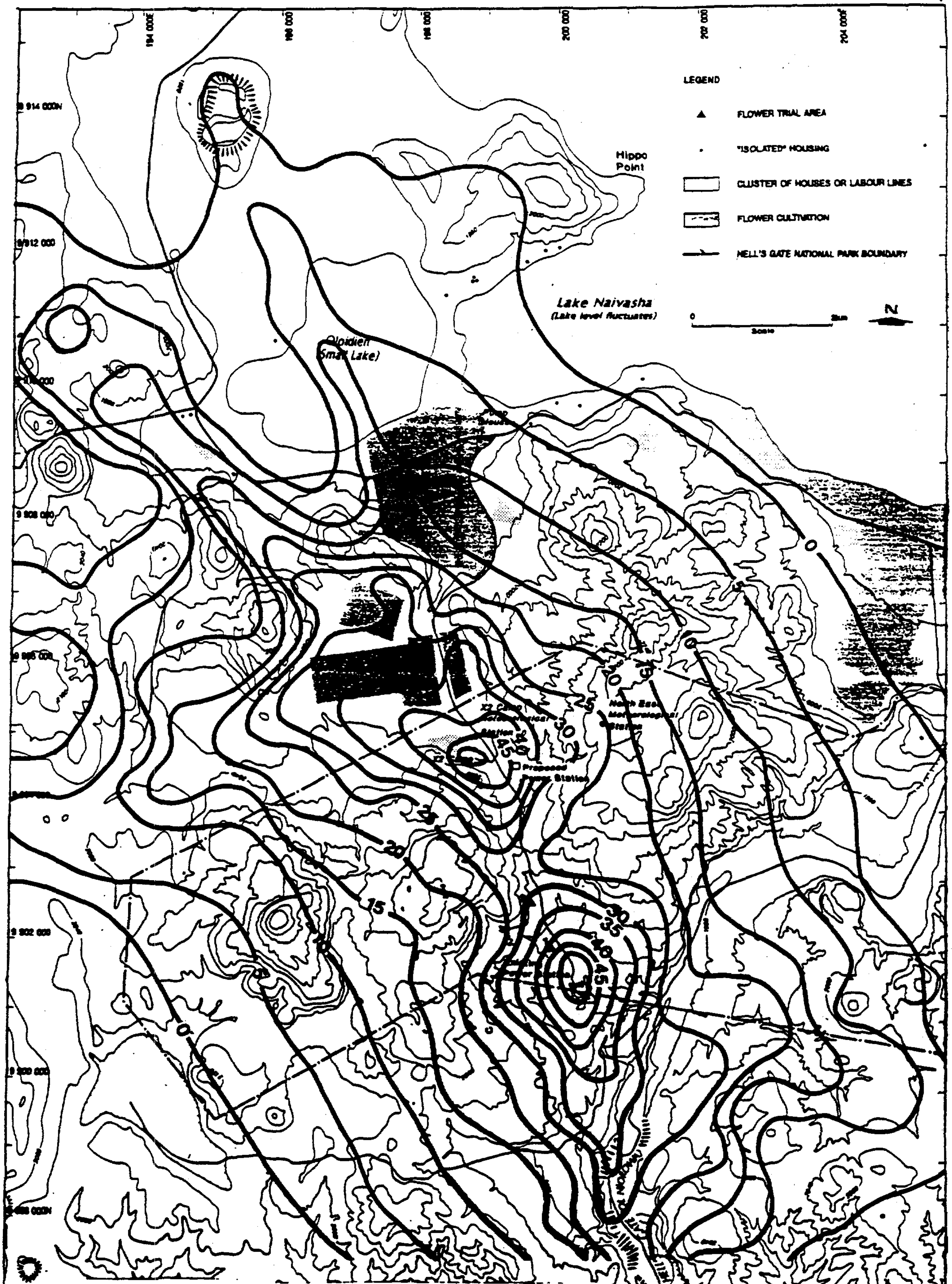
7.6.1 Introduction

The single source for all water abstraction is Lake Naivasha. This includes direct water abstraction (eg drilling and housing estate) and indirect abstraction in the form of a postulated "hydraulic-link" from the lake to the geothermal steamfield (i.e. the drawdown of the steamfield would lead to a lowering of the lake). Both forms of impact are discussed (**Sections 7.6.2** and **7.6.3**).

7.6.2 Direct Water Abstraction

A detailed discussion of the consumption by the registered users of water from Lake Naivasha is provided in **Section 6.8.3**. A brief summary is presented here.

Information from the Water Bailiff of the Ministry of Water and Development, indicates that there are currently 108 registered direct water abstractions from the Lake for a total of 83340.3 m^3/day or 30.4 x 10^6 m^3/y. This figure represents 60% of the estimated water storage (S) or outflow from the lake indicating that current water abstraction has a significant influence on the water balance. However KPC is registered for only 2622.56 m^3/day or 3.1% of the total comprising water taken from three intakes; one for Eburru,



PREDICTED MAXIMUM NOISE LEVELS DURING OPERATIONAL PHASE - dB(A)

Figure 7.5.2

another for Olkaria and North East Olkaria, and the final smaller intake for the housing estate. KPC is the eighth largest abstracter, the two largest abstracters accounting for virtually a third of the total on their own. In addition the amount of water used by KPC will substantially diminish once drilling is completed. This is in contrast to other water abstracters who primarily use the water for irrigation and are more likely to increase their usage. It was therefore concluded that in terms of possible impact on the lake level because of water abstraction, KPC would not be a primary cause.

An independent estimate of water usage was also undertaken, based on power consumption. This indicated that direct water abstraction is probably almost double the licensed amount, however the usage by KPC still remains at 3% of the total.

Malewa Dam Development
As discussed in **Section 6.8.3**, the Malewa Dam project has the potential to impact significantly on lake levels, which in turn could affect abstraction by current users including KPC. In view of the potential for adverse impacts, the ability of Lake Naivasha to sustain the proposed water abstraction levels, will be the subject of a full environmental study.

7.6.3 Indirect Water Abstraction.

The issue of indirect water extraction, centres around a hydraulic link between the lake and the geothermal field. However, this issue has yet to be resolved. A detailed discussion of the evidence for the link in provided in **Section 6.8.4**. A brief summary of that evidence is presented here.

The data do not entirely support the notion of a link. On the contrary, a poorly permeable unit (aquiclude) underlies the lake, separating it from the dual steam and hot-water zones of the Olkaria field. A secondary, but significant, feature is the series of shallow, perched, unconfined aquifers on top of the aquiclude, which are found in numerous drill holes. The perched aquifers appear to be in direct hydraulic continuity with Lake Naivasha but not the deeper geothermal system.

Some support for a hydraulic link has been put forward on the basis of isotope evidence (**Clarke et al., 1990**), where it appears the geothermal reservoir is a mixture of about 40% to 50% lake water. The lake water is identified by its relatively heavy oxygen and hydrogen isotopes (resulting from solar evaporation of ponded water) compared to the relatively light water of meteoric origin occurring as groundwater from the Rift margin.

For this lake water to originate in modern Lake Naivasha, it is necessary to postulate a fairly unrealistic system in which lake water percolates vertically downward for several kilometres, becomes heated, then returns to within a few hundred metres of the surface as geothermal fluid, only a few kilometres distant from its point of descent. An alternative hypothesis is that the Olkaria reservoir does indeed contain a high percentage of evaporated lake water but that this water originates not from present-day Lake Naivasha, but from ancient lakes known to have formed and evaporated over the millennia of Rift Valley history.

The resolving of the extent and magnitude of any hydraulic link still awaits further and more detailed study. However, in order to provide some assessment on the potential impact that could occur, a "worse-case" scenario was assumed. That is, that a direct link did occur.

Preliminary estimates of subsurface flows from the Naivasha catchment suggest that the amount contributed by Lake Naivasha is around 50 x 10^6 m^3/y (which is 20% of the total recharge estimated by a previous water balance study). Flow to the south via relatively shallow aquifers may be the most significant route for water flow from the catchment (Clarke et al., 1990).

The average well at Olkaria is estimated to produce about 6 kg/s of steam, equivalent to around 2.5 MWe. Therefore in order to produce 45 MWe, the present wellfield discharges approximately 100 kg/s of steam, equivalent to a liquid discharge rate of approximately 3 x 10^6 m^3/y. This is only a small proportion of even the minimum estimated total natural southerly flow from the Naivasha area (41 x 10^6 m^3/y). With the North East Olkaria (64 MWe) development, reinjection is to be practised and it is also proposed to reinject at the existing Olkaria field. Assuming that this will occur, consumption would stay at about 4 x 10^6 m^3/y or less than 10% of the minimum Lake Naivasha underflow calculated for the region.

Therefore, even assuming the "worst-case", namely that 100% of the water released by the wells is derived directly from the Lake, it is concluded that the impact of the steamfield on the lake level will not be major.

7.6.4 Summary of Likely Impacts

The amount of lake water drawn by the existing geothermal project and the proposed development has been shown to be a small proportion of the total amount of water abstracted. On its own therefore it is unlikely to affect the lake level significantly. Indirect abstraction via a possible hydraulic link between the Lake and the wells is also unlikely to have a major impact.

Historically water-levels at Lake Naivasha fluctuate significantly and it is likely that they will continue to do so. It is important to consider that over the expected 30-year life of the proposed power station, there are likely to be periods when the lake level is very low. KPC should therefore not rely on the lake as a source of water for the entire life of the well. Contingency plans should be made for alternative water sources for drilling and domestic purposes when the need arises.

7.7 WATER DISPOSAL

A 64 MWe geothermal development produces a substantial amount of waste-water, which needs to be disposed of safely without adverse effects on the environment. Previous methods of disposal via gullies and natural draininge lines, have led to significant soil erosion. The proposed long-term method of waste-water disposal is by deep reinjection, which should have minimal surface impact.

The disposal of geothermal waste waters poses a problem because the fluid is a brine containing chemicals in concentrations that are potentially harmful to both flora and fauna. A 64 MWe development produces a substantial volume of waste water, all of which needs to be disposed of safely. The preferred option for waste brine disposal during steamfield operation and that recommended in the feasibility report, is for deep reinjection into a number of purpose drilled or unused production wells and this option is to be implemented.

The impact of this disposal option and temporary brine disposal options during the construction phase of the development are assessed.

A detailed discussion of the well water quality and potential impacts is presented in **Section 6.9.2.** Although by world standards the brine is not particularly toxic, it poses a health risk and needs to be disposed of in a safe manner. The elements of most concern are fluoride and lead.

Waste-water disposal is required during all phases of the project cycle, however the original practise of disposal into gullies and natural drainage lines, led to serious erosion. This form of impact has been assessed and discussed in an earlier section. The present system for water disposal was initiated recently by KPC and involves piping all brine from wells being tested into a collection pond and then gravity reinjecting. A similar activity has been initiated for drilling waste-water.

During the long term commissioned phase of the project, the geothermal brine will be disposed of by deep reinjection. The level of reinjection will be below lake level and there is little possibility of surface or groundwater pollution. The problem of pipe blockages due to precipitation of dissolved silica will be overcome by the use of conditioning ponds. The proposed development will mean about 700 t/h will need to be reinjected. The large ponds adjacent to the station will probably attract wildlife during extended dry periods and therefore need to be securely fenced.

One advantage of the fact that the brine will have been cooled, is that the reinjection line can be buried. This is recommended so that the pipeline does not become a barrier to wildlife movement, particularly since the proposed reinjection wells lie some distance from the production field wells.

Summary of Likely Impacts
Previous methods of waste-water disposal into gullies and natural drainage lines have led to unacceptable levels of soil erosion. The current and proposed techniques of reinjection will not cause any significant impacts at the surface and are sufficiently deep that there is little possibility of groundwater contamination.

7.8 SOCIO-ECONOMICS

7.8.1 Introduction

For the purpose of assessing social and economic impacts, two areas have been considered. The first is referred to as the primary impact area, which includes the Hell's Gate National Park and the adjoining land to the north, which may experience direct effects due to the project, either due to being able to see the development, experience odours or hear noise from the project. Because of variability in the direct impacts as the dispersion conditions change, or as noise propagation conditions change, it is not possible to define these areas precisely. However, beyond a distance of three to four kilometres from the proposed power station, the direct effects are expected to be minimal. The secondary impact area includes a much wider area where other social and economic effects may be experienced. This has been taken to include the Naivasha Location (940 km^2).

Further, in assessing the impacts of the proposal the two stages of the project have been included. These are construction and operation. The exploration phase has not been considered in any detail because this stage is essentially complete at this time. Decommissioning is also only discussed very briefly as the precise nature of this phase is not known nor indeed is the environment in which it will take place.

The consultants' findings on anticipated impacts and appropriate mitigating measures throughout all sectors follow a broad theme of provision of the required facilities by the project, rather than relying on Naivasha town and the facilities of the Municipality. This is because, as reported in the baseline study, Naivasha town and its environs has witnessed very rapid population growth over the last ten years. Recent estimates suggest an annual growth of around 10 per cent for the town itself and around 6 per cent for the surrounding rural areas, have been sustained for most of the 1980s. While many employers around the lake have provided housing, schooling and other facilities for their employees, some have not and those that have, do not provide for the large number of casual workers who gravitate to the area.

This effect, compounded by very little development in the Municipality itself in recent years, has lead to a situation where the infrastructure of Naivasha town is stretched far beyond capacity. Social services are inadequate, as are health, education, water and community facilities. Apart from a few small projects, no systematic development has taken place for many years in the public housing sector and private development has been limited and largely unplanned. The impact of the unplanned population increase is visible throughout the municipality. The roads are in a parlous state and even major residential areas are either not served at all by roads, or the roads are no longer in a condition fit for vehicular traffic. With a rapidly growing informal sector, building kiosks and workshops along the smaller streets, both suburban dwellers and business people complain of frequent water shortages.

The consultants have studied the Municipality development plans and have held discussions with local officials, as well as residents and business people. The clear conclusion is that any major project in the Naivasha area, including the Olkaria geothermal project, is advised, both in its own interests as well as the Municipality's, not to put any further burdens on the infrastructure of Naivasha town. The approach will have to be one of self-sufficiency within the project area.

The consultants recommend that provided adequate steps are taken, as indicated here, in the area of infrastructure and social facilities, and provided a joint planning approach continues between KWS and KPC for the optimum management of hell's Gate National Park, the socio-economic aspects of the project will not cause undue concern.

7.8.2 Construction

The following socio-economic aspects have been examined:

Impact on Population
The total peak workforce during the Main Civil Works and Power Station, High Voltage sub-stations, High Voltage Transmission line and Steamfield Development Construction is estimated to be 920. The total period will be two years.

The expected labour requirement by skill level are listed in **Table 7.8.1**. The numbers are as follows:

TABLE 7.8.1- PLANNED PEAK LOCAL WORK FORCE

	Required Labour	Already Living in the Area	Immigrants to the Area
Unskilled	500	500	-
Semi-skilled	150	75	75
Skilled	130	-	130
Foreman Grade	40	-	40
Administration staff	30	-	30
Supervisory staff	70	-	70
Total Peak	**920**	**575**	**345**

Five hundred and seventy five staff are expected to be drawn from people already living in the area. Thus the total number of people affected will be approximately 2 875 people including an estimated four dependents per worker. This may be compared with the estimated 48 000 people living south of the lake or within the 40 000 in Naivasha town.

Three hundred and forty five are expected to be recruited into the area from outside. Taking an average household size of three, this represents around 1035 additional people, coming into a south-of-the-lake population of some 48 000, an increase of 2 per cent.

The existing KPC project has on site 687 people, of whom 150 are generation staff (Olkaria East Power Station) and 537 fall under the Development Operations (drilling, scientific, civil, safety, training, personnel, administration, finance staff). The requirement during construction phase, on average, will be roughly comparable to the existing workforce.

In terms of absolute numbers, the influx is relatively little compared with the increase of over 5 per cent per annum in population over the last few years. However, the impact on the socio-economics of the area will be significant, and is reviewed in the following paragraphs.

Local Economy

The construction phase will bring in 345 salaried staff into the area, with commensurate local spending power. Most spending is expected in the shops south of the lake, and will provide paid employment for a further 575 staff already in the area. Given the relatively low wage employment in Naivasha urban area of around 5 000 in a population of at least 40 000, the project will contribute around a 12 per cent increase in employment, a significant positive impact. The gross income for the project staff at peak level will be in excess of KShs 4.9 million per month.

Given that the earnings in urban Naivasha were around KShs 100 million/annum in 1988, this represents a significant increase in local spending power. This will in turn give rise to a commensurate increase in roadside trading, which expanded following the introduction of the upgraded Moi South Lake Road and the flower farms. It will also produce a temporary increase in the demand for transport into Naivasha. Much of the temporary economic boost will however be felt not in the project area, but in the various districts from which the immigrant workers will come. The pattern is for such workers to remit home a substantial portion of their earnings to their family to pay school fees and assist wives in the running of their subsistence farms. Thus the multiplier effect may not be as great as would occur if the spending was confined to the Naivasha area.

Impact on Housing
The existing KPC X2-Camp is expected to experience an increase in hydrogen sulphide odour and noise levels as a result of the proposed development. The existing levels, while not exceeding workplace goals, are sufficient to cause a nuisance and any increase will exacerbate the problem. The camp is therefore considered to be unsuitable for the existing 300 resident employees as well as the additional 345 strong construction workforce.

X2-Camp will therefore need to be relocated. In order to minimise disturbance in Hell's Gate National Park, the new housing camp will have to be located outside the Park boundaries. This is consistent with the Park management strategy adopted by KWS and with widely accepted management practices for national parks. The site should be restored to a condition satisfactory to KWS.

The selected contractor will have two options for housing arrangements for the construction workers, namely:

- to negotiate a local arrangement for a camp with neighbouring property owners. A suitable option would have been to approach Oserian Development Company Ltd. However, Oserian have recently expanded their operations to the extent that they may not be able to provide such facilities, and other neighbouring property owners will need to be consulted.

- to house the workers in or around Naivasha town and then arrange for their daily transportation to and from the site. In the latter case baseline studies have shown that there is a severe housing shortage in Naivasha. In addition, health, education, water and social services are already inadequate for the existing population.

In view of the above, the better option for the contractor would be to enter into negotiations with neighbouring property owners on site. Regarding the remaining 100 employees consisting of 30 administrative staff in the contractors' and consultants' offices and 70 supervisory staff made up of consultants and contractor engineers, additional housing will need to be provided at the KPC housing estates. However, not all the 70 supervisory staff will be present throughout the construction period, but only during the particular contract programs.

There is potential for the building of additional senior staff houses at the Lake Side housing estate which currently has 65 houses of which 24 are for senior staff and 41 are for technicians. At the same time, KPC has allocated an area near Lake View estate from the development of additional junior and senior staff housing. This area, originally ear-marked for the development of a second tree nursery, in addition to that at the Lake Side estate, is adequate for the additional permanent housing requirements of not more than 100 houses during construction phase.

Water and Sewage

Water

The biggest impact during construction will be on the additional 245 strong workforce to be housed at X2-Camp or re-located KPC camp. Already there are 300 people at X2-Camp. Considering water requirements of 60 litres per day person and assuming that 10 per cent of the additional workforce will bring a wife and child, the additional water requirement will be 17 700 litres per day, which basically doubles the existing requirement of 18 000 litres per day.

At present raw water is tapped from the new water supply line and passes through a water treatment plant on the X2-Camp site. Potable water is pumped from this plant to a storage tank at a high elevation in the nearby hillside which feeds the camp site. Contractors' water demand would need to be examined to confirm the above proposed requirements which will have to be provided at the contractors' expense.

At the KPC estate, water is currently pumped from the lake to a raw water tank. The raw water then passes through a treatment plant and then via 6" pipe to elevated water tanks at both the KPC housing estates. The water supply to the housing estates is considered to be just enough for the existing population. Further expansion of the housing estates will entail expansion of the existing storage facilities by installing larger water tanks.

KPC plans to provide the option of both raw water as well as treated water to the housing estates, in a bid to limit the use of treated water to only those situations where it is necessary, thus reducing the strain on the existing water treatment facility.

Sewage

The existing sewage facilities at X2-Camp will not be adequate to cater for the increased workforce. Some of the existing facilities could be utilised and additional facilities eg toilets will have to be built and maintained by the Contractors. The consultants strongly recommend that separate facilities be constructed for the additional workforce and their families.

Schools

It has been demonstrated that there is a severe shortage of schooling facilities in Naivasha town. During the construction phase, it is expected that 100 administrative staff and supervisory staff will have with them an average of 2 young children per family. The older children are expected to be left to continue with their primary/secondary education wherever they are. From the estimated total number of 200 young children expected to accompany the staff, it is estimated the 50 per cent will be below school-going age.

The existing Mvuke Primary School has a total of 403 pupils of which 324 or 78 per cent are children of KPC employees. The Standard One and Two classes have two streams each while Standard Three to Eight have only one stream. The total number of teachers in the Primary School is nine.

During the construction phase it is envisaged that there will be minimal requirement for additional primary school facilities since it is expected that a majority of the construction staff will choose to allow their primary school-going children to continue studies at their existing school. However provision for the expansion of the primary School will have to be made for the operating staff during the Operation Phase.

The existing Mvuke Nursery School has a total of 126 pupils all of whom are children of KPC employees, and three full-time teachers. During the construction phase, 25 per cent of the employees are expected to have at least one nursery school age child. Taking into account a 5 per cent per annum increase in population, there will be an added requirement for 100 nursery school places. KPC will therefore need to expand its existing Nursery School by almost 100 per cent.

The consultants have noted however, that KPC has already put into place plans for expansion of the existing schooling facilities. KPC have purchased 14 acres of land near the existing schools to cater for the expansion of both the primary and nursery schools.

Health

Although KPC has its own health centre at Olkaria - besides those of Sulmac Ltd and Oserian Development Company Ltd - the influx of 920 people during the construction phase, is expected to create heavy pressure on this existing facility. Substantial additional health facilities will need to be provided for basic out-patient services. It is the consultants' recommendation that KPC double the existing facility to cater for this very substantial influx.

The existing KPC dispensary caters for an average of 600 cases/month. There is a full-time clinical officer and two nurses. In addition, a doctor visits the dispensary twice a week. In view of the expected increased demand for medical facilities, KPC are considering the idea of upgrading the existing dispensary into a fully-fledged hospital.

This step will also reduce transport costs, costs of purchasing drugs from other sources and costs incurred when patients are referred to other hospitals for specialised treatment.

The consultants also recommend that a routine health monitoring program be set up at the onset of the construction phase. This program will assist in alleviating some of the misconceptions about the effect of the geothermal power plant emissions on the health of people in the area.

Impact on Roads and Transport

The movement of heavy earth-moving machinery and construction equipment will not have any major impact on the physical condition of the Moi South Lake Road because this machinery will be transported to site on wheel loaders and will remain on site until completion of the construction activities. However, providing that an active road maintenance program is in place, this road will not require upgrading since it has been constructed to international standards.

From the workforce of 920, about 575 or 62.5 per cent are expected to commute to and from the power station site. Transportation could be provided by the selected contractor using lorries/buses, or by public means that is buses and matatus. In the latter case the demand on public transport will call for a doubling of the existing capacity, representing a 22 per cent increase in total motorised vehicular traffic. However, given the very low traffic levels reported in the baseline study, this increase will not create a problem.

In addition to vehicular traffic, the number of pedestrians is also expected to rise substantially. During the baseline tourist survey it was noted that 17 per cent of the tourists visiting Hell's Gate National Park entered the park via the Olkaria Gate. Tourists, construction workers, KWS personnel and KPC staff who will be travelling on foot stand a higher risk of road accidents. The consultants recommend that safety measures be incorporated to safeguard pedestrians against such accident. The safety measures would include:

- o clear and frequent road signs along the road alerting all road users of KPC activities in the area;
- o zebra-crossings at appropriate places;
- o side railings along the road to separate vehicular traffic from pedestrians;
- o construction of a bicycle path to cater for the high number of cyclists;
- o clear speed limit indications for all vehicles both outside and within the National Park.

Impact on Tourism

This is the area that need not be of great concern if all the necessary measures are taken. The biggest probable impact during this stage may be the discouragement of tourists visiting the park through the Olkaria Gate by the very presence of construction activities just inside the park.

Close dialogue between KPC and KWS is necessary to work out a strategy whereby the new power station, although designed to be more aesthetically pleasing, does not create a deterrent to tourism.

As proved during the tourist survey carried out during the baseline studies, there is no evidence that the presence of a geothermal power station is putting foreign tourists off visiting the National Park. In fact, Kenya being one of the few countries in the world with such a facility, the Geothermal Power Station could be used to attract more tourists to the area thus generating more foreign exchange. In order to achieve this however, there is the need to change the existing perceptions about the Hell's Gate National Park. It is suggested that the park be designated into two areas, namely the Geothermal zone and the National Park zone, so as to clearly distinguish options for visitors to the area. This zoning will enable the joint KPC-KWS management to issue different sets of rules and regulations pertaining to the two different zones. This strategy will strengthen the concept of the peaceful coexistence of the two and promote the concept of sustainable development.

Impact on the Maasai

As discussed in **Section 6.10**, the power station development and operation interact very little with the Maasai. The major interaction is that the power station provides a reliable supply of water. At present the Maasai living close to the boundary of the park make use of this water to supplement their other supplies of water. The Maasai also have the potential to interfere with the security of power station facilities such as equipment, fencing etc. This is a matter that is presently handled by KPC taking normal security precautions. These will inevitably be defeated at times, but it is recommended that KPC continue with its present policy of regular consultation with the Maasai leaders, who are met with during the Hell's Gate National Park Management Committee meetings. With this channel for communication and the spirit of cooperation between KPC and the Maasai that presently exists it is unlikely that major difficulties will develop.

One area in which some consideration should be given is the indirect impact that could occur if geothermal development within Hell's Gate National Park results in KWS needing additional areas. Expansion of the park to the west or north is not feasible because of existing significant land development. Any expansion of the park to the south or east to "compensate" for geothermal development activities within the park would impact on Maasai who presently use this area. Even though these settlements are within Nakuru District and not Narok District (see **Figure 6.10.7**), there would be a displacement of families, who may have no firm legal rights of occupation, but who would require alternative areas in which to live.

The Narok District between the southern boundary of Hell's Gate National Park and Suswa presently shows signs of poor vegetative cover as a result of grazing and in dry periods there is significant wind erosion of the top soil. The capacity of this area to accept additional people living a traditional pastoralist life-style should be examined in detail if geothermal development should indirectly cause people to be displaced from the land they presently use.

Impact on Recreational Facilities

The influx of an additional 1035 people into the area will impact on the existing recreational facilities because these facilities will not be able to cater for the expanded population. The existing recreational facilities consist of:

- a Senior Staff recreational facility consisting of a converted three-bedroom house at the Lake Side housing estate. This facility has a television, a small swimming pool, and provision for indoor games;
- a Junior Staff Social Hall located at X2-Camp which has a television, a music system and provision for indoor games, and;
- a football field that is well used and popular to the extent that it is frequently utilised for National League matches.

The consultants recommend that both the existing Senior Staff and Junior Staff facilities be upgraded and expanded.

7.8.3 Operation

Impact on Population

The workforce during the operation phase of the project is expected to be around 113 people or 75 per cent of the existing East Olkaria Power Station generation staff. Many of the existing staff at the Olkaria East Power Station will take up additional duties at the new North East Olkaria Power Station. The additional 113 employees, will represent an influx of 565 people, taking an average household size of five. This is an increase of 1 per cent in the projected South-of-the-lake population of 53 280, and represents 55 per cent of the influx of people during the construction phase.

Impact on Local Economy

The operation phase will bring 113 permanent salaried staff into the area with commensurate spending power with the shops south of the lake.

The gross income for the operating staff at peak level will be in excess of KShs 390 000 per month representing annual earnings of KShs 4.7 million.

Impact on Housing
The following tables give an overview of the housing situation. Table 7.8-2 sets out the status of the existing housing and Table 7.8-3 the proposed housing arrangements when the North East Olkaria Power Station is commissioned.

TABLE 7.8.2- HOUSING SITUATION FOR EXISTING OLKARIA EAST POWER STATION

Location of employees	Number of employees: Operation Phase
Employees in temporary houses on site	50
Employees at X2-Camp	300
Employees at KPC Estate housing: Lake Side and Lake View	174
Employees not housed	163
Total	687

TABLE 7.8.3- HOUSING REQUIREMENTS FOR PROPOSED OLKARIA NORTH EAST POWER STATION

Location of employees	Number of Employees	
	CONSTRUCTION PHASE	OPERATION PHASE
Contract workers already living in the area	575	-
Contract workers at negotiated housing camp	245	-
KPC Estate housing: Lake side and Lake View	100	113
Total	920	113

The consultants therefore recommend that 113 additional permanent houses be constructed to cater for the additional 100 administrative supervisory staff to be housed during the construction phase, who will be replaced by 113 people drawn partly from the same group and partly from outside the area.

Impact on Water and Sewerage
The existing KPC housing estates use water from Lake Naivasha. The current water capacity will not be adequate to cater for the additional housing and the occupants. The consultants concur with Ewbank Preece Limited regarding the provision of water for the additional population namely:

The existing water reticulation system at the housing estates area will have to be reviewed for upgrading and increasing the capacity for the additional housing and their occupants. The new scheme will depend upon the layout of the new housing. A possible scheme would be for the water from Lake Naivasha to be pumped to a new treatment works and elevated storage tank at the top of the high ground at the site with water supplied to the houses under gravity. At the new treatment works particular attention will be paid to improving the quality of the water from the lake to reduce the high fluoride content. Excessive fluoride intake can cause adverse effects on teeth and bones, particularly in young children.

Regarding the water requirements at the power station, provision for a branch water pipeline has been made by Ewbank Preece Limited in their feasibility study where it is also stated that a potable water treatment plant will be provided with distribution within the station via a pipe network.

Designs for adequate provision of sewage facilities have also been incorporated by Ewbank Preece in their report. All sewage will pass through a conventional septic tank arrangement with the foul water discharging into a soakway. The solids will be periodically collected by the Naivasha Town Council. With these provisions no impacts are expected.

Impact on Schools
KPC have existing Primary and Nursery Schools at the Lake View housing estate catering for children of the operating staff at the Olkaria East Power Station. It is estimated that the operating staff of the new station will bring in about 295 nursery school going children and 590 primary school going children.[8]

The consultants recommend that the new nursery school to be built to cater for the additional 100 children during the construction phase, be designed for more capacity to accommodate an additional 195 children during the operational phase. Secondly, the existing primary school will need to be expanded to cater for 590 additional children, that is more streams be introduced per class.

Impact on Health
The consultants consider that the facilities established during the construction phase of the project will adequately cater for the operating staff, and with the proposed monitoring program in place, should provide sufficient out-patient services.

Impact on Roads and Transport
The volume of traffic generated by construction activities will be considerably reduced.

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[8] Although the employees housed at the KPC Estates will have at least one nursery school age child and two primary school age children, and that 10% of employees housed at X2 Camp will have the same number of school-going children (X2 camp actually has bachelor status but it is expected that the employees will have families with them, as is the existing case for Olkaria East)

However, the volume of KPC vehicles, private vehicles, tourist vehicles, matatus and buses is expected to increase due to increased activity in the area. KPC at present have two buses which make two trips per day between the existing power station and Naivasha providing transport for the 163 operating staff at the existing power station, who live in Naivasha. The new power station will call for the acquisition of an additional two buses to cope with the increased population. The same basic safety measures should be put into place as during construction.

For the duration of the period of construction, there will be intermittent disruption of traffic due to heavy construction machinery but due to the width of Moi South Lake Road and the current sparse traffic rate of two KPC vehicles per hour, no major disruption is envisaged.

It is expected that during the operation phase, the volume of traffic due to KPC vehicles will increase by 100 per cent representing 8.5 per cent of the total vehicular traffic on Moi South Lake Road. The increase in volume of traffic due to KPC vehicles is thus not expected to impact significantly in terms of damage to the Moi South Lake Road.

Impact on Tourism

The Geothermal Project on the whole will have a positive impact on tourism, for reasons stated earlier. However, the critical factor in ensuring that the project will have a positive influence on tourism and hence the economy of the country, will be the close collaboration between KPC and KWS in their commitment to environmental conservation. The consultants wish to report that as a result of deliberations at a senior management levels of KWS and KPC, and detailed discussions at working levels during Hell's Gate National Park Management Committees a special collaborative joint KWS-KPC committee was initiated in August 1991. The objectives of the Wildlife Conservation/Geothermal Exploration and Development Committee is to work out a joint management strategy regarding present and future geothermal development and its effect on the environment of Hell's Gate National Park. Membership of the committee is composed of:

- Chairman - Assistant Director (Planning) KWS;
- Member - Geothermal Development Coordinator, KPC;
- Member - Superintendent of Operation, KPC;
- Member - Geothermal Development Manager, KPC;
- Member - Warden, Hell's Gate National Park, KWS;
- Member - Adviser to KPC Geothermal Development Project;
- Member - Provincial Wildlife Officer, Nakuru, KWS;
- Member - Environmental Officer, KPC, and;
- Member - Resource Planner, KWS.

To date, two meetings have taken place on 14 February 1992 and 25 February 1992, the latter one on site. Specific issues discussed so far have included:

- o rehabilitation of abandoned well pad sites;
- o an agreement for joint discussion on future road designs for the benefit of both geothermal development and tourism;
- o an action plan for rehabilitation measures on abandoned well sites in North East Olkaria;
- o an action plan on rehabilitation of sites that had infrastructure no longer in use;
- o action on undesirable roadside weeds;
- o housing for construction workforce during the construction of the North East Olkaria Power Station;
- o joint participation in the development of the community in the area, and;
- o appropriate security measures for visitors to the Park;

The consultanst recommend that this important dialogue continues throughout the life of the project so that appropriate measures can be taken to offset any negative impacts and enhance the positive ones.

Impact on the Maasai
As for the construction phase, no impacts are envisaged on the Maasai because there are no Maasai in the National Park.

Impact on Recreational Facilities
The recreational facilities recommended for the construction phase will be adequate to cater for the KPC employees and families during the operations phase. The increased population in the area is expected to create an increase in number of visitors to hotels along Moi South Lake Road namely Lake Naivasha Hotel, Safariland Hotel, Crescent Island Tented Camp, YMCA, Fisherman's Camp and Elsamere Conservation Centre.

7.8.4 Mitigating Measures and Recommendations

One of the most significant environmental impacts of the proposed development from a socio-economic perspective is the presence of a full-time residential workforce within the Park. This is not consistent with good environmental management of national parks, nor is it consistent with the approach adopted by KWS in moving the Maasai out of the Park. In addition, the ambient concentrations of hydrogen sulphide already experienced at the X2-Camp, while not at an acutely toxic level are such that chronic effects may occur. The present levels do not exceed workplace goals, but irritation of the respiratory system and the eye may be experienced if individuals are exposed for longer periods. It is therefore strongly recommended that there be no residential camps located within the park boundaries.

The following is a list of recommendations for the management of the impacts of the proposed development:

1. X2-Camp or re-located KPC camp will need to be expanded to accommodate additional 245 employees. It is recommended that this accommodation be located outside the Park.

2. 220 additional permanent houses will have to be built at the estate. It has, in the past, been suggested by KPC that some of the existing Junior staff houses be demolished to provide land for two or three storey flats.

3. The additional water requirement at X2-Camp will have to be catered for by increasing the existing water supply. At the same time, the existing supply at the estates should be upgraded and capacity increased.

4. Additional sewage facilities will be required both at X2-Camp and the estates housing.

6. KPC will need to acquire 2 more staff buses.

7. The present KPC-KWS committee should continue to meet at regular intervals during all the phases of the Geothermal Development.

8. KPC should renovate and expand the existing recreational club and upgrade its indoor games facilities. In addition, a new football pitch should be built.

9. Adequate road safety measures should be put in place, after joint KPC-KWS discussions, to ensure the safety of KPC and KWS employees and visitors to the Hell's Gate National Park.

TABLE 7.8.4 STAFF STRUCTURE: OLKARIA EAST AND OLKARIA NORTH EAST (SOURCE: FEASIBILITY STUDY FOR A GEOTHERMAL) POWER STATION AT NORTH EAST OLKARIA, EWBANK PREECE LIMITED, 1979)			
Category	East Olkaria	North East Olkaria	Total
1. Superintendent			1*
2. Admin Officer			1*
3. Stores	2	3	5
4. Clerical	2	2	4
5. Drivers			4*
6. Cleaners			4*
7. Security			25*
8. Maint. Superintendent			1*
9. Operations Superintendent			1*
10. Mechanical Foreman	1	1	2
11. Workshop Foreman	1	1	2
12. Electrical Foreman			1*
13. Instrument Foreman			1*
14. Civil Foreman			1*
15. Asst. Operations Superintendent	1	1	2
16. Mechanical Personnel	18	18	36
17. Workshop Personnel	2	7	9
18. Electrical Personnel			4*
19. Instrument Personnel			4*
20. Civil Personnel			24*
21. Power Station Operations	24	24	48
22. Steam Field Operation	14	14	28
	Totals		208

With 75 per cent increase, total staff	208
therefore, at East Olkaria East	119
At North East Olkaria	89

* Common personnel for both stations

TABLE 7.8.5- OLKARIA NORTH-EAST WORKFORCE REQUIREMENTS

Skill	No	Wage	Housing
Unskilled	500	140/- (196/-)	Locally recruited
Semi skilled	150	180/- (252/-)	50% Local 50% x 2 Camp
Skilled	130	240/-(336/-)	x 2 Camp
Foreman	40	300/-(420/-)	x 2 Camp
Admin staff	30		Olkaria
Supervisory staff	70		Olkaria
Total	**920**		

Key
( ) - includes 40 per cent employers costs covering Tax, Insurance Sick Pay, Training Levy etc EPL estimated this to be 20 per cent - 40 per cent of shift rate.

Source: Ewbank Preece Limited 2 June 1992

7.9 POWER TRANSMISSION LINES

The impact assessment presented here is confined to the area within Hell's Gate National Park and the immediate neighbourhood. The assumptions as to the route and mode of construction are based on the information on the power transmission line provided in the feasibility report (**Ewbank Preece 1989**). Minor deviations from the information would not change the assessment. Impacts beyond the park can be inferred from the discussion, but a detailed analysis is beyond the scope of this study.

In general power transmission lines have the potential to cause a range of environmental effects as follows:

- o visual impacts
- o soil erosion
- o fire hazard
- o effects due electromagnetic radiation
- o noise
- o hazards to aircraft.

The feasibility study (**Ewbank Preece 1989**) sets out the general principles that should be followed in designing the line and selecting the route. Consideration of these principles will ensure that impacts are kept to acceptable levels. Specific effects are discussed below in the context of the power transmission line requirements for North East Olkaria.

Visual effects

The routes of existing and proposed transmission lines are shown in **Figure 5.3.6**. The design of the line has taken account of visual impacts and has adopted an appropriate compromise between engineering requirements and visual impact. A short 4 km 132 kV line is to be constructed between the existing East Olkaria Power Station and the proposed North East Power Station and a 220 kV line will carry power to Nairobi. The impacts of the new 132 kV power transmission line will be similar to those due to the existing line, which are acceptable. The new 220 kV line will be larger and will follow a different route. It will adopt a basic span of approximately 370 m. Each tower will be approximately 25 m high and will be constructed of galvanised steel, which will weather to a dull light grey with time. It is proposed that conductors be made of blue/grey insulators to reduce visual impacts.

These colours are suitable for the Olkaria environment and the existing power lines blend in well and are generally do not form a significant part of the visual environment except from viewing points which allow the towers to be viewed against the sky as the power line crosses ridges. The route of the transmission line within the park has been reviewed and it will not affect any areas with high scenic value such as the gorge area. After leaving the park the route initially will run northeast before turning to the east and joining the existing 132 kV line to Nairobi (see **Figure 5.3.6**). From the northern side of the transmission line (eg on the Moi South Lake Road) it will be visible against the hills near the northern boundary of the park and the Elsa Gate entrance to the park. However, this is a developed area with many houses and agricultural buildings already forming a significant part of the landscape. The existing power line follows a similar route. The visual impact of the new power transmission line is unlikely to be considered significant either by existing residents of the area or by visitors.

Soil erosion
There is a potential for the transmission line tower foundations and construction activities to give rise to soil erosion in areas with steep slopes. Simple commonsense precautions will prevent these impacts being realised.

Effects of electromagnetic radiation
Electromagnetic radiation from power transmission line can interfere with radio reception, particular with AM reception in areas where signals are weak. Interference with radio reception will be confined to areas within a few tens of metres of the power line and will not be a significant problem.

The calculated electric field strength directly under the conductor at midspan is estimated (**Ewbank Preece 1989**) to be approximately 2.8 kV/m when the conductor height above ground-level is 7.5 m at midspan. This will not give rise to any danger to humans or animals. However, particularly within the park and in the vicinity where giraffe might be expected, care must be taken to ensure that safety margins are maintained

There is concern that electromagnetic radiation from power transmission lines can give rise to adverse health effects. However, these effects if any, are at a very low level and researchers so far have been unable to provide convincing evidence of a link between health effects and electromagnetic radiation at the levels that would be experienced from the type of power transmission line proposed.

Fires
There is a possibility that power transmission lines can initiate bush fires if wires come too close to vegetation under dry and windy conditions. The type and height of vegetation in the park means that the fire hazard from this source should be negligible.

Noise
Noise emissions due to wind blowing through the wires and towers is not expected to have any effect on animals within the park.

Aircraft safety
The route chosen by the power transmission line takes account of existing landing fields and hazards to aircraft will be within accepted standards.

8. Conclusions and Recommendations

This section summarises the major findings of each study and lists in point form the recommendations for monitoring and management. It should be noted that recommendations made under each study have not been cross referenced. Thus the fauna study may recommend re-location of X2-Camp to minimise impacts on the Hell's Gate National Park animals, the air quality study recommends relocation to ameliorate odour impacts, the noise study recommends relocation to minimise noise impacts and the socio-economic studies recommend relocation to ensure compliance with KWS's policy to not permit human habitation in National Parks and to ensure consistency of the application of the law to both KPC and the Maasai. These individual recommendations each stand on their own, but of course when assessed for appropriateness those that arise from more than one analysis may be considered to have additional weight.

The overall conclusion is that the proposed power station as set out in the feasibility study (**Ewbank Preece, 1989**) is an acceptable development from an environmental point of view. This conclusion assumes that the power station is constructed as described in the feasibility study and in particular that reinjection of waste water takes place. It is noted that the feasibility study has not demonstrated that reinjection can accept the volumes of water that will need to be disposed of. Also a number of important mitigating measures are proposed. These are summarised below.

8.1 FLORA

Flora studies have documented baseline conditions in the area around the existing and proposed power stations. The broad information from the baseline studies has been summarised on the vegetation distribution map **Figure 6.2.1**. The main ways in which geothermal development could be expected to affect vegetation would be via the action of gaseous emissions, by the action of hot or cold geothermal brine either as flowing water on the surface or as airborne droplets of geothermal brine and finally by the physical removal of vegetation to make way for roads, drilling pads, buildings and so on.

The vegetation distribution map shows only evidence of effects caused by the latter activity. Physical removal of vegetation results not only in the destruction of the vegetation but may also result in the introduction of new species to the area and the displacement of existing useful species that may be food sources for the local fauna. Because of the status of the area as a National Park, it will be important to minimise changes to the existing flora through introduced species. This can be achieved by replanting disturbed areas with local grasses and vegetation as soon as possible after the disturbance and by removing by hand, unwanted plants as they appear.

Detailed inspections of the area reveal vegetation that has been damaged by the action of hot geothermal brine. These effects are very local (a few metres generally) and are confined to drill pads and water courses where hot geothermal brine has been allowed to flow unconfined over the ground. This procedure is no longer practiced. Such damage is generally temporary, but it provides an opportunity for exotic species to invade and displace indigenous species, which the local fauna may rely on for food.

Detailed studies have been undertaken to determine species occurrence in four one hectare plots, two in a site that lies in the area of influence of the existing power station and two in an area that might be expected to be affected by the proposed power station. Data from these plots showed no effects that could be attributable to the existing power station. These data will also form useful baseline data that will allow changes in species occurrence to be detected if any such changes do occur as a result of the power station development and operation.

Flower trial studies have been undertaken as a joint study with Oserian Development Company to attempt to find adverse effects on commercially important plants grown on the flower farms. The principal concern is that power station emissions could affect flower growth and quality. To date, although differences in plot performance have been found it is considered that these are most likely to be due to non-air pollution factors. These studies will be continued.

In summary the following safeguards and monitoring work should be adopted to minimise impacts.

1. Keep area of natural vegetation cleared to a minimum.

2. Make use of deep reinjection of brine and drilling water to avoid potential toxic effects on flora.

3. Cleared areas should be quickly rehabilitated with appropriate indigenous flora to prevent the growth of opportunistic species.

4. Monitoring of the abundance and diversity of natural vegetation should continue. If necessary, appropriate action should be taken by KWS such as controlled grazing and burning of park areas. The Environmental Unit of KPC should be made fully aware of all such activities.

5. The potential effect on local flower farms should be monitored with the flower trails continuing for a total of two years. If the Oserian Estate wish to extend the trials longer than this they should be given access to the plots.

KPC's Environmental Monitoring Unit at Olkaria have sufficient expertise to undertake this work, provided assistance (through a local Kenyan consultancy) is available for specialist advice such as the species occurrence studies.

8.2 SOILS

Soil erosion has been identified as a particularly difficult area of the environment to manage at Olkaria. Soils comprise deep, poorly consolidated volcanic ash deposits overlaying lava flows. These are readily eroded by rainfall run-off, waste water from wells (drilling or testing) and burst water pipes or sumps. Erosion channels once initiated can then grow spectacularly until a stable land form is re-established. Much of erosion control rests in the application of good engineering practice. The following points list mitigating measures and monitoring studies.

1. It is recommended that effectiveness of the erosion control measures be monitored by visual inspections undertaken at monthly intervals during construction and annually in the operation phase.

2. KPC should provide strong guidelines for the resident engineer who should be briefed by a soils expert as to the nature of the risks. The resident engineer should closely supervise contractors to ensure that contractors activities do not lead to erosion.

3. Disturbed areas cleared of vegetation should be minimised.

4. Slopes in cut and fill earthworks should be minimised.

5 Revegetation of disturbed areas should be undertaken as soon as possible. Signs should be placed to indicate areas undergoing rehabilitation.

6. All fluid discharges should be piped or transferred in concrete lined open channels from the source to sumps or disposal areas.

8.3 FAUNA

The fauna survey has identified approximate baseline conditions for large herbivores, their migration routes and the avian species in the area. It is concluded that the power station development will result in the loss of some habitat due to presence of physical structures, buildings, roads, pipelines and so on. In addition the presence of increased human activity will alienate some areas.

Despite these inevitable impacts it is concluded that power station development would not result in an unacceptable level of impact. The following list summarises the safeguards and monitoring programs that should be undertaken to ensure that impacts are minimised.

1. Game-proof fencing of the holding ponds to prevent wildlife drinking geothermal brine, which if consumed over an extended period may lead to chronic poisoning due to excess fluoride and other trace elements in the water.

2. Deep reinjection of drilling water and brine.

3. Location of drains and pipelines so that they do not form barriers for small animals.

4. Introduction of speed humps to reduce animal deaths from excessive vehicle speeds.

5. Minimising area taken up by roads, padsites and plant to reduce loss of habitat.

6. Training of workers regarding park regulations particularly with regard to interaction with animals and littering.

7. Adequate facilities for waste disposal.

8. Bans on the introduction by the workforce of exotic animals (such as domestic dogs and cats) and exotic plants (apart from indoor plants).

9. Cleared areas should be rehabilitated with indigenous vegetation as soon as possible to restore habitat.

10. In general, fencing should be kept to a minimum to avoid loss of habitat. Care should be taken to ensure that there are no small animals trapped inside fenced areas.

11. Animal numbers, movements and distribution should be monitored. This should be done either independently by KPC or in liaison with KWS. KPC's Environmental Monitoring Unit should actively participate in these studies and should be made aware of the findings of these studies and the management decisions which are made as a result of these findings.

12. Vehicle movements within the park should be monitored.

13. It is considered desirable that in the long-term there are no human settlements within the park.

8.4 AIR QUALITY

Air quality studies have concluded that existing air quality in the vicinity of the existing power station, is satisfactory in that no health effects would be expected. However odour impacts occur over a large area. Emissions from the proposed power station will occur through discharge into the cooling tower plumes. This is predicted to result in much lower ground-level concentrations of hydrogen sulphide than occur from the existing power station, despite the fact that the proposed power station will be have 42 per cent greater generating capacity than the existing one.

It is concluded that for most sites odour impacts will remain more or less at present levels, in terms of the number of times the odour threshold is exceeded. The exception is sites close to the proposed power station such as X2-Camp and the Olkaria Gate area. At X2-Camp the number of detected odours is expected to increase by approximately 38 per cent. All other occupied residential areas are expected to experience only minor increases in odour events.

Small amounts of radioactive radon will be emitted as non-condensable geo gas. Maximum long-term ground-level concentrations are predicted to be of the order of one per cent of the WHO air quality guideline.

The following recommendations concerning air quality are made.

1. X2-Camp should be relocated to prevent occupants from being exposed to nuisance levels of odour.

2. Meteorological monitoring should be continued at the X2-Camp site.

3. One and preferably two continuous hydrogen sulphide monitors (with logging equipment) should be established to monitor hydrogen sulphide concentrations at the flower trial areas to the north of the East Olkaria power station and at X2-Camp. Data collected by the monitor should be used to verify the prediction made by the dispersion modelling study and the model should be fine-tuned so that KPC have an improved predictive tool to assess impacts and to provide further data to other environmental monitoring programs, such as vegetation monitoring.

4. The cooperative flower trial studies with Oserian Development Company should be continued until such times as Oserian Development Company are satisfied that the sensitivity of their operations to hydrogen sulphide has been determined. It would be useful if these studies were to establish the threshold at which adverse effects begin to occur. This would be useful information for KPC's future planning. It is envisaged that these studies may need a further period of at least two years.

5. A survey of radon concentrations in the ambient air near the existing powers station and proposed power station should be undertaken.

6. KPC's Environmental Unit at Olkaria should continue to develop its expertise in dispersion modelling and air quality monitoring and to make use of monitoring data to assess the performance of the dispersion model. This enhancement in expertise will require overseas training or the use of outside consultants with expertise in air quality matters, or a combination of both.

8.5 NOISE

Noise studies have concluded that background-levels in the area will be very low, less than 30 dB(A), from time to time. Given this, it is concluded that an appropriate environmental noise quality goal is that L_{A10} levels from the development should not exceed 35 dB(A) at any residential receptor. In the absence of natural topographic barriers that would attenuate noise, levels from wells under test are predicted to exceed 35 dB(A) at distances of between 4 and 5 km from the well. Given the temporary nature of the well testing operation, these impacts are not seen as causing a problem and should be excluded from the 35 dB(A) goal provided this activity remains a temporary or intermittent activity. Noise emission from the proposed power station when operating, will exceed the 35 dB(A) level out to approximately two kilometres. From time to time (under conditions of low background noise) the noise level from the power station will be intrusive at X2-Camp.

Recommended mitigating measures are as follows:

1. Re-locate X2-Camp to outside the 35 dB(A) contour for operational noise; and

2. Monitor noise levels at the Olkaria Gate KWS residences and provide acoustical treatment of these residences if the measured L_{A10} levels due to the power station are above 35 dB(A) and if the affected residents request such treatment.

8.6 LAKE NAIVASHA

Lake Naivasha is an important body of fresh water in the Rift Valley. Lake levels have shown large variations over the course of this century and presumably will continue to do so regardless of whether geothermal development takes place or not. The water balance for the lake is not well understood. Part of the complication lies in determining the unknown sub-ground flows which are generally acknowledged as the mechanism by which the water stays "fresh" despite the lake being in a high annual evaporation area and there being no surface outflow.

KPC is a user of Lake Naivasha water for drilling, power station make-up water and domestic water supply. KPC's abstraction in 1990 was estimated to be approximately 3.1 per cent of total water abstracted. With this comparatively low level of abstraction the impact of KPC's activities on the lake are concluded to be minor.

KPC also abstract water from the geothermal field in the process of using steam. The proposed power station will reinject much of this water back into the geothermal field. There is also a proposal that the existing power station adopt a policy of reinjection. Net water abstraction from the geothermal field is estimated to be approximately 4×10^6 m^3/year. This is estimated to be approximately 10 per cent of the lowest estimate of ground water flow under the lake. Thus in the unlikely event that the lake is hydraulically connected to the geothermal field, the power development activities would only perturb the flow by 10 per cent (at most).

It is clear that the lake will come under increasing pressure as development in the region makes greater and greater demands for water in other towns and cities, not only Naivasha. The Malewa dam proposal plans to abstract water from a river that is a major input to the lake. There is a need for a thorough understanding of the lake's water balance so it is possible to develop reliable, sustainable, development plans for the lake. Even through KPC is a relatively minor user of the lake (3.1 per cent of the total abstraction) it is in its interest to support studies that will help improve the understanding of the water balance.

8.7 WATER DISPOSAL

The consultants have based their environmental assessment on the assumption that waste water will be disposed of by reinjection. It is understood that field experience world-wide shows that one or two wells are adequate for the disposal of water from high enthalphy fields. It is desirable to undertake tests to confirm that the proposed reinjection wells do have the capacity to accept water at a suitable depth and at the required rate without interference with the geothermal field.

8.8 SOCIO-ECONOMICS

Socio-economic studies have established baseline data on a range of socio-economic topics including population size, schools, housing, health facilities, traffic, water supplies, employment, tourism, structure of the local economy, community attitudes, attitudes/perceptions of tourists, recreational facilities, the Maasai and the Hell's Gate National Park.

The main conclusion of these studies is that the infrastructure of the area is presently stretched beyond its capacity. Thus even though KPC's development plans represent only a relatively minor increase in population and hence demand for services, it will be important that the project be developed in a self sufficient way. That is that housing, schooling, medical services, recreational facilities and so on should be provided by the project and no reliance should be put on these facilities being provided by the existing local government.

It is also concluded that the project will not have an adverse impact on tourism and can be made to enhance the attraction of the area to tourists, particularly to visitors to the Hell's Gate National Park. It is considered that the upgraded road makes access to the park far easier and allows the park to be accessed by visitors from Nairobi relatively easy. The improved road has also been a significant gain to most of the local community with travel times from the Naivasha to the SW side of the lake being halved. Also dust fallout levels on areas adjacent to the road have been very much reduced. The power station itself also has the capacity to draw visitors to the park. There will of course be some negative impacts on the park as the power station buildings and infrastructure and associated human presence will alienate some land from use by animals.

Specific recommendations to ensure that the project does not strain the Naivasha area infrastructure and that the impacts on the park are minimised, are listed below.

1. X2-Camp or re-located KPC camp will need to be expanded to accommodate an additional 245 employees. It is recommended that this accommodation be located outside the park.

2. 220 additional permanent houses will have to be built at the Estate. It has, in the past, been suggested by KPC that some of the existing Junior staff houses be demolished to provide land for two or three storeyed flats.

3. The additional water requirement at X2-Camp, will have to be catered for by increasing the existing water supply. At the same time, the existing supply at the Estates should be upgraded and capacity increased.

4 Additional sewage treatment facilities will be required both at the relocated X2-Camp and the Estates housing.

5. KPC will need to acquire 2 more staff buses.

6. The present KPC-KWS committee should continue to meet at regular intervals during all the phases of the Geothermal Development.

7. KPC should renovate and expand the existing recreational club and upgrade its indoor games facilities. In addition, a new football pitch should be built.

8. Adequate road safety measures should be put in place, after joint KPC-KWS discussions, to ensure the safety of KPC and KWS employees and visitors to the Hell's Gate National Park.

8.9 INTERACTION WITH THE PARK

This summary draws together views developed in a number of specialist studies. It is the consultants' view that the effect of KPC's activities in the Hell's Gate National Park can be managed so that the outcome is positive, at least in terms of the park's function as a tourist attraction. The effects on the conservation function of the park will of course not be positive, except to the extent that additional income from tourists (that KPC's presence may produce), would provide KWS with additional resources to undertake its conservation role. However, it is considered that even the inevitable negative impacts on the conservation function can be managed in a way that will be acceptable to KWS. Some recommended actions, such as relocation of X2-Camp and restoration of the area, would serve to partially compensate the park for land lost to the power station.

The following are recommendations made concerning actions to be undertaken by KPC to assist in integrating the proposed power station into the park so that the benefits for tourism are maximised. These recommendations are additional to those made for the protection of flora, fauna, soils and so on, which have been discussed elsewhere.

- KPC and KWS should maintain the formal meeting structure already established to plan a detailed management strategy for the way in which the park and the power station should interact and to deal with management issues as they arise.

- KPC should prepare explanatory material on geothermal power generation to be incorporated in the Hell's Gate National Park's interpretation centre, which is located near the central tower. This material should be prepared so that it is compatible in style with the display information already being prepared by KWS.

- KPC and KWS should prepare a high quality explanatory leaflet that can be handed to tourists visiting the park. The leaflet should set out the following information:

    - the basic park rules and safety precautions that should be adopted by tourists to protect them from harm or unpleasant experiences associated with the fauna and geothermal activities;

    - the locations of major attractions in the park including the interpretation centre and geothermal power station, and;

- the facilities available to tourists wishing to find out more about the power station.

- o KPC should develop a simple "tourist trail" that could be followed by visitors interested in this aspect of the park. The trail would lead tourists to a series of features with high quality, professionally prepared signs explaining points of interest. The tourist trail could include a well-head, a separator station, any sites or equipment used in the environmental monitoring programs (for example meteorological station, air quality monitoring station, flower trial areas and so on) and the power station itself.

- o KPC should include in the power station design, facilities that will allow tourists to inspect the power station without disturbing power station workers. This should include suitable signs and explanatory material to ensure that tourist do not visit areas which may be unsafe, or where they may interfere with the normal running of the power station. Power station personnel should be briefed on appropriate ways of interacting with visitors. Guided tours should be provided at set times, or days of the week, so that it will become known when guided tours are available.

KPC should conduct all its activities in a way which recognises the status of the land as a gazetted National Park. This imposes constraints on work-practices that would not apply in other areas. For example very high standards must be applied concerning the disposal of rubbish and disused equipment, such as pipes, silencers, building material, earth-moving equipment and so. Some remedial work needs to be done on the matter of disused equipment and abandoned sites. All waste disposal areas should be outside the park boundary. Finally, a significant reduction in visual impact can be achieved for visitors approaching the park from the north through the Olkaria Gate entrance by planting trees and shrubs on the western side of the approach road. Visual impacts looking down on the power station from elevated viewing point will be very much reduced by carefully selecting "natural" colours for power station buildings, power line pylons and unburied pipes. A weathered galvanised finish on the power pylons can be considered a suitable colour for the pylons. The pylons on the existing power plant transmission line blend well with the natural vegetation in the area.

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[1] Project managers for different periods.

Appendix 6.2.1 - The Ecological Checklist - North East Olkaria

	Location on Map (See Figure 6.2.1)
ACANTHACEAE	
Monechma debile (Forssk.) Nees	disturbed sites in C & D
Justicia sp. 'A' of U.K.W.F.	roadsides
Hypoestes aristata (Vahl) Roem. & Schult.	roadsides and shaded areas
Thunbergia alata Sims	disturbed areas with Kikuyu grass
Hypoestes verticillaris (Linn.f.) Roem. & Schult	roadsides and shaded areas
Dyschoriste radicans Nees	roadsides
ADIANTACEAE	
Pellaea calomelanos (Swartz) Link	steam vents
P. quadripinnata (Forssk.) Prantl	steam vents
P. adiantoides (Willd.) J. Sm.	steam vents
P. viridis (Forssk.) Prantl	steam vents
Actiniopteris radiata (Swartz) Link	steam vents
AGAVACEAE	
Sansevieria ehrenbergii Bak.	luggas and drainage areas
S. intermedia N.E. Br.	luggas and drainage areas
AIZOACEAE	
Hypertelis bowkeriana Sond.	R
Delosperma nakurense (Engl.) Herre	R
Sesuvium sp.	R
AMARANTHACEAE	
Aerva lanata (L.) Juss.	overgrazed areas in C D G
Cyathula cylindrica Moq.	B C D E
Amaranthus hybridus L.	disturbed sites
Achyranthes aspera L. var. pubescens (Moq.) C.C. Townsend	disturbed sites
Gomphrena celosioides Mart.	C D E
ANACARDIACEAE	
Rhus natalensis Krauss	luggas and drainage areas
Rhus vulgaris Meikle	C and Luggas
APOCYNACEAE	
Carissa edulis (Forssk.) Vahl	luggas and drainage areas
Acokanthera schimperi (DC.) Benth.	C and Luggas
ARALIACEAE	

Schefflera volkensii (Harms) Harms	steep slopes of drainage Sites
Cussonia spicata	luggas and valley sides
C. arborea	luggas and valley sides
ASCLEPIADACEAE	
Sarcostemma viminale (L.) R. Br.	R
GLEICHENIACEAE	
Dicranopteris linearis (Burm. f.) Underw.	steam vents
ASPLENIACEAE	
Asplenium aethiopicum (Burm. f.) Becherer	steam vents
BORAGINACEAE	
Heliotropium steudneri Vatke ssp. bullatum Verdc.	B C D E G especially overgrazed areas
CAESALPINIACEAE	
Cassia didymobotrya Fres.	disturbed sites
C. grantii Oliv.	roadsides
C. mimosoides L.	B C D E G R
CAPPARACEAE	
Capparis tomentosa L.	luggas and drainage areas
Maerua sp.	D E G
Cleome monophylla L.	disturbed sites
CAMPANULACEAE	
Wahlenbergia abyssinica (A. Rich.) Thulin	B C D E
W. virgata Engl.	B C D E
CARYOPHYLLACEAE	
Pollichia campestris Ait.)	
Silene burchellii DC.)	B C D E in overgrazed sites
CHENOPODIACEAE	
Chenopodium opulifolium Koch. & Ziz.)	
C. carinatum R. Br.)	disturbed and newly opened up sites
C. pumilio R. Br.	
COMMELINACEAE	
Commelina benghalensis L.	B D E
C. imberbis Hassk.	B C D R
C. africana L.	B C D
C. purpurea Rendle	B C D E G
Aneilema sp.	E R
COMPOSITAE	
Tarchonanthus camphoratus L.	B C D E G R
Psiadia punctulata (DC.) Vatke	disturbed sites
Tagetes minuta L.	roadsides and disturbed areas
Bidens pilosa L.	roadsides and disturbed areas
Osteospermum vaillantii (Decne) T. Norl.	B C D E

Aspilia mossambicensis (Oliv.) Wild		luggas and drainage areas
Bothriocline fusca (S. Moore: M. Gilbert		newly opened up areas
Notonia hildebrandtii Vatke		R
Felicia abyssinica A. Rich. (Thunb.) Nees		B C D E
F. municata		B C D E
Carduus nyassanus (S. Moore) R.E. Fries		drainage areas
Helichrysum cymosum		disturbed areas
H. forskahlii (J.F. Gmel.) Hilliard & Buntt. (syn. & H. cymosum)		disturbed areas
H. globesum Sch. Bip.	)	
H. glumaceum DC.	)	disturbed sites
H. odoratissimum (L.) Less.		B C D E
Bidens ruepellii (Sch. Bip.) Sherff		drainage areas
Galinsoga parviflora Cav.		disturbed sites
G. ciliata (Rafn.) Blake		disturbed sites
Artemisia afra Willd.		B C D E
Conyza newii Oliv. & Hiern		roadsides
Crassocephalum mannii (Hook. f.) Milne-Redh.		steep sides of valleys
C. crepidioides (Benth.) S. Moore		steep sides of valleys
Pluchea bequaertii Robyns		edges of ponds and drainage areas
Vernonia lasiopus O. Hoffmn.	)	
Hirpicium diffusum (O. Hoffm.) Roess. -	)	B C D E
Gutenbergia cordifolia Oliver	)	
Senecio handensis S. Moore (syn. S. petitianus)		drainage areas
CRASSULACEAE		
Crassula coleae Bak.	)	
C. alba Forssk.	)	
C. pentandra (Edgerworth) Schonl. -	)	B C D E in open areas
C. alsinoides (Hook. f.) Engl.	)	
C. volkensii Engl.	)	
Cotyledon barbeyi Schweinf.		luggas and drainage areas
Kalanchoe densiflora Rolfe	)	
K. glaucescens Britten	)	
K. lanceolata (Forssk.) Pers. -	)	B C D
Umbilicus botryoides A. Rich	)	
CRUCIFERAE		
Rorippa cryptantha (A. Rich.) Rob. et Boutique	)	
R. micrantha (Roth) Jonsell	)	
Farsetia undulicarpa Jonsell	)	
F. stenoptera Hochst. ssp. stenoptera	)	B C D R
Crambe abyssinica R. E. Fries	)	
CUCURBITACEAE		
Cucumis sp.		drainage valleys
Kedrostis foetidissima (Jacq.) Cogn.		B C D
Zehneria scabra (Lin. f.) Sond.		B C D E
CUPRESSACEAE		
Juniperus procera Endl.		steep slopes of drainage areas

CYPERACEAE	
Fimbristylis exilis (H.B.K.) Roem. & Schult.	steam vents
F. hispidula (Vahl) Kunth	
Bulbostylis coleotricha (A. Rich.) C.B. Cl.	
Mariscus amauropus (Stendel) Curf.	B C D E
Cyperus obtusiflorus Vahl	B C D E
C. rigidifolius Steudel	B C D E
C. laevigatus	water collecting ponds
C. immensus C.B. Cl.	B C D E
DAVALLACEAE	
Oleandra distincta Kunze	steam vents
EBENACEAE	
Euclea divinorum Hiern	steep sides of cliffs
ERICACEAE	
Agauria salicifolia (Lam.) Oliv.	cliff edges and gorges
Erica arborea L.	cliff edges and gorges
EUPHORBIACEAE	
Euphorbia inaequilatera Sond.	widespread in all areas
E. kibwezensis	luggas and dry areas
Ricinus communis L.	disturbed areas
Phyllanthus rotundifolius Willd.	cliff edges
FLACOURTIACEAE	
Dovyalis abyssinica (A. Rich.) Warb.	cliff edges and luggas
GERANIACEAE	
Geranium aculeolatum Oliv.	B C D E
G. ocellatum Cambess.	B C D
Monsonia angustifolia A. Rich.	B C D E G
Pelargonium allchemilloides (L.) Ait.	B C D E
GLEICHENIACEAE	
Gleichenia linearis (Burm.) C.B. Cl.)	
Dicranopteris linearis (Burm. f.) Underw.)	steam vents
GRAMINEAE	
Rhynchelytrum repens (Willd.) C.E. Hubbard	disturbed sites, G
Setaria pumila (Poir.) Roem. & Schult.	overgrazed sites, G
Panicum maximum Jacq.	drainage areas and luggas
Sporobolus fimbriatus (Trin.) Dur. & Sch.	drainage areas
Eragrostis cilianesis (All.) F.T. Hubboard	B C D E G
Brachiaria leersioides (Hochst.) Stapf	B C D E G
Pennisetum squamulatum Fresen)	
P. procerum (Stapf) W.D. Clayton)	
P. clandestinum Chiov.)	disturbed areas
Cynodon dactylon (L.) Pers.	B C D E G and newly opened sites
C. nlemfuensis Vanderyst var. nlemfuensis	B C D E G & newly opened sites
C. plectostachyus (K. Schum.) Pilg.	pockets of disturbance in G & D E
Chloris gayana Kunth	G B C D E
Harpachne schimperi A. Rich.	disturbed areas
Hyparrhenia hirta (L.) Stapf	B C D E G

H. papillipes (A. Rich.) Stapf.	B C D E G
Themeda triandra Forssk.	disturbed areas
Tragus berteronianus Schult.	poorly drained sites G
Digitaria abyssinica (A. Rich.) Stapf -	poorly rained sites, G
Aristida keniensis Henr.	disturbed sites
A. congesta Roem. & Schult.)	
A. adoensis Hochst.)	D E G
A. mutabilis Trin. & Rupr.)	
Cymbopogon nardus (L.) Rendle	D E G
Sporobolus africanus (Poir.) Robyns & Tourney	G
S. macranthelus Chiov.	G
Setaria sphacelata (Schummach.) Moss var. aurea (A. Br.) W.D. Clayton	B C D E G
Eragrostis racemosa (Thunb.) Steud.	D E G
E. tenuifolia (A. Rich.) Steud.	D E G
E. olivacea K. Schum.	D E G
E. braunii Schweinf.	D E G
Dactyloctenium aegyptium (L.) Wild.	disturbed areas
Paspalum scrobiculatum L.	disturbed areas
Microchloa kunthii Desv.	R
Heteropogon contortus (L.) Roem. & Schult.	D E G
HYPERICACEAE	
Hypericum revolutum Vahl	B C D E
IRIDACEAE	
Aristea angolensis Bak.	R and parts of E
Gladiolus newii Baker ssp. newii	R and parts of E
LABIATAE	
Tetradenia riparia (Hochst.) Codd	cliffs and gorges
Becum obovatum (E. Mey.) N.E. Br.	sides of luggas
Ocimum suave Willd.	D E G
Leucas glabrata (Vahl) R. Br.	B C D E
L. pratensis Vatke)	
L. neuflizeana Courb. -)	B C D E
Plectranthus marrubioides Benth.	luggas and drainage sites
P. barbatus Benth.	cliff and gorges
P. sp. aff. pseudomarrubioides R.H. Willemse	cliff edges
P. zatarhendi (Forssk.) E.A. Bruce	B C D E
P. caninus Roth	B C D E
P. pubescens Bak.	B C D E
Leontis mollissima Guerke)	
L. nepetifolia R. Br.)	disturbed areas of B C D E
Satureja biflora (D. Don) Benth.	B C D E
Iboza multiflora (Benth.) E.A. Bruce	gorges and cliff sides
Fuerstia africana T.C.E.Fr.	B C D E
LILIACEAE	
Asparagus buchananii Bak.	R
A. africanus Lam.	R
Bulbine abyssinica R. Rich.	R
Kniphofia thomsonii Bak.	R
Aloe kedongensis Reynl.	luggas and cliff edges
A. myriacantha (Harv.) R. & S.)	

A. secundiflora Engl.	)	luggas and cliff edges
Gloriosa superba L.		R and some parts of B D E
LINACEAE		
Linum volkensii Engl.		luggas and drainage areas
LOBELIACEAE		
Lobelia holstii Engl.		gorges
LOGANIACEAE		
Buddleia polystachya Fresen.		cliff edges
LORANTHACEAE		
Englerina heckmanniana (Engl.) Balle	)	
Odontella fischeri Engl.	)	epiphytic and Parasitic
Tapinanthus zizyphifolius (Engl.) Danser	)	on other woody species
LYCOPODIACEAE		
Lycopodium cernuum L.		steam vents
MALVACEAE		
Abutilon mauritianum (Jacq.) Medic.	)	
A. longiscupe Hochst.		valley bottoms and G
Hibiscus fuscus Garcke		D E G
H. flavifolius Ulbr.		D E G
H. aponeurus Sprague & Hutch.		B C D E G
Sida tenuicarpa Vollesen		B C D E R
S. cuneifolia Roxb.		B C D E R
S. rhombifolia L.	)	
S. schimperiana A. Rich. -	)	B C D E R
S. ovata Forssk.	)	
Pavonia patens (Andr.) Chiov.		D E G
MELASTOMATACEAE		
Dissotis irvingiana Hook. var. alpestris		
(Taub.) A.R. Fernandes		luggas and gorges
forma alpestris	)	
D. senegambiensis (Guill. & Perr.) Triana var.	)	" "
senegambiensis	)	
D. senegambiensis (Guill. & Perr.) Triana var.	)	" "
alpestris (Taub.) A. & R. Fernandes	)	
MELIACEAE		
Ekebergia capensis Sparrm.		gorges
MIMOSACEAE		
Acacia seyal Del. var. seyal		B and gullies
A. gerrardii Benth. var. gerrardii		B and gullies
A. drepanolobium Sjostedt		B C D E G
A. xanthophloea Benth.		drainage areas
MORACEAE		
Ficus ingens Miq.	)	cliff edges and gorges
F. pretoriae B. Davy	)	
F. thonningii Guerke	)	

MYRICACEAE
Myrica salicifolia A. Rich. | luggas and drainage areas.

MYRSINACEAE
Myrsine africana L. | cliff edges

OLEACEAE
Olea europaea L. ssp.
africana (Mill.) S.P. Green | cliff edges

OPHIOGLOSACEAE
Ophioglossum rubellum A. Br. | steam vents

ORCHIDACEAE

Angraecum humile Summer		epiphytic near humid vents
Ansellia gigantea Reichb. f. var. nilotica	)	epiphytic near vents
Cyrtorchis arcuata (Lindl.) Schltr.	)	" " "
Pleroglossaspis ruwenzoriensis Rolfe	)	" " "

OXALIDACEAE
Oxalis obliquifolia A. Rich. | drainage gullies

PAPIOLIONACEAE

Crotalaria sp. aff. C. chrysochlora Harms	)	
C. dewildemaniana Wilczek	)	B C D E G
C. deserticola Bak. f.	)	
C. agatiflora Schweinf. ssp. engleri (Taub.) Polhill		drainage sites
C. spinosa Benth.		D E G
C. incana L. ssp. purpurescens (Lam.) Milne-Redh.		B C D E G
C. agatiflora Schweinf. ssp. agatiflora		drainage sites
C. chrysochlora Harms		drainage areas
Indigofera tanganyikensis Bak. f. var. strigulosior Gillett	)	
I. ambelacensis Schweinf.	)	
I. masaiensis Gillett	)	B C D E G
I. bogdanii Gillett	)	
I. arrecta A. Rich.	)	
Zornia pratensis Milne-Redh.		B C D E G
Z. setosa Bak. f. ssp. obovata (Bak. f.) J. Leon & Milne-Redh.		B C D E G
Argyrolobium rupestre (E. Mey.) Walp.		cliff edges
Lotus becquetii Boutique		B C
L. goetzii Harms		B C
Macrotyloma axillare (E. Mey.) Verdc.		D E G
Tephrosia emeroides A. Rich.	)	
T. linearis (Willd.) Pers.	)	B C D E

PITTOSPORACEAE
Pittosporum viridiflorum Sims — B C

PHYTOLACCACEAE
Phytolacca dodecandra L'Herit.)
P. octandra L.) — disturbed opened areas

POLYPODIACEAE
Pleopeltis macrocarpa (Willd.) Kaulf. — steam vents

POLYGALACEAE
Polygala abyssinica R. Br.)
P. amboniensis Gurke) — drainage gullies with deep soil
P. sphenoptera Fresen.)

POLYGONACEAE
Rumex usambarensis (Dammer) Dammer — pond edges
Polygonum senegalense Meisn. — drainage areas
Oxygonum sinuatum (Meisn.) Dammer — disturbed areas

PORTULACACEAE
Talinum portulacifolium Schweinf. — R
Portulaca kermesina N.E.Br. — R

PROTEACEAE
Protea gaguedi J.F. Gmel. — gorges and cliff edges

RHAMNACEAE
Scutia myrtina (Burm. f.) Kurz. — cliff edges

RUBIACEAE
Galium aparinoides Forssk. — B C D E G
G. spurium L. — B C D E G
Kohautia caespitosa Schnizl. var.
amaniensis (K. Krause) Brem. — B C D E G
Pentas zanzibarica (Kl.) Vatke — D E G
P. parvifolia Hiern — D E G
Oldenlandia corymbosa L.)
O. scopulorum Bullock)
O. wiedemannii K. Schum.) — B C D E G
Rubia cordifloia L.)
Pentanisia ouranogyne S. Moore — D E G
Canthium phyllanthoideum Baill. — cliff edges

RUTACEAE
Teclea simplicifolia (Engl.) Verdoorn — slopey and rocky areas

SANTALACEAE
Osyris abyssinica A. Rich. — cliff sides

SAPINDACEAE
Allophylus abyssinicus (Hochst.) Radlk. — dry water courses
Dodonea angustifolia L.f. — C R also gorges
D. viscosa L.) Jacq. — C R also gorges

SCROPHULARIACEAE	
Alectra sessiliflora (Vahl.) Kunth	
var. senegalensis (Benth.) Hepper	B C D E
Misopates orontium (L.) Rafin	B C D E
Cycnium volkensii Engl.	B C D E
C. tubulosum (L.f.) Engl. ssp.	
montanum (N.E.Br.) O.J. Hansen	B C D E
(syn. Rhamphicarpa montana)	
Striga linearifolia (Schum. & Thonn.) Hepper	B C D E
Hebenstretia dentata L.	B C D E
Pseudosopubia hildebrandtii (Vatke) Engl.	B C D E G
Striga asiatica (L.) Kuntze	B C D E G
Cycniopsis obtusifolia Skan	B C D E
Craterostigma pumilum Hochst.	B C D E G R
TILIACEAE	
Grewia similis K. Schum.	luggas and drainage areas
TYPHACEAE	
Typha latifolia L.	water collecting ponds
T. domingensis Pers.	water collecting ponds
ULMACEAE	
Trema guineensis (Schm. & Thonn.) Ficalho	luggas and drainage areas
SOLANACEAE	
Solanum incanum L.	disturbed and overgrazed sites
S. mauense Bitter	luggas and drainage areas
S. nigrum L.	disturbed and overgrazed sites
Cestrum aurantiacum Lindl.	C E
Datura stramonium L.	disturbed and overgrazed sites
Nicotiana glauca R. Gran.	roadsides and other disturbed areas
Withania somnifera (L.) Dunal	roadsides and other disturbed sites
UMBELLIFERAE	
Ferula communis L.	C D E
Heteromorpha trifoliolata (Wendl.) Eckl. & Zeyh	steep sides of luggas where rocky
VERBENACEAE	
Clerodendrum myricoides Vatke	gorges
Lippia ukambensis Vatke	D E
L. javanica (Burm.f.) Spreng	D E
Lantana camara L.	disturbed sites
VISCACEAE	
Viscum tuberculatum A. Rich.	epiphytic
VITACEAE	
Cyphostemma nierense (Th. Fr. jr.) Desc.	drainage areas and R
ZYGOPHYLLACEAE	
Tribulus terrestris L.	disturbed ground with deep soil

Plate 13 - Bushland.

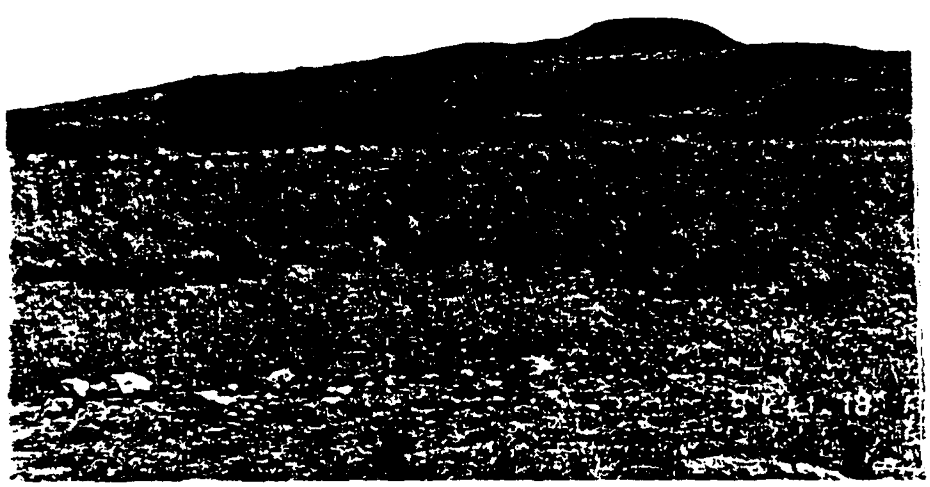


Plate 14 - Shrubbed grassland (see text for details).

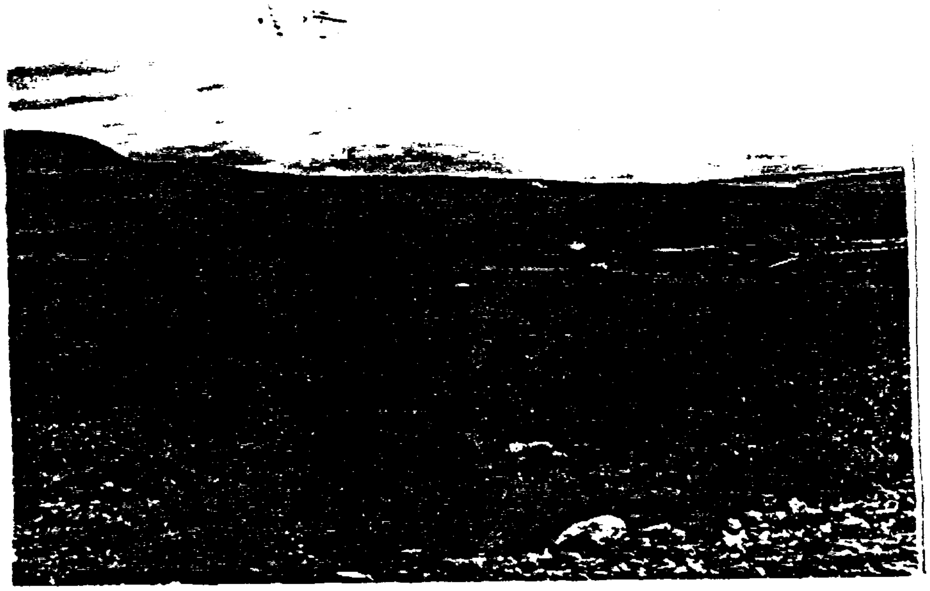


Plate 15 - Grassland (see text for details).

Plate 16 - Rock outcrop with medium shrubland in the foreground (see text for details).

Appendix 6.3.1 -
Soil Physical Properties

(Determined in Civil Engineering Dept. University of Nairobi)

	Sample No			
	1.	2.	3.	4.
1. **Soil Texture** (Percentage by weight)				
Gravel (more than 2 mm)	4	13	10	4
Sand (0.05 to 2 mm)	67	58	63	63
Medium to Coarse Silt (0.01 to 0.05 mm)	22	24	22	28
Fine Silt and Clay (less than 0.01 mm)	7	5	5	5
	100	100	100	100
2. **Atterberg Limits**				
Liquid limit	nil	nil	nil	nil
Plastic limit	nil	nil	nil	nil
Linear Shrinkage	nil	nil	nil	nil
3. **Shear Box Test**				
Angle of internal friction (degrees)	52.4	55.0	46.04 9.4	
Cohesion	nil	nil	nil	nil

SOIL PHYSICAL AND CHEMICAL PROPERTIES

(Determined in Department of Soil Science, University of Nairobi)

Soil samples taken from successive horizons
on 7 m high cut slope at well no. 717

	Sample nos.*					
	1 top	2	4	5	6	7 bottom
Soil texture (% by weight)						
sand	79	79	73	85	77	79
silt	19	19	23	14	21	19
clay	2	2	4	1	2	2
Texture class						
	loamy	loamy	sandy	sand	loamy	loamy
	sand	sand	loam		sand	sand
pH (soil:water ratio 1:2)	6.6	7.4	10.4	10.6	10.3	10.4
Organic matter (Walkley-Black method)						
% carbon	1.31	0.04	0.04	0.04	0.29	0.13
% organic mat	2.26	0.08	0.07	0.08	0.50	0.22

* There is no sample no. 3 as the horizon was inaccessible

Appendix 6.3.1.1 - Description of well-sites at Olkaria NE (13 June 1991)

No.	Height & Angle Cut Slope/Fill Slope	Ground Slope	Devel. Stage	Waste water	Erosion Hazard
701	stable/stable	< 10%	tested	pond	low
702	stable/stable	< 10%	tested	pond	low
703	3 m 50 deg/stable	< 10%	tested	pond	low
704	7 m 35 deg/5 m 35 deg	27%	for re-injection	mod	
705	2 m 50 deg/stable	< 10%	tested	bush	low
706	2 m 45 deg/2 m 45 deg	< 10%	tested	valley	low
707	5 m 20 deg/irregular	16%	tested	pond	v high
708	stable/stable	2%	re-injection	well	low
709	stable/4 m 60 deg	< 10%	tested	pond	mod
710	irregular/irregular	< 10%	tested	valley	mod
711	2 m 40 deg/stable	< 10%	tested	pond	high
712	irreg/8 m 45 deg	< 10%	testing	gully	v high
713	6 m 60 deg/3 m 45 deg	18%	tested	gully	v high
714	3 m 80 deg/irregular	14%	tested	pond	mod
715	4 m 70 deg/3 m irregular	12%	testing	pond	mod
717	7 m 80 deg/6 m 30 deg	14%	to be tested	valley	v high
718	4 m 80 deg/7 m 35 deg	14%	to be tested	bush	v high
719	4 m 65 deg/3 m irregular	16%	start tested	pond	mod
720	4 m 45 deg/?m 45 deg	18%	to be tested	?	high
721	4 m 70 deg/5 m 40 deg	15%	to be tested	?	mod

	Height & Angle Cut Slope/Fill Slope	Ground Slope	Devel. Stage	Waste water	Erosion Hazard
722	4 m 75 deg/2 m 30 deg	10%	to be tested	?	low
723	stable/stable	2%	to be tested	pond	low
724	stable/stable	6%	drilling	low	
725	3 m 80 deg/3 m 35 deg	12%	to be drilled	mod	
726	5 m 22 deg/2 m 6 deg	12%	to be drilled	mod	
727	3 m 80 deg/3 m 45 deg	10%	to be drilled	low	
NE-G	5 m 80 deg/5 m 40 deg	27%	rejected	nil	v high
M2	3 m 40 deg/stable	< 10%	scientific	-	low

NB. Figures given are approximations. The degree of erosion hazard refers to the risk of erosion from the cut slope, the fill slope and from any gully which may have started as a result of the development. Well pads with high or very high erosion hazard require close attention. Grass was being planted on the fill slope of 714 in November 1990 and the fill slopes of 726 and 717 in May - June 1991.

FURTHER NOTES ON WELL PADS

701. This is on almost level ground and is stable.

702. Same condition as 703. Some Kikuyu grass appears to have been planted on the spoil along the N side. It would be better if the ground was graded uniformly before planting.

703. This pad is on nearly level ground and is quite stable.
Some grass planting on bare surfaces is needed.

704. This is apparently an unproductive well. The cut slope is high but the angle is not too steep and stabilisation with grass may be possible. The fill slope is very broken. There are cracks and holes which are partly covered with grass and rather dangerous. Smoothing and replanting is needed.

705. Well pad is on nearly level ground and stable.

706. This pad is on fairly level ground and apart from some minor gullying where the waste water has been discharged, it is stable.

707. The cut slope is badly rilled. The fill slope is very irregular. A large gully on the N side has been partly filled but grass planting is needed urgently. The outwash from the sump pond during drilling caused gullying and there is a deep gully alongside the

access road due to the failure of a culvert. Stabilisation of the bare ground to minimise runoff by planting grass should be carried out urgently.

709. This pad is on nearly level ground and is stable.

710. The pad is stable but the spoil needs smoothing and grassing.

711. The pad is fairly stable but the sump pit broke and caused a deep gully to the S side. The upper part of the gully is partly stabilised but the lower section is eroding badly and has joined a new gully that has developed below 709.

712. There is a serious gully on the S side of this well pad which has developed in a small valley that was carrying effluent during the drilling phase. The gully is about 4 m wide and 5 m deep and there are huge heaps of spoil which are eroding rapidly. They need to be stabilised with grass as soon as possible. The well is currently under test and waste water is being discharged to a pond on the fill side. There is a gully at the NE end which appears to have been caused by breaching of an earlier pond.

713. This well was under test in November and the waste water was channeled into a nearby valley. Although the first section of the channel was stabilised with concrete, a huge gully, about 10 m wide and 7 m deep, developed in the valley below. The gully sides are slumping and the gully floor is filled with bush that has fallen in. Potentially there is much sediment that could be transported to the channel alongside the power station. However where this valley is crossed by the tarmac road it appears to be well grassed and stable.

714. Grass planting (Kikuyu and star) was in progress in November but was partially negated by the construction of a sump pond for use during testing.

715. The cut slope has partly stabilised with star grass. The toe slope was very irregular but has been smoothed. Star grass should be planted.

717. The cut slope is very high, about 7 m, and nearly vertical. The spoil on the lower side has been smoothed and grassing is taking place (June, 1991). The southern end of the pad needs grassing urgently as it is a potential source of sediment that can be carried to the power station.

718. The fill slope was very irregular but has been graded uniformly and needs planting with star grass as a matter of urgency to prevent sediment being carried to the power station.

719. The fill slope is broken up and should be smoothed and planted with grass as soon as testing of the well is completed.

720. This well has still to be tested. The valley to the S of the pad should not be allowed to carry the waste water. It is well vegetated with trees and shrubs which are different from those on the surrounding slopes. There is considerable risk of erosion in this valley and waste water should be piped to the sump below 715 for subsequent reinjection at 708.

721. This well is in an area of rock. The cut slope and fill slope are fairly stable on account of the rock fragments. Establishment of grass may be difficult but there is little risk of erosion.

722. This well pad is on fairly level ground and there is minimal risk of erosion.

723. This well has just been drilled. Some grass planting is needed to stabilise the loose spoil but is not urgent.

724. Drilling is in progress. The risk of erosion is not high.

725. This is a new pad which has still to be drilled. The risk of erosion is not high but the fill slope should be stabilised with grass.

726. This is a new pad. The fill slope has been well graded and stabilised with star grass. The cut slope has been bevelled to an angle of about 22 degrees. Stabilisation with grass should be carried out before it erodes.

727. This is a new pad. The risk of erosion is not high but the fill slope should be stabilised with grass.

NE-G. This pad has been sited on a very steep hillside and both the cut slope and the toe slope are unstable. The site is not far from the existing camp. Apparently it has been abandoned on environmental grounds. If this is so, immediate steps should be taken to repair the damage as far as possible and to grass the bare surfaces. Well pad 708 was also abandoned after partial testing due to proximity to the camp.

M2. This is referred to as a scientific well. The area is stable.

Appendix 6.4.1 - List of Mammals of Hell's Gate National Park

<u>Large Herbivores</u>	
Kongoni	Alcephalus buselaphus coki
Zebra	Equus burchelli
Thompsons gazelle	Gazella thomsonii
Grants gazelle	Gazella grantii
Giraffe	Giraffa cemelopardalis
Eland	Taurotragus oryx
Reedbuck	Rendunca redunca
Warthog	Phacochoerus aethiopicus
Impala	Apyceros melampus
Dik-dik	Rhynchotragus kirkii
Steinbuck	Rhaphicerus campestris
Klipspringer	Oreotragus oreotragus
Buffalo	Syncerus caffer
Waterbuck	Kobus defassa
<u>Small Herbivores</u>	
Hare	Lepus spp.
Spring hare	Pedetes capensis 1
Mole rat	Tachyorectes plendens 1
Squirrel	Finisciurus spp.
Rat-like rodents	
<u>Carnivores</u>	
Lion	Panthera leo 2
Leopard	Panthera pardus 2
Jackal	Canis spp.
<u>Other Mammals</u>	
Aardvark	Orycteropus afer 1
Olive baboon	Papio anubis
Rock hyrax	Heterophyrax brucei
Hedgehog	Erinaceus albiventris

Appendix 6.4.2 - Birds of Hell's Gate National Park

	Ostrich	Struthio cemlus
*	White Pelican	Pelicanus onocratalus
*	Secretary Bird	Saggitarius serpentarius
*	Rupell's Vulture	Gyps ruppellii
*	White-backed Vulture	Gyps bengalensis
	Nubian Vulture	Torgos tracheliotus
*	Egyptian Vulture	Neophron percnopterus
	Lammergeyer	Gypaetus barbatus
	Harrier Hawk	Polybariodes radiatus
*	Batleur	Terathopius ecaudatus
	Auger Buzzard	Buteo rufofuscus
	Long-crested Eagle	Lophaetus occipitalis
*	African Hawk Eagle	Hieraaetus spilogaster
*	Tawny Eagle	Aquila rapax
	Verreaux's Eagle	Aquila verrauxii
	Whalberg's Eagle	Aquila wahlbergi
*	African Fish Eagle	Haliaeetus vocifer
	Lanner	Falco biarmicus
	Peregrine	Falco peregrinus
*	African Hobby	Falco cuvieri
	Fox Kestrel	Falco alopex
*	Spotted Eagle Owl	Bubo africanus
	Cocqui Francolin	Francolinus coqui
	Hildebrandt's Francolin	Francolinus hildebranti
	Scaly Francolin	Francolinus squamatus
*	Helmeted Guinea Fowl	Numida melaegris
*	Kori Bustard	Ardeotis kori
	Crowned Plover	Vanelus coronatus
	Common Sandpiper	Tringa hypoleucos
	Temminck's Courser	Cursorius temminckii
*	Speckled Pigeon	Columba guinea
	Red-eyed Dove	Streptopelia semitorquata
*	Ring-necked Dove	Streptopelia capicola
	Laughing Dove	Streptopelia senegalensis
	Red-chested Cuckoo	Cuculus solitarius
*	Didric Cuckoo	Chrysococcyx caprius
	Klaas's Cuckoo	Chrysococcyx klaas
	White-browed Coucal	Centropus superciliosus
	Nightjar sp.	Caprimulgus sp.
*	Mottled Swift	Apus aequatorialis
	Nyanza Swift	Apus niansae
	Little Swift	Apus affinis
	Horus Swift	Apus horus
	Speckled Mousebird	Colius striatus
*	White-fronted Bee Eater	Merops bullockoides
	African Hoopoe	Upupa epops

	Abyssinian Scimitarbill	Phoeniculus minor
*	Gold-tailed Woodpecker	Campethera cailliautii
	Bearded Woodpecker	Thripias namaquus
	Plain-backed pipit	Anthus leucophrys
*	Rufus-naped Lark	Mirafra africana
	Redwing Bush Lark	Mirafra hypermetra
*	African Rock Martin	Hirundo fuligula
	European Swallow	Hirundo rustica
*	Red-rumped Swallow	Hirundo daurica
*	Grey-rumped Swallow	Hirundo griseopyga
	Grey Wagtail	Motacilla clara
	African Pied Wagtail	Moticilla aguimp
	Richard's Pipit	Anthus novaeseelandiae
	Yellow-vented Bulbul	Pycnonotus barbatus
*	Black-backed Puffback	Dryoscopus cubla
	Brown-headed Tchagra	Tchagra australia
*	Tropical Boubou	Laniarius ferruineus
*	Fiscal Shrike	Lanius collaris
*	Grey-backed Fiscal Shrike	Lanius excubitorius
	Stone Chat	Saxicola torquata
	Schalow's Wheatear	Oenanthe lugubris
*	Anteater Chat	Myrmecocichla aethiops
	Robin Chat	Cossypha caffra
*	White-browed Robin Chat	Coccypha heuglini
	Black-lored Babbler	Turdoides melanops
	Wood Warbler	Phylloscopus sibilatrix
	Brown Woodland Warbler	Phylloscopus umbrovirens
	Willow Warbler	Phylloscopus trochilus
*	Rattling Cisticola	Cisticola chiniana
	Tawny-flanked Prinia	Prinia sublava
	Black-breasted Apalis	Apalis flavida
	Red-faced Apalis	Apalis rufifrons
*	Buff-bellied Warbler	Phyllolais pulchella
	Grey-backed Camaroptera	Camaroptera brevicaudata
	Crombec	Sylvietta brachyura
*	Dusky Flycatcher	Alsenax adustus
*	White-eyed Slaty Flycatcher	Dioptornis fischeri
	Grey Flycatcher	Bradornis microrhynchus
*	Chin-spot Flycatcher	Batis molitor
	Hunter's Sunbird	Nectarina hunteri
	Scarlet-chested Sunbird	Nectarinia senegalensis
	Variable Sunbird	Necterinia venusta
*	Bronze Sunbird	Nectarinia kilimensis
	Golden-breasted Bunting	Emberiza flaviventris
	Cinnamon-breasted Rock Bunting	Emberiza tahapisi
	Yellow-rumped Seed Eater	Serinus atrogularis
	Brimstone Canary	Serinus sulphuratus
	Crimson-rumped Waxbill	Estrilda rhodopyga
*	Common Waxbill	Estrilda astrild
	Purple Grenadier	Uraeginthus ianthinogaster
*	Pin-tailed Whydah	Vidua macroura

*	Richenow's Weaver	Ploceus baglafeht
	Vitteline Masked Weaver	ploceus velatus
	Yellow Bishop	Euplectes capensis
*	Rufous Sparrow	Passer motitensis
	Grey-headed Sparrow	Passer griseus
	Redwing Starling	onychognathus morio
*	Blue-eared Glossy Starling	Lamprotornis chalybaeus
	Superb Starling	Spreo superbus
*	Red-billed Oxpecker	Buphagus erythrorhynchus
	Black-headed Oriole	Oriolus larvatus
	Diongo	Dicurus adsimilis

Note: * Species seen during survey

Appendix 6.5 - Climate and Meteorology Data

Appendix 6.5.1- Examples of Meteorological Data

1. Examples of data from the microprocessor-controlled weather station
2. The structure of the data file used in the dispersion model

05-01-91	00:00,	4.2,	148,	15.8,	100,	6,	0.0,	8.5
05-01-91	00:10,	3.7,	148,	15.8,	100,	6,	0.0,	8.5
05-01-91	00:20,	3.7,	155,	15.8,	100,	6,	0.0,	8.5
05-01-91	00:30,	4.2,	150,	15.5,	100,	6,	0.0,	8.5
05-01-91	00:40,	3.4,	160,	15.5,	100,	6,	0.0,	8.5
05-01-91	00:50,	4.5,	161,	15.3,	100,	6,	0.0,	8.5
05-01-91	01:00,	3.8,	151,	15.3,	100,	6,	0.0,	8.5
05-01-91	01:10,	5.9,	145,	15.0,	100,	6,	0.0,	8.5
05-01-91	01:20,	5.8,	151,	15.0,	100,	6,	0.0,	8.5
05-01-91	01:30,	3.7,	154,	15.0,	100,	6,	0.0,	8.5
05-01-91	01:40,	4.3,	158,	15.0,	100,	6,	0.0,	8.5
05-01-91	01:50,	4.0,	155,	14.7,	100,	6,	0.0,	8.5
05-01-91	02:00,	4.8,	155,	14.7,	100,	6,	0.0,	8.5
05-01-91	02:10,	3.8,	138,	14.7,	100,	6,	0.0,	8.5
05-01-91	02:20,	5.0,	141,	14.7,	100,	6,	1.0,	8.5
05-01-91	02:30,	5.9,	147,	14.7,	100,	6,	1.4,	8.5
05-01-91	02:40,	4.6,	144,	14.7,	100,	6,	0.8,	8.5
05-01-91	02:50,	3.8,	151,	14.4,	100,	6,	0.8,	8.5
05-01-91	03:00,	3.0,	167,	14.4,	100,	6,	0.6,	8.5
05-01-91	03:10,	2.9,	128,	14.4,	100,	6,	0.4,	8.5
05-01-91	03:20,	2.1,	145,	14.4,	100,	6,	0.6,	8.5
05-01-91	03:30,	2.7,	162,	14.4,	100,	6,	0.2,	8.5
05-01-91	03:40,	2.7,	192,	14.4,	100,	6,	0.0,	8.5
05-01-91	03:50,	3.5,	155,	14.4,	100,	6,	0.0,	8.5
05-01-91	04:00,	4.5,	158,	14.4,	100,	6,	0.2,	8.5
05-01-91	04:10,	4.0,	168,	14.7,	100,	6,	0.0,	8.5
05-01-91	04:20,	4.8,	165,	14.4,	100,	6,	0.0,	8.5
05-01-91	04:30,	2.6,	160,	14.7,	100,	6,	0.0,	8.5
05-01-91	04:40,	2.7,	182,	14.7,	100,	6,	0.0,	8.5
05-01-91	04:50,	2.9,	141,	14.7,	100,	6,	0.0,	8.5
05-01-91	05:00,	4.6,	160,	14.7,	100,	6,	0.0,	8.5
05-01-91	05:10,	3.4,	161,	14.4,	100,	6,	0.0,	8.5
05-01-91	05:20,	3.8,	157,	14.4,	100,	6,	0.0,	8.5
05-01-91	05:30,	4.3,	174,	14.7,	100,	6,	0.0,	8.5
05-01-91	05:40,	2.6,	171,	14.4,	100,	6,	0.0,	8.5
05-01-91	05:50,	3.4,	171,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:00,	2.7,	165,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:10,	2.1,	154,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:20,	2.9,	174,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:30,	2.2,	154,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:40,	2.1,	161,	14.4,	100,	6,	0.0,	8.5
05-01-91	06:50,	2.4,	165,	14.4,	100,	12,	0.0,	8.5
05-01-91	07:00,	3.4,	169,	14.4,	100,	29,	0.0,	8.5
05-01-91	07:10,	2.1,	158,	14.4,	100,	41,	0.0,	8.5
05-01-91	07:20,	2.4,	161,	14.7,	100,	53,	0.0,	8.5
05-01-91	07:30,	3.0,	160,	14.7,	100,	59,	0.0,	8.5
05-01-91	07:40,	2.6,	185,	15.0,	100,	76,	0.0,	8.5
05-01-91	07:50,	3.8,	164,	15.0,	100,	82,	0.0,	8.5
05-01-91	08:00,	3.4,	171,	15.0,	100,	106,	0.0,	8.5
05-01-91	08:10,	3.2,	167,	15.0,	100,	112,	0.0,	8.5
05-01-91	08:20,	2.7,	158,	15.3,	100,	88,	0.0,	8.5
05-01-91	08:30,	2.7,	134,	15.3,	100,	165,	0.0,	8.5
05-01-91	08:40,	4.0,	168,	15.5,	100,	106,	0.0,	8.5
05-01-91	08:50,	3.7,	148,	15.5,	100,	171,	0.0,	8.5
05-01-91	09:00,	4.3,	168,	15.5,	100,	165,	0.0,	8.5
05-01-91	09:10,	4.0,	151,	15.5,	100,	153,	0.0,	8.5
05-01-91	09:20,	3.8,	145,	15.8,	100,	188,	0.0,	8.5
05-01-91	09:30,	3.7,	144,	16.1,	100,	265,	0.0,	8.5
05-01-91	09:40,	5.3,	176,	16.6,	100,	382,	0.0,	8.5
05-01-91	09:50,	3.0,	154,	17.2,	100,	359,	0.0,	8.5
05-01-91	10:00,	3.0,	157,	17.2,	100,	435,	0.0,	8.5
05-01-91	10:10,	4.8,	172,	17.5,	100,	318,	0.0,	8.5
05-01-91	10:20,	3.2,	168,	17.5,	100,	265,	0.0,	8.5
05-01-91	10:30,	4.5,	176,	17.5,	100,	218,	0.0,	8.5
05-01-91	10:40,	4.0,	178,	17.2,	100,	253,	0.0,	8.5
05-01-91	10:50,	3.7,	189,	17.5,	100,	300,	0.0,	8.5
05-01-91	11:00,	4.2,	184,	17.7,	98,	265,	0.0,	8.5
05-01-91	11:10,	5.0,	160,	18.5,	95,	412,	0.0,	8.5
05-01-91	11:20,	3.5,	179,	18.0,	94,	206,	0.0,	8.5
05-01-91	11:30,	4.3,	150,	18.5,	89,	429,	0.0,	8.5
05-01-91	11:40,	5.3,	174,	18.5,	87,	276,	0.0,	8.5
05-01-91	11:50,	4.8,	169,	18.0,	91,	265,	0.0,	8.5
05-01-91	12:00,	4.3,	160,	18.0,	94,	218,	0.0,	8.5
M D Y	H M	WS	WD	T	H	SR	R	BV

Y=year, M=month, D=day, T=temperature (°C), WS=wind speed (m/s), WD=wind direction (degrees from north), H=humidity (%), SR=solar radiation (W/m^2), R=rainfall total (mm in ten minutes) and BV=logger battery voltage.

X2 1991 (adj. temp. and full days of data inc ND90+JF91)

90010101	17	1.3	61	F	82	45.5
90010102	16	1.6	79	E	78	18.5
90010103	16	2.1	294	F	101	31.0
90010104	16	1.3	354	E	72	6.0
90010105	17	1.1	315	E	66	15.0
90010106	18	1.1	334	F	152	21.5
90010107	19	1.0	306	A	385	32.0
90010108	21	1.3	39	C	609	18.0
90010109	22	1.2	282	D	820	11.0
90010110	24	1.3	283	A	1012	30.5
90010111	25	1.3	264	B	1180	25.0
90010112	27	1.8	180	A	1320	60.0
90010113	27	2.4	153	A	1429	39.0
90010114	28	4.1	330	A	1505	40.0
90010115	28	3.6	234	B	1544	22.0
90010116	28	2.4	82	B	1547	22.5
90010117	27	3.7	166	D	1512	18.5
90010118	27	7.2	163	D	1595	13.5
90010119	25	5.4	108	D	1191	11.0
90010120	24	2.4	172	F	62	42.5
90010121	22	1.9	330	F	98	40.0
90010122	21	1.8	268	F	94	26.5
90010123	19	1.9	109	D	416	13.5
90010124	18	1.0	27	D	230	11.0
90010301	17	.9	213	E	59	6.0
90010302	16	.9	303	F	66	21.0
90010303	16	1.1	141	E	64	17.0
90010304	16	1.2	3	E	67	14.0
90010305	17	1.0	270	F	72	30.0
90010306	18	1.0	181	F	152	24.5
90010307	19	1.2	138	A	385	36.0
90010308	21	1.0	330	C	609	15.0
90010309	22	1.4	297	C	820	16.0
90010310	24	2.3	180	A	1012	60.0
90010311	25	1.8	292	A	1180	43.5
90010312	27	2.2	265	A	1320	45.5
90010313	27	2.6	180	A	1429	60.0
90010314	28	3.0	150	B	1505	20.0
90010315	28	5.0	157	B	1544	17.5
90010316	28	6.9	150	C	1547	13.0
90010317	27	8.0	156	D	1512	12.0
90010318	27	5.3	249	D	1178	58.0
90010319	25	2.7	25	F	66	22.5
90010320	24	3.4	85	E	114	36.5
Y M D H	T	WS	WD	S	MH	SIG

Y=year, M=month, D=day, T=temperature (°C), WS=wind speed (m/s), WD=wind direction (degrees from north), S=Pasquill-Gifford stability class, MH=mixed-layer height (m) and SIG=standard deviation of wind direction.

Appendix 6.9- Water Quality Data (North East Olkaria Wells)

APPENDIX 6.9

TABLE 1- WATER QUALITY DATA: NORTH EAST OLKARIA WELLS.
(All results in mg/l and analysis performed on filtrates)

	Detectable Limits	OW-701	OW-702	OW-703	OW-704	OW-705	OW-706	OW-707	OW-708
pH	0.01	9.48	9.11	9.14	9.21	9.38	9.04	9.69	7.36
TDS		2276	-	2918	-	2020	2096	2186	-
Boron (B)	0.01	4.0	4.0	1.3	-	0.84	2.9	-	2.6
Chloride (Cl)	0.1	730	670	895	-	470	671	587	507
Sodium (Na)	0.5	637	500	645	402	496	640	430	339
Potassium (K)	0.14	98	104	120	75	67	70	70	87
Silicon (Si)	1.00	466	420	448	140	333	299	259	297
Magnesium (Mg)	0.01	0.05	0.20	0.20	0.27	0.30	0.10	ND	0.10
Ammonia (NH_4)	0.003	1.0	-	-	-	-	-	-	-
Zinc (Zn)	0.17	-	-	ND	-	ND	ND	1.6	-
Chromium (Cr)	0.009	-	-	ND	-	ND	ND	ND	-
Iron (Fe)	0.01	-	-	ND	-	ND	ND	188.6	-
Fluoride (F)	0.10	63	60	96	50	65	48	29	25
Lead (Pb)	0.005	-	-	ND	-	-	-	2.0	-
Mercury (Hg)	0.0005	-	-	-	-	-	-	-	-
Calcium (Ca)	0.05	0.16	2.00	0.30	2.50	0.10	0.20	ND	0.30
Arsenic (As)	0.008	-	-	ND	-	ND	ND	ND	-

TABLE 2- WATER QUALITY DATA: NORTH EAST OLKARIA WELLS, CONTINUED.
(All results in mg/l and analysis performed on filtrates)

	Detectable Limits	OW-709	OW-710	OW-711	OW-712	OW-713	OW-714	OW-715	OW-716
pH	0.01	9.45	9.32	-	8.99	-	9.57	9.79	7.78
TDS		-	2108	2478	-	-	2292	-	2884
Boron (B)	0.01	5.5	1.2	1.4	-	-	-	-	8.3
Chloride (Cl)	0.1	786	519	570	31	-	633	-	863
Sodium (Na)	0.01	830	505	600	478	520	650	522	554
Potassium (K)	0.01	213	99	112	81	80	120	108	115
Silicon (Si)	0.01	289	320	420	298	343	210	297	385
Magnesium (Mg)	0.01	ND	ND	0.01	ND	0.03	ND	ND	ND
Ammonia (NH_4)	0.01	-	-	1.0	-	1.3	-	-	-
Zinc (Zn)	0.01	-	-	-	0.01	70.6	1.8	-	21.0
Chromium (Cr)	0.001	-	-	0.007	-	0.007	ND	-	ND
Iron (Fe)	0.01	-	-	0.015	-	59.0	94.5	-	900.0
Fluoride (F)	0.01	164	53	120	46	51	56	26	47
Lead (Pb)	0.001	-	-	0.03	-	2.3	1.0	-	16.6
Mercury (Hg)	0.001	-	-	0.001	-	0.001	-	-	-
Calcium (Ca)	0.01	ND	ND	2.1	ND	2.1	ND	ND	ND
Arsenic (As)	0.001	-	-	0.14	-	ND	ND	-	ND

TABLE 3- WATER QUALITY DATA: NORTH EAST OLKARIA WELLS, CONTINUED.
(All results in mg/l and analysis performed on filtrates)

	Detectable Limits	OW-717	OW-718	OW-719	OW-720	OW-721	OW-722	OW-723	OW-724
pH	0.01			9.4	9.3	9.6			
TDS				-	-	-			
Boron (B)	0.01			-	-	-			
Chloride (Cl)	0.1			575	536	586			
Sodium (Na)	0.01			608	549	667			
Potassium (K)	0.01			92.2	68.7	112			
Silicon (Si)	0.01			255	255	296			
Magnesium (Mg)	0.01			0.08	0.07	0.05			
Ammonia (NH_3)	0.01			0.34	0.50	0.62			
Zinc (Zn)	0.01			0.83	0.01	<0.01			
Chromium (Cr)	0.001			-	-	-			
Iron (Fe)	0.01			5.90	2.40	6.00			
Fluoride (F)	0.01			92.7	106.9	90.8			
Lead (Pb)	0.001			<0.001	0.006	<0.001			
Mercury (Hg)	0.001			-	-	-			
Calcium (Ca)	0.01			0.12	0.09	0.04			
Arsenic (As)	0.001			<0.001	0.455	<0.001			

Appendix 6.10 - Archaeological Data

Sheet 133/3 - Sakutiek - G + Ji

1. Site Name - Ndabibi Estate LR 10998
   Sases # - G+Ji/1
   Coordinates - AK 887 144
   Map Scale - 1:50 000
   Latitude - 0° 46' 22"
   Longitude - 36° 12' 12"E
   Functional type - Habitational
   Cultural Identity - pottery LSA
   Position of site and surroundings - on the edge of a channel on a flood plain covered with grass and scattered bush.
   Material observed - Obsidian

2. Site Name - Ndabibi Estate LR 10998
   Sases # - G+Ji/2
   Coordinates - AK 932 152
   Map Scale - 1:50 000
   Latitude - 0° 46' 00"S
   Longitude - 36° 14' 40"E
   Cultural Identity - LSA
   Functional type - occupation
   Position of site and surroundings - open grassland
   Material observed - scrapers, backed pieces

3. Site Name - Ndabibi Estate
   Sases # - G+Ji/3
   Coordinates -
   Map Scale - 1:50 000
   Latitude - 0° 45' 57"S
   Longitude - 36° 14' 14"E
   Functional type - Habitational
   Cultural Identity - LSA (pottery early pastoral)
   Position of site and surroundings - on a low, NSW trending ridge (probably a cindar cone remnant)
   Material observed - pottery, waste

Sheet 133/4 - Longonot - GtJj

1.	Site Name	-	GtJj/4
	Sases #	-	BK 140110
	Functional type	-	Habitational
	Cultural Identity	-	LSA
	Position of site and surroundings	-	tools eroding from an airfall ash above a lucustrine bed, along an erosional wash trending NW
	Material observed	-	informal tools and waste
2.	Site Name	-	Crescent Island
	Sases #	-	GtJj/2
	Coordinates	-	112146
	Map Scale	-	1:50 000
	Functional type		
	Cultural Identity		
	Position of site anc surroundings	-	site lies on an island with the same name in Lake Naivasha
	Material observed	-	stone bowls, fragments, pestle, rubbers, grindstones, hippo tooth, animal bones, a polished stone axehead and lithic artifacts and waste.
3.	Site Name	-	Sanctuary farm
	Sases #	-	GtJj/3
	Coordinates	-	BK 118 138
	Latitude	-	0° 46' 42"
	Longitude	-	36° 24' 39"E
	Map scale	-	1:50 000
	Functional type	-	Habitational
	Cultural Identity	-	LSA (pottery, early pastoral)
	Position of site anc surroundings	-	elevation 62 000' in a causeway connecting the mainland to Crescent Island
	Material observed	-	waste, informal tools
4.	Site Name	-	Ndabibi LR 10250/R
	Sases #	-	GtJj/5
	Coordinates	-	AK 946 118
	Map Scale	-	1:50 000
	Functional type	-	factory
	Cultural Identity	-	LSA
	Position of site anc surroundings	-	appears on eastern side of slope to crest of hill. Approximately 100 mt from road
	Material observed	-	mainly waste material

5.	Site Name	-	Ndabibi Estate LR 10998
	Sases #	-	GtJj/6
	Coordinates	-	AK 944 112
	Map Scale	-	1:50 000
	Latitude	-	0° 48' 10"S
	Longitude	-	36° 15' 22"E
	Functional type	-	Habitational
	Cultural Identity	-	LSA (Kenya Capsian)
	Position of site and surroundings	-	in grassy swabs trending EW E162 90' or 1965M
	Material observed	-	obsidian waste and flakes
		-	some water worn flakes and
		-	obsidian cobbles
6.	Site Name	-	Ndabibi Estate LR 10250/R
	Sases #	-	GtJj/7
	Coordinates	-	AK 951 118
	Map Scale	-	1:50 000
	Latitude	-	0° 46' 05"S
	Longitude	-	36° 15' 35"E
	Functional type	-	complex
		-	occupation factory,
		-	quarry, burial
	Cultural Identity	-	LSA, early pastoral, pottery
	Position of site and surroundings	-	north area - grass covered knoll, south area - eroded under cone grass, some fever trees and bush
	Material observed	-	north area - debitage
		-	south area - cones-debitage
		-	Sirikwa hole caims
7.	Site Name	-	Makaa
	Sases #	-	GtJj/16
	Coordinates	-	AK 967 149
	Map Scale	-	1:50 000
	Latitude	-	0° 46' 07"S
	Longitude	-	36° 16' 29"E
	Functional type	-	open habitational
	Cultural Identity	-	LSA with pottery
	Position of site and surroundings	-	open area, short grass - surrounded by acacia trees
8.	Site Name	-	Rema Island
	Sases #	-	GtJj/15
	Coordinates	-	AK 976 167
	Map Scale	-	1:50 000
	Latitude	-	0° 45' 10"S
	Longitude	-	38° 17' 01"E
	Functional type	-	Habitational
	Cultural Identity	-	LSA with pottery

Position of site and surroundings	-	covers the island and open area adjacent to the hippo pool
Material observed	-	bones, decorated potsherds
	-	lots of Obsidian, quarry ground stones
	-	burnt earth

1.

Site Name	-	Marmonet I
Sases #	-	GtJi/7
Coordinates	-	AK 881 165
Map Scale	-	1:50 000
Latitude	-	0° 45' 18"S
Longitude	-	36° 11' 52"E
Functional type	-	Habitational
Cultural Identity	-	Elementaita
Position of site and surroundings	-	crest and west slope of hill currently under wheat, part of pasture cycle
Material observed	-	devise scatter of obsidian some pottery, bone chesh

1.

Site Name		
Sases #		
Coordinates		
Map Scale	-	1:50 000
Latitude	-	0° 45' 30"
Longitude	-	36° 12' 0"
Functional type	-	rock shelter
Cultural Identity	-	LSA (Neolithic) W pottery
Position of site and surroundings	-	SE facing volcanic rockfall shelter formed in pyroclastic agglomerate

6.

Site Name	-	Ngunyumu I
Sases #	-	GtJi/16
Coordinates	-	AK 883 093
Map Scale	-	1:50 000
Latitude	-	0° 49' 15"
Longitude	-	36° 12' 0"E
Functional type	-	Habitational
Cultural Identity	-	Neolithe
Position of site and surroundings	-	on east side of N/S trending ridge at north end of ridge on moderate slope. Vegetation - Tarchonanthus, Acacia drepanolobium
Material observed	-	flaked stone, pottery, teeth and bones

7.	Site Name	-	
	Sases #	-	GtJi/17
	Coordinates	-	AK 884 074
	Map Scale	-	1:50 000
	Latitude	-	
	Longitude	-	
	Functional type	-	iron furnace
	Cultural Identity	-	Iron Age
	Position of site and surroundings	-	one edge of incised stream channel in path opposite mouth of GtJi/12 (Enkapuneya Muto at base of very steep section of Mau escarpment)
	Material observed	-	charcoal, burnt earth, soil bumps
8.	Site Name	-	Ndabibi crater west
	Sases #	-	GtJi/18
	Coordinates	-	901170
	Latitude	-	0° 45' 0"
	Longitude	-	36° 13' 0"
	Map Scale	-	1:50 000
	Cultural Identity	-	LSA with pottery
	Functional type	-	Habitational
	Position of site and surroundings	-	on light rise, west slope, on side of irregular elongate crater in centre
	Material observed	-	flaked obsidian, undercoated pottery
9.	Site Name	-	Ndabibi 2
	Sases #	-	GtJ1/19
	Coordinates	-	AK 890 143
	Map Scale	-	1:50 000
	Functional type	-	Habitational
	Cultural Identity	-	Neolithic
	Position of site and surroundings	-	flat open plain adjacent to sink hole in fields under mechanised cultivation for wheat
	Material observed	-	obsidian, pottery bones
10.	Site Name	-	Ndabibi 3
	Sases #	-	GtJ1/20
	Coordinates	-	AK 892 136
	Map Scale	-	1:50 000
	Latitude	-	
	Longitude	-	
	Functional type	-	Habitational
	Cultural Identity	-	Neolithic

	Position of site and surroundings	-	occasional aardvak burrows, eroded road cut and cattle track
	Material observed	-	flaked stone, pottery, some well preserved bones found in-site
11.	Site Name	-	Olgos Orok 1
	Sases #	-	GtJi/21
	Coordinates	-	AK 927 130
	Map Scale	-	1:50 000
	Latitude	-	0° 47' 12"
	Longitude	-	36° 14' 20"E
	Functional type	-	Habitational/quarry
	Cultural Identity	-	LSA with pottery
	Position of site and surroundings	-	east facing slope in light Acacia xanthophoea/lelshwa woodland
	Material observed	-	pottery, bones, unprecedented quantities of obsidian debitage
12.	Site Name	-	Ndabibi 4
	Sases #	-	GtJi/22
	Coordinates	-	AK 934 153
	Map Scale	-	1:50 000
	Latitude	-	
	Longitude	-	
	Functional type	-	Habitational
	Cultural Identity	-	LSA with pottery
	Position of site and surroundings	-	between two low outcrops of very poor quality obsidian marked on geological (maps) scatter extends around both hillocks
	Material observed	-	flaked stones, pottery
13.	Site Name	-	Ndabibi 5
	Sases #	-	GtJi/23
	Coordinates	-	AK 929 140
	Map Scale	-	1:50 000
	Functional type	-	Habitational
	Cultural Identity	-	Neolithic, Savanna
	Position of site and surroundings	-	on slight rise in rolling open (secondary) grassland plains
	Material observed	-	flaked stone very abundant, bones fragments
14.	Site Name	-	Ndabibi
	Sases #	-	GtJi/24
	Coordinates	-	AK 903 121

Map Scale	-	1:50 000
Functional type	-	Habitational
Cultural Identity	-	Neolithic
Position of site and surroundings	-	on western about 60 cm facing Gathe slope on edge of flat open plains with open bush grassland
Material observed	-	Obsidian tools, pottery

Naivasha Sheet 133/2 GSjj

3.

Site Name	-	Robin Morgan LR 10995
Sases #	-	GSJj/4
Coordinates	-	AK 958 323
Map Scale	-	1:50 000
Latitude	-	0° 36' 41"S
Longitude	-	36° 16' 03"E
Functional type	-	Habitational
Cultural Identity	-	Iron Age
Position of site and surroundings	-	elevation M7600' grass cover, scattered bush
Material observed	-	waste

4.

Site Name	-	Morgan Robin (LR 10995)
Sases #	-	GSJj/15
Map Scale	-	1:50 000
Latitude	-	0° 35' 30"
Longitude	-	36° 16' 58"E
Functional type	-	Habitational
Cultural Identity	-	MSA (Stillbay)
Position of site and surroundings	-	elevation 6875' on an erosional wash surface scattered bush

5.

Site Name	-	A cole LR 9361/5
Sases #	-	GSJj/6
Coordinates	-	AK 982 358
Map Scale	-	1:50 000
Latitude	-	0° 34' 49"
Longitude	-	36° 17' 20"E
Functional type	-	Habitational
Cultural Identity	-	pottery, early pastoral
Position of site and surroundings	-	in basin formed by recent basaltic flows with black faulting

6.

Site Name	-	Arthur Cole LR 9361/5
Sases #	-	GSJj/7
Coordinates	-	AK 977 365
Map Scale	-	1:50 000
Latitude	-	0° 34' 23"S

	Longitude	- 36° 17′ 04"E
	Functional type	- Habitational
	Cultural Identity	- MSA Stillbay
	Position of site and surroundings	- elevation 6650′ on an erosional wash surface
	Material observed	- waste, cones, informal tools
7.	Site Name	- Marula Estate LR 11313
	Sases #	- GSJj/22
	Coordinates	- BK 022 290
	Latitude	- 0° 38′ 30"S
	Longitude	- 36° 19′ 30"E
	Functional type	- Habitational
	Cultural Identity	- MSA (still bay) LSA (?)
	Position of site and surroundings	- elevation 6725′ around a dam on an erosional surface in a barrow area
	Material observed	- waste and informal tools
8.	Site Name	- Marula Estate LR 421-1
	Sases #	- GSJj/24
	Coordinates	- BK 026 288
	Map Scale	- 1:50 000
	Latitude	- 0° 38′ 35"S
	Longitude	- 36° 20′ 18"E
	Functional type	- Habitational
	Cultural Identity	- LSA (pottery)
	Position of site and surroundings	- below escarpment just East of Masaai Gorge elevation 6450′
	Material observed	- waste, informal tools, blades
9.	Site Name	- Marula Estate LR 11313
	Sases #	- GSJj/25
	Coordinates	- BK 032 294
	Map Scale	- 1:50 000
	Latitude	- 0° 38′ 17"
	Longitude	- 36° 20′ 03"E
	Functional type	- Habitational
	Cultural Identity	- pottery (LSA)
	Position of site and surroundings	- on west side of gorge at head of gorge elevation - 6675′
	Material observed	- tools and waste
10.	Site Name	- M Kangari (LR 420/4)
	Sases #	- GSJj/29
	Coordinates	- BK 031 267
	Latitude	- 0° 40′ 20"
	Longitude	- 36° 19′ 55"E
	Map Scale	- 1:50 000
	Functional type	- Habitational

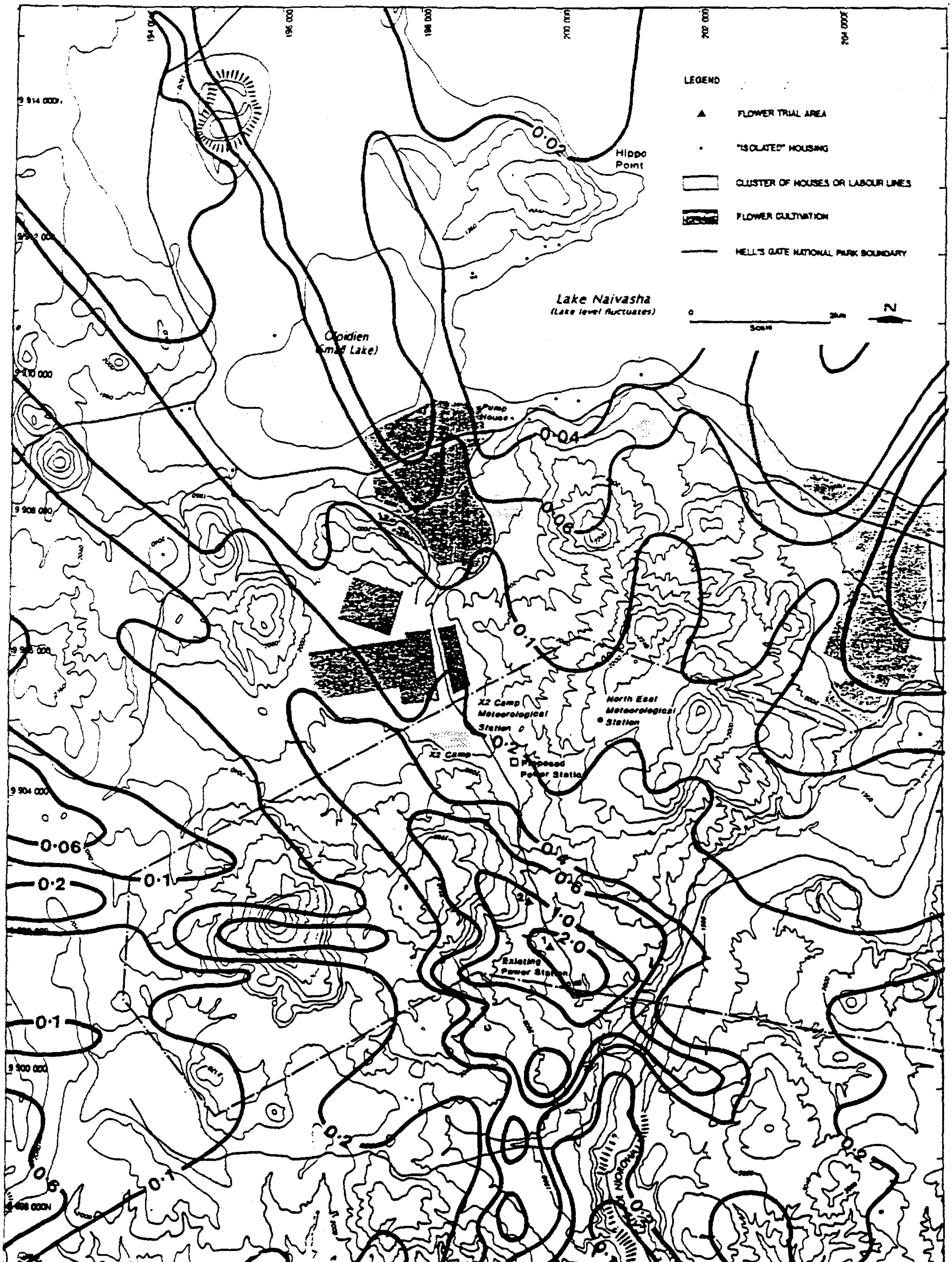
	Cultural Identity	-	LSA (Kenya capsian) pottery
	Position of site and surroundings	-	in river at gully
	Elevation	-	6400'
11.	Site Name	-	Marula Estate LR 420/2
	Sases #	-	GSJj/30
	Coordinates	-	BK 028 275
	Latitude	-	0° 39' 30"
	Longitude	-	36° 19' 15"
	Map Scale	-	1:50 000
	Functional type	-	Habitational
	Cultural Identity	-	LSA (pottery)
	Position of site and surroundings	-	in the foot hills above and NW of river cut on small colluvial plateau on ridge top
	Material observed	-	debitage and broken flakes of obsidian
12.	Site Name	-	Marual Estates LR 11313
	Sases #	-	GSJj/37
	Map Scale	-	1:50 000
	Coordinates	-	BK 015 292
	Latitude	-	0° 38' 24"S
	Longitude	-	36° 19' 08"E
	Functional type	-	open site
	Cultural Identity pastoralists	-	LSA w/pottery, early
	Position of site and surroundings	-	on broad bench north of Masaai Gorge along track leading eastward from the Eburru Road
	Material observed grindstones	-	pottery, tools, pottery
13.	Site Name	-	LR 418
	Sases #	-	GSJj/45
	Coordinates	-	00.0 23.5
	Latitude	-	0° 41' 30"S
	Longitude	-	36° 18' 18"E
	Map Scale	-	1:50 000
	Functional type	-	workshop and quarry
	Cultural Identity	-	MSA, LSA w/pottery
	Position of site and surroundings	-	on north western flank of prominent hill to south east or North Lake Road
	Material observed	-	stone tools, pottery
14.	Site Name	-	Eburru Quarry Site
	Sases #	-	GSJj/50
	Coordinates	-	AK 943 302
	Map Scale	-	1:50 000
	Latitude	-	0° 37' 58"S

Longitude	-	36° 15' 10"E
Functional type	-	quarry/habitational
Cultural Identity	-	Elementatita
Position of site and surroundings	-	on NE slope in recently cleared forest on Mt Eburru
Material observed (quarry)	-	bone, pottery, rare debris

15.

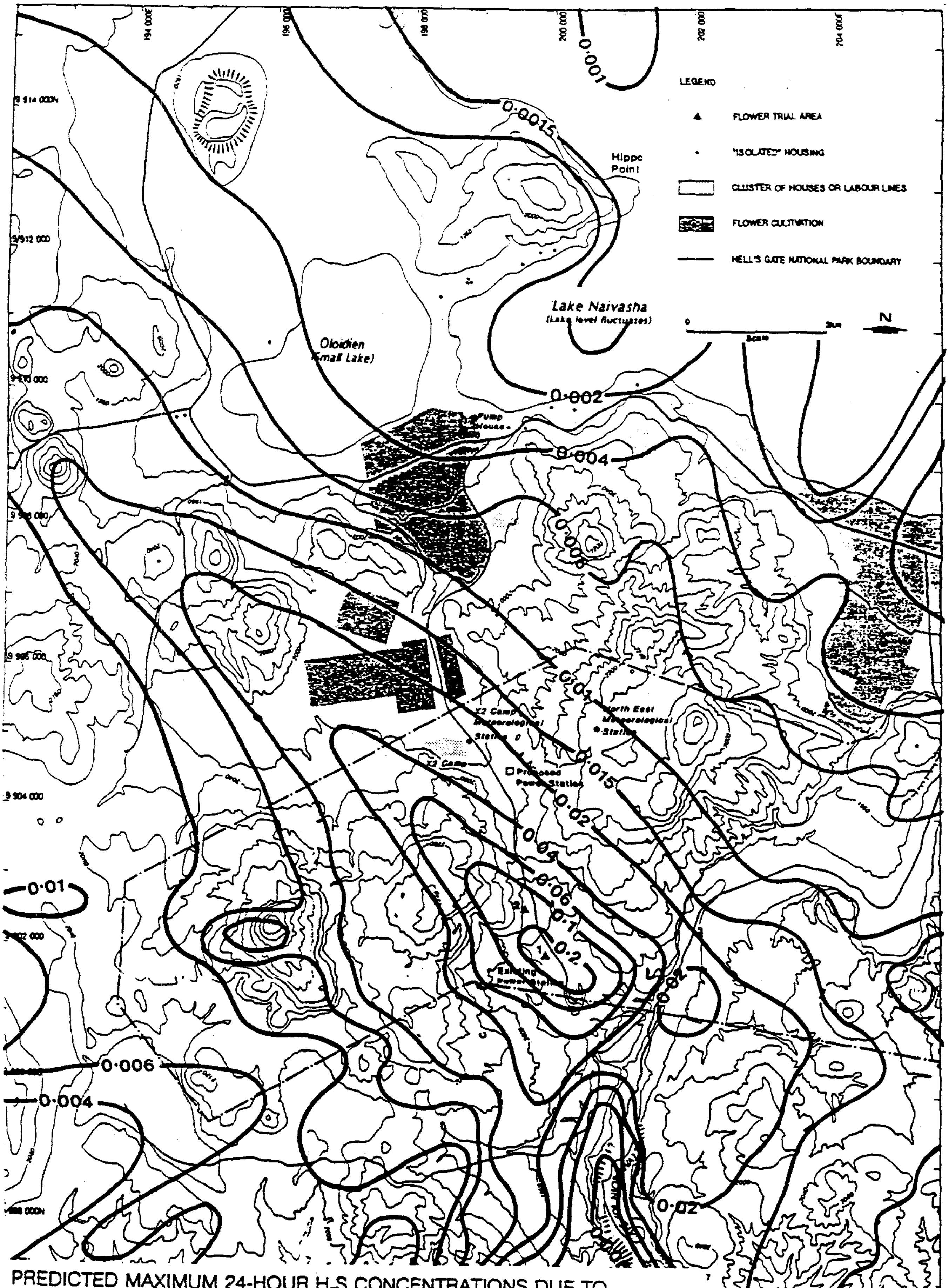
Site Name	-	Karongo Farm West campsite
Sases #	-	GSJj/51
Coordinates	-	AK 962 184
Map Scale	-	1:50 000
Latitude	-	0° 44' 12"
Longitude	-	36° 16' 15"E
Functional type	-	Habitational
Cultural Identity	-	Late Iron Age
Position of site and surroundings	-	top of ridge with eastern exposure between shallow drainage lines, vegetation is leleshwa scrub with dry thicket element

Appendix 7.4- Predicted Ground-Level Concentration of Hydrogen Sulphide



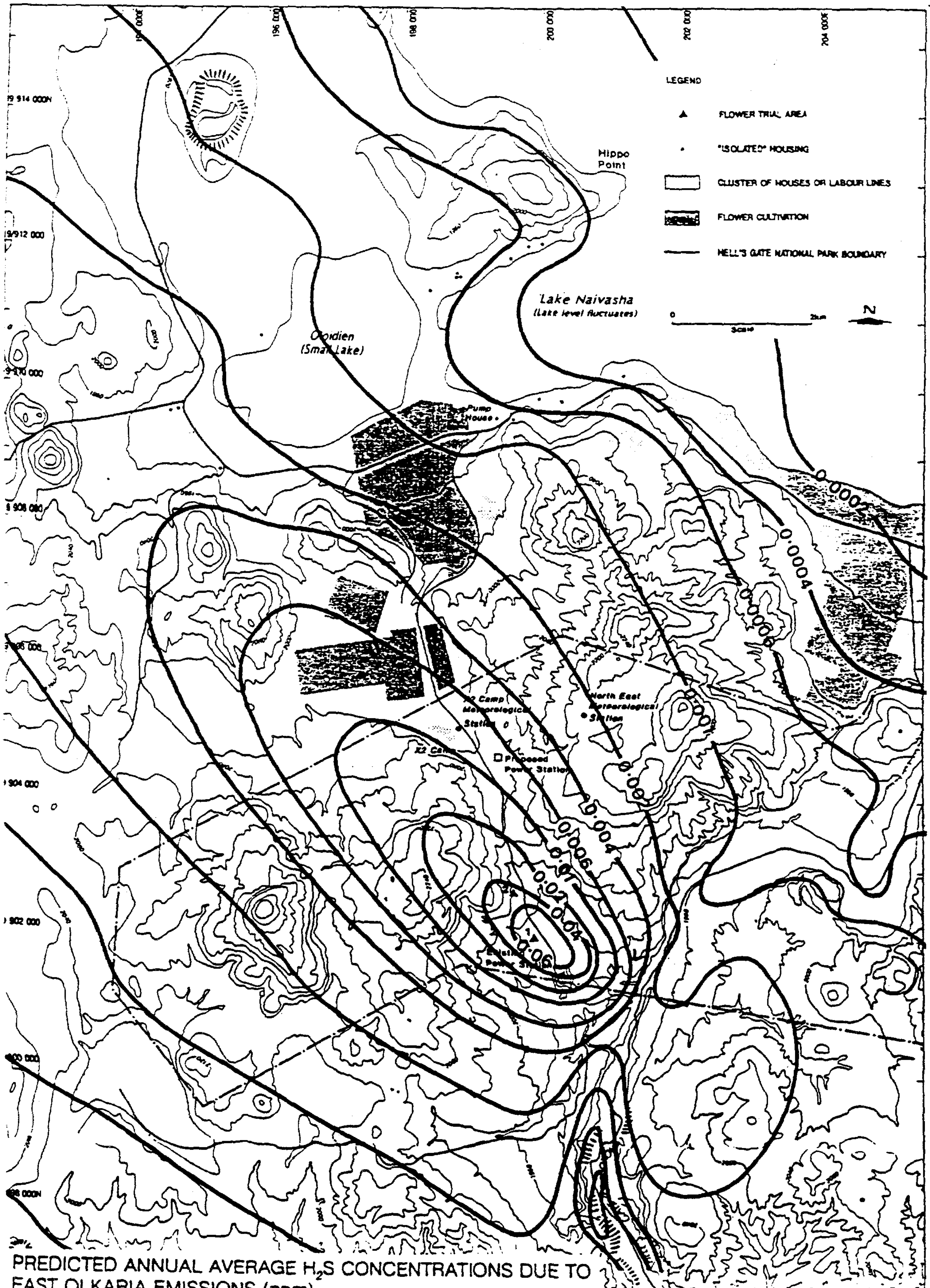
PREDICTED MAXIMUM 1-HOUR H_2S CONCENTRATIONS DUE TO EAST OLKARIA EMISSIONS (ppm)

FIGURE 1.



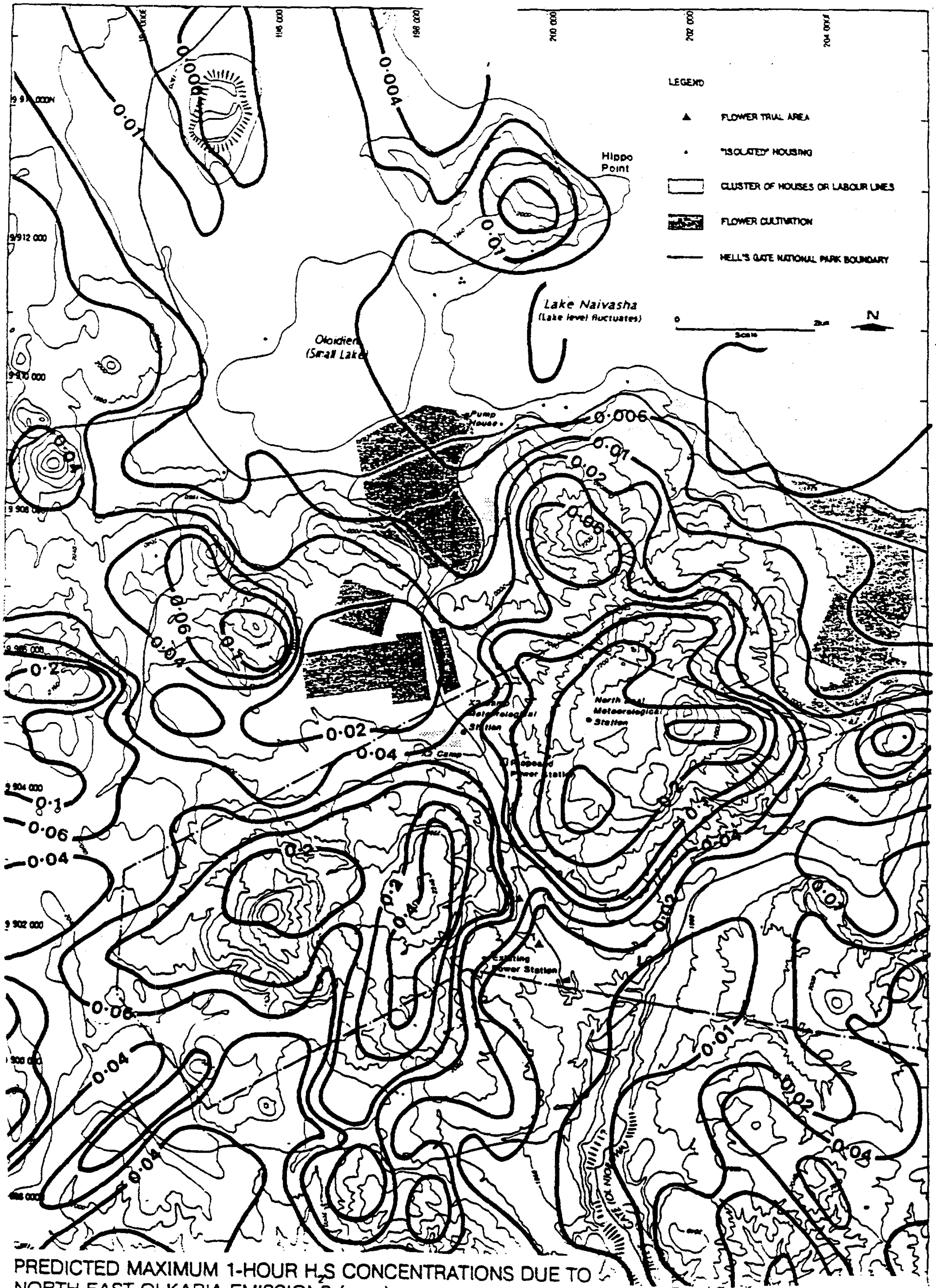
PREDICTED MAXIMUM 24-HOUR H_2S CONCENTRATIONS DUE TO EAST OLKARIA EMISSIONS (ppm)

FIGURE 2



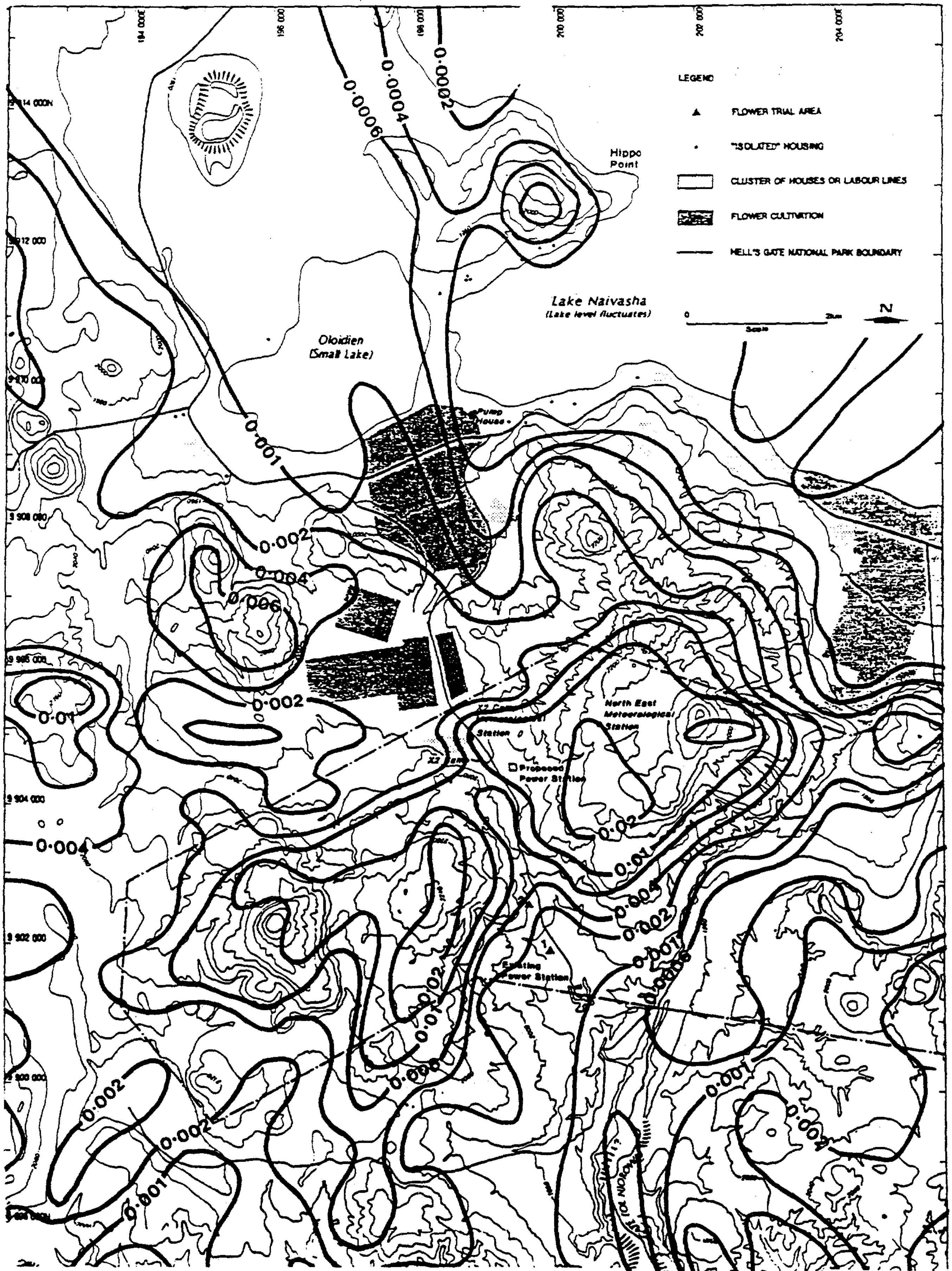
PREDICTED ANNUAL AVERAGE H_2S CONCENTRATIONS DUE TO EAST OLKARIA EMISSIONS (ppm)

FIGURE 3



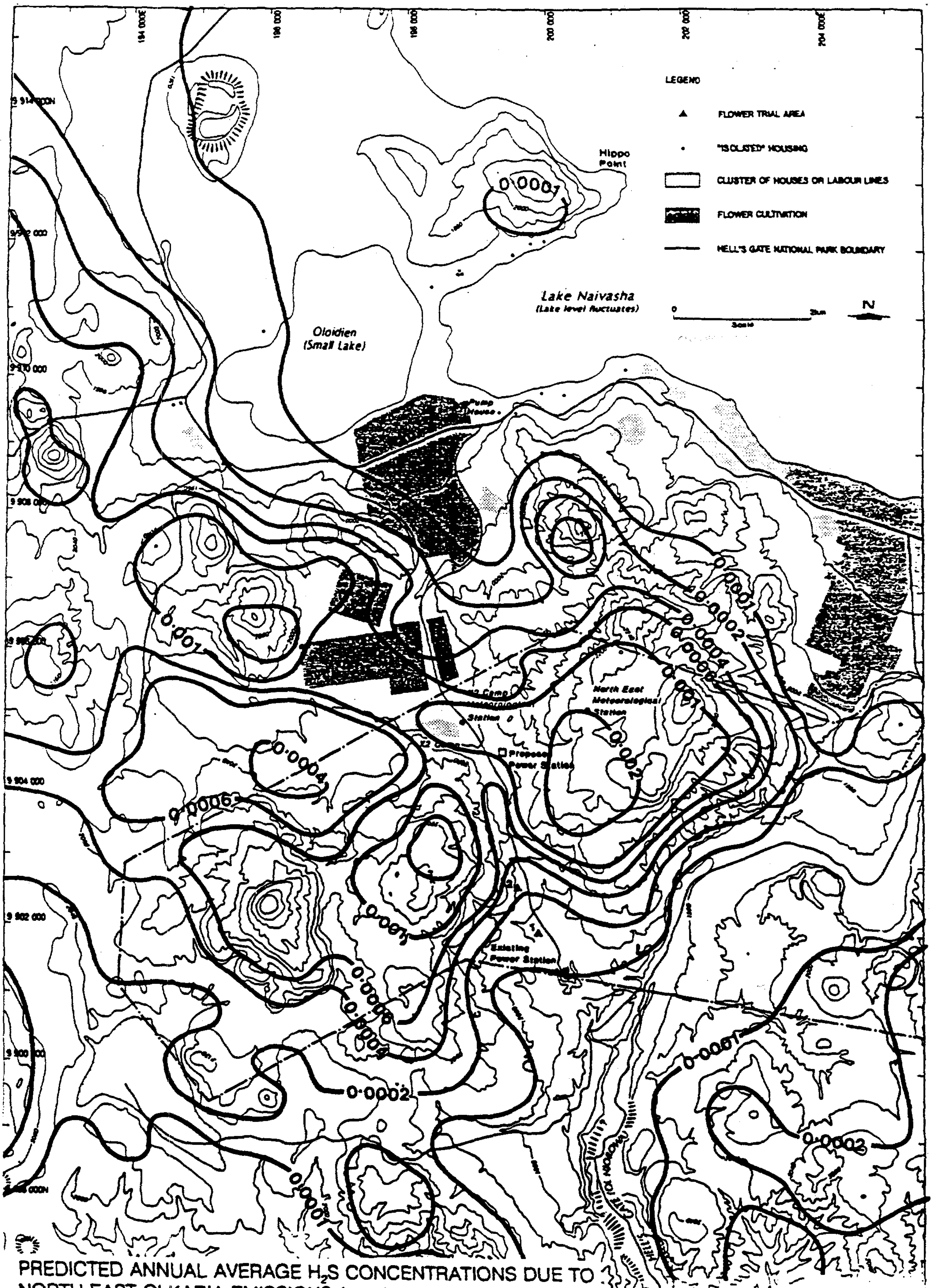
PREDICTED MAXIMUM 1-HOUR H_2S CONCENTRATIONS DUE TO NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 4



PREDICTED MAXIMUM 24-HOUR H_2S CONCENTRATIONS DUE TO NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 5



PREDICTED ANNUAL AVERAGE H_2S CONCENTRATIONS DUE TO NORTH EAST OLKARIA EMISSIONS (ppm)

FIGURE 6