GIBB

E-186
Vol. 3

JORF LASFAR POWER PLANT

ASH DISPOSAL SITE DEVELOPMENT

PHASE 2B - DESIGN OF LONG TERM SITE

INTERIM REPORT

NOVEMBER 1996
This report, and information or advice which it contains, is provided by GIBB solely for internal use and reliance by its Client in performance of GIBB's duties and liabilities under its contract with the Client. Any advice, opinions, or recommendations within this report should be read and relied upon only in the context of the report as a whole. The advice and opinions in this report are based upon the information made available to GIBB at the date of this report and on current UK standards, codes, technology and construction practices as at the date of this report. Following final delivery of this report to the Client, GIBB will have no further obligations or duty to advise the Client on any matters, including development affecting the information or advice provided in this report. This report has been prepared by GIBB in their professional capacity as Consulting Engineers. The contents of the report do not in any way, purport to include any matter of legal advice or opinion. This report is prepared in accordance with the terms and conditions of GIBB's contract with the Client. Regard should be had to these terms and conditions when considering and/or placing any reliance on this report. Should the Client wish to release this report to a Third Party for that party's reliance, GIBB may, at its discretion, agree to such release provided that:

(a) GIBB's written agreement is obtained prior to such release, and

(b) By release of the report to the Third Party, that Third Party does not acquire any rights, contractual or otherwise, whatsoever against GIBB and GIBB, accordingly, assume no duties, liabilities or obligations to that Third Party, and

(c) GIBB accepts no responsibility for any loss or damage incurred by the Client or for any conflict of GIBB's interests arising out of the Client's release of this report to the Third Party.
CMS GENERATION CO. &
ABB ENERGY VENTURES INC.

JORF LASFAR POWER PLANT

ASH DISPOSAL SITE DEVELOPMENT

PHASE 2B
DESIGN OF LONG TERM SITE
INTERIM REPORT

November 1996

J96291B

Revision 0
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EXECUTIVE SUMMARY</td>
<td></td>
</tr>
<tr>
<td>1-1</td>
<td>INTRODUCTION</td>
<td>1-1</td>
</tr>
<tr>
<td>2</td>
<td>REGIONAL AND SITE CHARACTERISTICS</td>
<td>2-1</td>
</tr>
<tr>
<td>2.1</td>
<td>Regional Physiography and Geology</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2</td>
<td>Historical Summary of Port Quarry</td>
<td>2-2</td>
</tr>
<tr>
<td>2.3</td>
<td>Topography of Port Quarry</td>
<td>2-3</td>
</tr>
<tr>
<td>2.4</td>
<td>Geological and Hydrogeological Conditions at the Site</td>
<td>2-4</td>
</tr>
<tr>
<td>2.5</td>
<td>Groundwater and Site Sensitivity</td>
<td>2-9</td>
</tr>
<tr>
<td>3</td>
<td>METEOROLOGICAL DATA</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1</td>
<td>General</td>
<td>3-1</td>
</tr>
<tr>
<td>3.2</td>
<td>Rainfall</td>
<td>3-1</td>
</tr>
<tr>
<td>3.3</td>
<td>Temperature</td>
<td>3-1</td>
</tr>
<tr>
<td>3.4</td>
<td>Wind</td>
<td>3-2</td>
</tr>
<tr>
<td>4</td>
<td>WASTE STREAM</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1</td>
<td>Waste Stream</td>
<td>4-1</td>
</tr>
<tr>
<td>5</td>
<td>SITE END USE</td>
<td>5-1</td>
</tr>
<tr>
<td>5.1</td>
<td>Site End Use</td>
<td>5-1</td>
</tr>
<tr>
<td>6</td>
<td>CONCEPTUAL DESIGN</td>
<td>6-1</td>
</tr>
<tr>
<td>6.1</td>
<td>General</td>
<td>6-1</td>
</tr>
<tr>
<td>6.2</td>
<td>Voidspace and Landform</td>
<td>6-1</td>
</tr>
<tr>
<td>6.3</td>
<td>Settlement and Compaction Requirements</td>
<td>6-2</td>
</tr>
<tr>
<td>6.4</td>
<td>Operational Lifetime</td>
<td>6-3</td>
</tr>
<tr>
<td>6.5</td>
<td>Site Preparation and Design</td>
<td>6-3</td>
</tr>
<tr>
<td>6.6</td>
<td>Site Access and Facilities</td>
<td>6-5</td>
</tr>
<tr>
<td>6.7</td>
<td>Site Restoration</td>
<td>6-6</td>
</tr>
<tr>
<td>7</td>
<td>OPERATIONAL PROCEDURE</td>
<td>7-1</td>
</tr>
<tr>
<td>7.1</td>
<td>General</td>
<td>7-1</td>
</tr>
<tr>
<td>7.2</td>
<td>Bund and Lagoon Construction</td>
<td>7-1</td>
</tr>
<tr>
<td>7.3</td>
<td>Ash Conditioning</td>
<td>7-1</td>
</tr>
<tr>
<td>7.4</td>
<td>Placement Method</td>
<td>7-2</td>
</tr>
<tr>
<td>7.5</td>
<td>Dust Control</td>
<td>7-4</td>
</tr>
<tr>
<td>7.6</td>
<td>Monitoring</td>
<td>7-4</td>
</tr>
</tbody>
</table>
3.3 Mean and Maximum Temperatures For Safi

8.1 Cost Estimate

Plates

2.1 Port Quarry Entrance and Stockpiled Soil Overburden and Marl Waste
2.2 Port Quarry Panorama Viewed Northwards
2.3 Backfilled Soil Overburden on Western Side of Quarry
2.4 Logged Section of the Lower and Upper Quarry Faces
2.5 Oil Contamination on Northern Side of Quarry
2.6 Oil Residue Deposited Following Recession of Surface Water
EXECUTIVE SUMMARY

GIBB Phase 1 studies recommended the Port Quarry, located some six kilometres from the Jorf Lasfar Power Plant, as the preferred location for the long term disposal of ash. Desk studies, reconnaissance-level engineering geological mapping, and some limited soil/groundwater sampling and testing have now been carried out. No new topographical survey and no new intrusive investigations were able to be carried out at this stage. Interpretation of the available data has been undertaken, and our preliminary findings are presented in this Interim Report.

We consider the site to be feasible for the long term disposal of ash to land by the haul and tip method. The site is considered to be sensitive with respect to any potential groundwater impacts. However, disposal to the site will have minimal impact on groundwater, providing that certain engineering works are undertaken and operational controls are put in place.

In combination with ash disposal at the Intermediate Site (refer to GIBB report, entitled "Phase 2A, Intermediate Site, Final Design Report" of November 1996), the Long Term Site will be able to accommodate the CMS/ABB minimum requirement of thirty years of ash production. A layout of the Long Term Site and a restoration drawing are included in this report, together with preliminary design details. Operational and monitoring requirements are outlined. A preliminary cost estimate and implementation schedule have also been prepared.

Redevelopment of the Long Term Site for industrial or other uses is considered entirely feasible after disposal operations are completed and provided that adequate controls are applied during ash disposal operations.
1 INTRODUCTION

This report is prepared for CMS Generation Co. (CMS) and ABB Energy Ventures Inc. (ABB) in accordance with Sir Alexander Gibb & Partners Ltd's (GIBB) faxed proposal of work for an interim report on ash disposal at the preferred Long Term (Port Quarry) Site, reference SDC/A110/J96291B of 27 September 1996.

The Long Term Site will not be immediately available. CMS/ABB require an intermediate site for ash disposal with a design life of at least three years from the date of CMS/ABB commencing operation of the Jorf Lasfar Power Plant. An interim report on the design of a separate intermediate site for ash disposal was submitted to CMS/ABB in October 1996.

CMS/ABB require an environmentally sound, long term site for permanent ash disposal which, in combination with the Intermediate Site, provides for a disposal period of at least 30 years. Preliminary conclusions regarding the long term disposal of ash were given in the Phase 1 - Preliminary Studies Report, prepared by GIBB and dated October 1996 (J96291A Rev. 2). The Port Quarry was identified in that report as the favoured site for long term ash disposal and recommendations were made for the necessary Phase 2 studies. The Port Quarry is located some 6 km to the north-east of the Jorf Lasfar Power Plant (see Figures 1.1 and 1.2).

This Interim Report presents findings of the initial Phase 2 studies with particular emphasis given to those topics on which CMS/ABB require advance information prior to completion of design and issue of a final report. These topics include: a conceptual design; a calculation of available voidspace; engineering and operational requirements; a preliminary cost estimate; and a preliminary implementation schedule.

The findings of this report are based upon topographic surveys of the Long Term Site performed in 1982 and 1988 by others, and the results of a drilling investigation performed by Tractebel in 1989. Regional and local desk studies were commissioned on the project area and these data, where applicable, are incorporated in this report. Engineering geological reconnaissance-level mapping of the Port Quarry has been carried out by GIBB. Samples of the groundwater beneath and surrounding the site were taken from a spring and from public wells and have been tested. In addition, tests have been conducted on silt, sand and gravel materials at the site which have the potential for reuse as cover material. Design concepts have been developed, comprising preliminary layouts, voidspace calculations and restoration options. Operational concepts and a preliminary cost estimate have been prepared.

The information provided in this Interim Report is based on the results of the field investigations and desk studies completed to date. Some of the information required to make substantiated conclusions and recommendations was not available for this study. The conclusions and recommendations provided should therefore be considered preliminary in nature. Nevertheless, these are backed up by sufficient information and data as to be useful for planning purposes.
2 REGIONAL AND SITE CHARACTERISTICS

2.1 Regional Physiography and Geology

The Jorf Lasfar Power Station and Port is situated within the El Jadida Province, which extends inland from Azemmour in the north-east to Safi 110 km to the south-west.

The northern boundary coincides with the River Oum Rbia, which rises in the Middle Atlas Mountains, and is tidal near Azemmour (Figure 1.1). The Province is characterised generally by a series of broad plateaux varying in elevation from 125 m to 200 m above mean sea level (AMSL). Jorf Lasfar is located along the western coastal margin of the El Jadida Plateau to the south-west of Mazagan. The western edge of the plateau exhibits a typical karstic terrain at an elevation of 50 to 60 m AMSL some 2 to 5 km inland. This terrain comprises mainly bedded limestones with only a thin soil cover, due to extensive wind erosion.

To the north-west, the ground level falls gradually towards the Atlantic Ocean. A relatively steep slope is developed about 0.5 km from the shoreline and represents a former cliff line of Plio-Quaternary age.

The regional geology of the El Jadida Province comprises a folded Pre Cambrian/Lower Palaeozoic basement overlain successively by Mesozoic, Tertiary and Quaternary strata. The basement, which outcrops in the south of the Province, includes schists, dolomites, siltstones, granites and rhyolitic lavas. The succeeding Triassic basalt lavas and Jurassic sandstones outcrop mainly along the banks of the River Oum Rbia.

The Cretaceous strata are subdivided into a lower division of Neocomian age and an upper division of Cenomanian age. The Neocomian is represented by red calcareous clays which occur north east of Safi and west of Mechra-Benabbou. The Cenomanian (Upper Cretaceous) strata are confined mainly to the El Jadida Plateau. The strata comprise a local basal conglomerate and an overlying sequence represented by calcarenites, marly limestones, marls and quartz sandstones.

The Tertiary strata occur as a broad north-east to south-west trending strip up to 20 km wide which broadens in the vicinity of Safi and comprises mainly sandy marls and red clays. The succeeding Quaternary deposits predominate to the east of the Tertiary outcrop and also occur as a thin strip along the coast. The deposits include uncemented and cemented calcareous dune sands and calcrites, together with alluvial muds along the permanent river courses. The karstic terrain is also characterised by a thin surficial layer of tufa which has been precipitated on much of the limestone outcrop.
2.2 Historical Summary of Port Quarry

The history of limestone extraction at Port Quarry, officially called Jorf Lasfar Quarry, has been determined from the following data sources:

- detailed site reconnaissance undertaken by GIBB in October 1996
- plans of the proposed extraction and operating quarry submitted to the Moroccan Ministry of Public Works and Communications in 1978 and 1982, respectively
- report prepared by Tractebel (1989), which included a then recent plan of the quarry and the results of ground investigations conducted by LPEE in 1975 for the Secondary Ports Authority

Limestone extraction commenced in 1977 at Port Quarry to provide armour stone for the construction of the breakwater at Port Jorf Lasfar. According to plans submitted to the Ministry of Public Works in 1978, the proposed boundaries of the quarry comprised an area of 750 m x 750 m, with the processing plant and site offices being located to the west. Excavation commenced with the removal and stockpiling of soil overburden along the north-south tract to the west of the quarry. A bench was then developed at about 9 m below ground level, remnants of which are still evident in the north-east and north-west corners of the quarry (Figure 2.1). The marly limestones near the top of the upper face, being relatively weak and closely bedded, were unsuitable for their intended usage at Port Jorf Lasfar and were stockpiled to the north-west of the quarry.

The underlying massive marly limestones, however, are strong with widely spaced vertical joints and occur as large equidimensional blocks which were suitable for use as armour stone. Subsequently, a lower face was developed in the crystalline shelly dolomitic limestones which are mainly massive and strong to very strong and hence suitable for the Port construction works. These faces were progressively worked eastwards with the subhorizontal quarry floor at 36 to 40 m AMSL. The summary borehole logs suggest that the interface between the shelly limestones and an underlying marly limestone corresponds to the level of the quarry floor. Exploitation of stronger limestones at greater depths would have necessitated the removal and stockpiling of these marly limestones and groundwater lowering to maintain dry conditions during quarry operations.

A comparison of the quarry plans prepared in 1982 and 1989 indicates that some limited backfilling of the quarry along the south-western and southern faces took place after 1982 (Figure 2.2). This backfill comprises soil overburden and marl waste which was previously stripped from above the usable rock. A comparison of these plans also indicates that limestone extraction between 1982 and 1989 was limited to a 40 m advance of the lower face in the north-east corner of the quarry and hence, active rock quarrying probably ceased soon after 1982.

Since 1989, some reworking and extraction of marl waste has been carried out on a limited scale adjacent to the quarry entrance (Plate 2.1). In addition, localised tipping or dumping of mixed quarry waste, reinforced concrete and limestone boulders has taken place along the western and southern margins of the quarry. A large fenced compound on the western side, possibly used for the storage of vehicular plant and explosives, has also been demolished but
the concrete foundations are still visible. A panoramic view of the Port Quarry is presented as Plate 2.2.

2.3 Topography of Port Quarry

Three topographical surveys are available of the area as follows:

- 1:5 000 scale mapping prepared for the Ministry of Public Works in 1977
- 1:1 000 scale mapping prepared for the Ministry of Public Works in 1982
- 1:2 000 scale mapping prepared for the Office National de L'Electricité (ONE) in 1988

The maximum dimensions of the quarry are about 700 m by 700 m and according to the topographic survey in 1988, the total area is 49.5 hectares. The face height from the base to the crest of the quarry varies from about 10.5 m in the north-west to about 18 m in the north-east. The elevation of the quarry floor decreases from 40 m AMSL in the south-east to 36.5 m AMSL in the north, which corresponds to an overall northward gradient of 1 in 185.

The 1982 survey included levelling of the quarry floor at approximately 20 m centres as well as levelling of the surviving remnant of the bench and around the crest of the excavation. The quarry plan presented in the Tractebel report (1989) includes only a few elevations for the floor. Closely spaced levels are recorded, however, at the intersection between the floor and the lower face, along the lower bench and around the quarry perimeter. This later plan also includes the distribution and levels for the backfilled soil overburden (Plate 2.3) and marl waste subsequently placed along the western and southern margins of the quarry. The tipping of quarry waste on the floor and limited excavation of marl waste near the entrance both post-date this most recent plan (Figure 2.2).

A topographic map of the quarry floor has been prepared combining the available information for the purposes of this report. The map incorporates the closely spaced levelling data presented on the 1982 survey. The contours have been interpolated at 0.5 m intervals and transposed onto the 1989 plan. The levels for the quarry floor shown on the 1989 plan are consistent with the earlier interpolated data. The combined plan uses the 1989 data for the quarry faces and perimeter together with the contoured floor, based on the 1982 data. The contours for the quarry floor have been constructed using the software package, Surfer. This combined plan has been used as a base map for plotting a variety of information: geological and hydrological data; the distribution, type and volume of potential borrow materials around the quarry perimeter; estimates of quarry waste on the floor; and the restoration surface. These applications of the base map are discussed in the relevant sections of this report.
2.4 Geological and Hydrogeological Conditions at the Site

2.4.1 General

The geological and hydrogeological conditions at Port Quarry have been determined from the results of previous ground investigations in the area, reconnaissance mapping undertaken by GIBB in October 1996, and subsequent well monitoring.

Ground investigations were carried out by Laboratoire Public d’Essais et d’Etudes (LPEE) in 1975 and comprised 16 cored boreholes, which were drilled to depths up to 38 m and located up to 3.25 km from Port Quarry. Ten piezometers were installed to monitor water levels. Summary geological logs were prepared along three alignments, which indicate that the sequence comprises interbedded limestones, marly limestones and marls, locally overlain by tufa and capped by soil overburden. Fossiliferous and siliceous units were recorded, together with crystalline limestones. The sequence is dominated by fractured and permeable limestones and marly limestones, which represent the local aquifer, whilst marls were only encountered in three boreholes. Marls or marly limestones, which occur in the deeper boreholes, may be relatively impermeable compared to the underlying rock types and therefore may represent a local aquiclude.

The summary logs indicate a lack of lithological continuity between boreholes which may be due to:

- lateral facies changes and/or erosion during accumulation of the carbonate deposits
- tectonic displacements along faults
- inconsistent identification of carbonate rocks

The geological and hydrogeological reconnaissance was undertaken by GIBB to determine:

- the accuracy of existing topographic surveys (as described in Section 2.3)
- the sequence of lithologies and their lateral continuity around the quarry
- the location, intensity and orientation of faults, joints and fissures
- the character, distribution and quantities of materials used as backfill around the quarry perimeter and floor
- the distribution of former and existing surface water, together with the location of springs
- the evidence of deleterious materials which may cause potential pollution of the aquifer
2.4.2 Geology of Port Quarry

A representative geological sequence was logged in the south-east corner of the quarry (GR 286.430N, 202.320E). As the majority of the quarry faces are subvertical to vertical, additional geological data was recorded and compiled as a composite summary log (Table 2.1).

The general sequence comprises a lower and an upper division, separated by a slight angular disconformity (Plate 2.4). Quarrying was advanced on two faces, which correspond to these divisions, and the intervening bench coincides with the disconformity.

The lower division comprises mainly moderately strong to strong, thinly bedded, highly fossiliferous, medium and coarsely crystalline dolomites with subordinate, strong, finely crystalline, dolomitic, marly limestones. The coarsely crystalline dolomite is characterised by abundant internal moulds of whole gastropods and lamellibranchs, which indicate dissolution of the hard parts, probably during the dolomitisation process. This replacement of calcium carbonate, probably precipitated as aragonite, by dolomite is accompanied by a volume reduction and a consequent increase in porosity. These limestones also exhibit current bedding with foresets inclined at up to 30°, which suggests deposition within a shallow marine environment. The medium crystalline dolomites include abundant voids due to dissolution of shell fragments rather than whole mollusca. The upper 3 m of this division also includes thickly interbedded units of unfossiliferous finely crystalline dolomitic limestone.

The bedding dip of the lower division varies between horizontal and about 10°, sometimes undulating over this dip range within a few metres. Variations in dip angle and also direction are interpreted to be depositional rather than tectonic in origin. The major joint set of the lower division is perpendicular to bedding and hence subvertical to vertical. The strike of this set averages 220°, which coincides with the orientation of the east and west exposed faces of the quarry. A subsidiary set of vertical joints strike 300 to 330°, which is similar to the trends of the north and south faces. Evidence of slight displacements was recorded along some faults parallel with the trend of the major joint set. The amounts of offset along these faults are minimal and characterised by minor drag folding.

The beds of the upper division are more or less horizontal and are distinguished from the underlying strata by the predominance of marly limestones. In addition, fossiliferous horizons are confined to the basal fine grained dolomitic limestone, which is inferred to be a passage bed or gradational boundary between the divisions. Large open cavities with iron-stained walls commonly occur within this unit. The overlying finely crystalline dolomitised marly limestone is apparently devoid of fossils and contains some vugs partially infilled by calcite. The succeeding unit varies in thickness and comprises interbedded massive finely crystalline and clastic dolomitic marly limestone. The unit is characterised by an erosional base and the variable thickness results from syndepositional slumping and also erosion preceding deposition of the mud clast horizons. The overlying massive dolomitic marly limestone attains a thickness of 3 m and contains numerous small unfilled vugs. The uppermost unit is represented by a similar lithology to that below but is thinly bedded. These marly limestones are apparently of similar thickness around the crest of the quarry.

2.4.3 Surface Water

From observations during the reconnaissance of the quarry, surface water appears to be maintained over part of the quarry surface even during the summer months. The area of surface water increases substantially in the winter months. This behaviour is interpreted as spring-fed surface water ponding, augmented in winter months by rainfall.
The quarry floor is characterised by many depressions up to 250 m in diameter which sometimes contain surface water or, more commonly, indicate former bodies of standing water. Sufficient water is available to support trees up to 2 m in height and a semi-continuous cover of low vegetation. The dry depressions indicate former water depths of about 0.5 m and are sometimes floored by the possible desiccated remains of algal blooms. At the time of the GIBB visit, most of these depressions were dry, presumably due to low rainfall and high rates of evaporation during the summer months.

Existing bodies of standing water up to 0.3 m in depth include two large pools on the eastern side of the quarry, which are divided by the main access track to the primary spring (Figure 2.1). A smaller pool of similar depth occurs on the south-western margin of the quarry floor. The large pools are continuously fed, even in the summer months, by the primary spring, which issues from an excavated hollow at the location indicated in Figure 2.1. The smaller pool in the south-west is thought to represent overflow from the large former pool to the north, and has survived evaporation due to its partially shaded position.

Evidence of former surface water levels within the quarry is also apparent along the northern face. During the reconnaissance, an oil-covered pool, approximately 15 m in diameter and 0.2 m in depth (Plate 2.5), was observed at the location identified on Figure 2.2. Observation indicated that this pool originally extended over an area of approximately 50 m x 20 m with a depth of about 0.6 m. The oil is also associated with miscellaneous waste items, such as tins, plastics, oil filters etc. Evaporation and probably partial burning has reduced the amount of oil and left a tar residue. During the winter months, it is thought that some oil forms an immiscible layer on accumulated surface water in the quarry. As surface water levels recede due to evaporation on a seasonal basis, the oil is deposited on the quarry face and limestone blocks on the floor as a series of bands which correspond to the water surface (Plate 2.6). A study of these band levels indicates a maximum elevation of 38.25 m AMSL corresponding to the maximum standing water level since the oil contamination incident.

Maximum flood levels within the quarry have also been predicted using computer-generated models of the quarry floor for a range of water levels and compared with the distribution of observed existing, and evidence of former, surface water. These data confirm that the maximum flood level since the incident is about 38.25 m AMSL. Figure 2.3 shows contours of the water depth for this flood elevation.

2.4.4 Groundwater

The Port Quarry is excavated within the Cretaceous limestones and marls of the El Jadida Plateau, described in Section 2.1 above. These limestones are the major aquifer of the region.

Available literature suggests the presence of significant groundwater, as confirmed by the presence of local water wells and spring issues, notably "Source de Cap Blanc", which recorded a flow rate of 3 l/s (Ferré and Ruhard, 1975). Tests at Sidi-Bou-Zid near El Jadida, derived permeabilities of 5x10^-3 to 5x10^-4 m/s (Ferré and Ruhard, 1975).

A primary spring, located within the quarry, close to the floor on the eastern side, provides a supply of water for local villagers. During the reconnaissance by GIBB in early October 1996, this spring was flowing at about 5 litres/minute. Evidence of two further springs (presently dry) was observed; one in the south-eastern corner of the quarry, the other to the north-east of the primary spring (Figure 2.1). Although seepage was not apparent, the lower ground in the vicinity supported grassy vegetation. Relatively high moisture contents were also noted at the toe of the slope of the marl waste backfilled along the southern side of the quarry (Figure 2.2). This evidence indicates likely seepage at the intersection of the waste with the quarry floor.
During the ground investigations conducted by LPEE in 1975, a piezometer was installed in borehole S15, located within the confines of Port Quarry but prior to its development. The recorded water level of 38.9 m AMSL corresponds to the elevation of the existing quarry floor at this location.

A simple model of the limestone aquifer underlying the quarry could be used to explain these observations. With the piezometric surface lying at or just below the quarry floor, spring issues form where the quarry floor intersects the water table, some springs drying in summer months as groundwater levels fall. With increased rainfall and a higher water table in the winter, surface drainage is further impaired and spring issues reappear and increase, resulting in significant standing water within the quarry.

However, these observations could also be explained by the presence of a marl aquiclude at the base of the quarry; with springs issuing at the base of the aquifer outcrop (intersection with the aquiclude); and poor drainage due to the possibly low permeability of the underlying material. There is some evidence to support this model, including: marls logged during investigations by LPEE in 1975 (Tractebel, 1989); marl outcrops observed elsewhere in the region; spring issues at the limestone/marl interface on the coast, and a shallow north-westerly dip of the strata (less than 1°). If the marl is present and of a low permeability, these flows may be associated with a perched water table and not the main regional aquifer. As permeability tests were apparently not carried out as part of the 1975 ground investigations, the permeability of the marl is unknown.

Since boreholes have not been drilled at this site during the current investigations, accurate water levels are not available. Depth to water has been measured for the purposes of this study at 14 wells in the vicinity of the quarry and groundwater elevation subsequently estimated, using available mapping, to ± 2 metres. The elevation of the primary spring within the quarry has also been estimated from these maps. Approximate groundwater elevations were also available from earlier investigations at several boreholes (Tractebel, 1989).

Groundwater elevation cannot be defined accurately without intrusive investigations at the site, but available information indicates groundwater flow towards the north-west (Figure 2.4). Consequently, six wells may potentially be affected by any pollutants released as a result of ash placement.

It is therefore recommended that intrusive investigations are undertaken at this site in order to

- prove or otherwise the presence and permeability of a marl aquiclude beneath the site
- prove the presence of the regional aquifer (as opposed to a perched water table)
- record accurate groundwater levels and seasonal fluctuations
- confirm the direction of groundwater flow
2.4.5 Groundwater Chemistry

Electrical conductivity (ECon) measurements have been taken at 14 wells in the vicinity of the Port Quarry in addition to the primary spring located within the quarry and are shown on Figure 2.4. In addition, water samples were taken from two of these wells and the spring for chemical analysis. Table 2.2 presents the results of these analyses, along with results from earlier analyses of groundwater from this area (Tractel, 1989; World Health Organisation (WHO) drinking water guide levels; and typical values for a carbonate aquifer.

Measured pH values are alkaline and typical of carbonate aquifers. This alkalinity is advantageous since it would minimise the mobility of any heavy metals which may potentially be present in future ash placement.

Electrical conductivity measurements provide a measure of the total dissolved solids within the water. This usually represents chloride concentration and, therefore, reflects the salinity. Electrical conductivity levels are elevated at all the wells and the primary spring (Figure 2.4). The primary spring (PQS2), and wells PQ1, PQC4 and PQC6 have conductivities below 3000 μS/cm. These values indicate the water to be brackish and above the WHO drinking water guidelines. However, in rural areas of developing countries, salinity at this level is not considered unhealthy due to the lack of salt in the diet. The primary spring is known to be used extensively as a drinking water source and if the quarry is to be developed for ash disposal an alternative potable source will probably need to be provided. This is further discussed in Section 6.6.

All other samples indicate groundwater to have a salinity considerably above WHO guidelines and can, therefore, be considered to be unpotable. Indeed conductivity levels at PQC1 can be defined as saline (10 000 to 100 000 μS/cm). Salinity levels generally increase towards the coast, as expected. However, there are anomalies within this trend, which may be a function of well depth or sample depth (saline water is more dense and salinity therefore increases with depth in the aquifer) or the presence of a direct conduit, eg. enlarged fissures typical of karstic terrains, between the well and the coast.

Previous groundwater sampling in the area (Tractel, 1989) also indicates elevated salinity levels which were interpreted as connate (trapped ancient) waters, saline intrusion or evaporation of salts onto the aquifer from ocean spray and mists.

A more extensive suite of analyses was carried out on samples taken from the primary spring (PQS2), and wells PQ4 and PQ5. All samples indicate levels of heavy metals below WHO guidelines except for lead and selenium at PQ4 and arsenic at PQ5.

The groundwater samples also indicate elevated levels of potassium, calcium, sulphate and chloride above WHO guidelines. Previous sampling (Tractel, 1989) indicated similarly elevated levels in addition to elevated levels of magnesium, sodium, nitrate and bicarbonate (Table 2.2).

Comparison with levels for typical dolomitic limestone aquifers (Table 2.2) indicates that measured levels of magnesium and bicarbonate are normal. Cations such as magnesium and calcium and corresponding anions bicarbonate and sulphate are commonly added to groundwater by solution from carbonate aquifers (Todd, 1980). Levels of calcium in the samples are higher than would be expected for a typical carbonate aquifer, but this, in conjunction with high levels of sulphate and potassium, indicates the presence of gypsum (Freeze and Cherry, 1979). Gypsum has been noted in exposures within the quarry. High levels of sodium and chlorides are expected where conductivity levels indicate saline water.
Relatively high levels of nitrate are thought to be due to fertiliser application in this rural location (Tractebel, 1989).

---

### 2.5 Groundwater and Site Sensitivity

#### 2.5.1 General

As described in Section 2.4.4, a primary spring, located within the quarry, close to the floor on the eastern side, provides a supply of water for local villagers. Other seasonal and permanent spring-fed surface pools support trees, grass and mixed vegetation, which provide grazing for sheep and cattle.

Sampling indicates that groundwater in the vicinity of the Long Term Site is of generally poor quality. However, this is a function of the rock chemistry and the proximity of the coast and is not especially harmful to public health. The primary spring within the quarry site is used extensively as a potable supply for humans and animals. Water wells to the north-west (down hydraulic gradient of the site) are more saline but are in regular use by villages for domestic washing and agricultural purposes. Utility water is supplied to the region but is not yet well distributed.

Two models are proposed in Section 2.4.4 to explain the observed hydrogeological conditions. The presence of a groundwater aquifer at the base of the placed ash would require some protection measures. The presence of an aquiclude in the quarry floor, however, would naturally reduce the possibility of any leachate movement into the aquifer but would require controlled drainage at the site margins.

Ash is considered a substance with only minor pollution potential but sensible precautions should be taken to protect the groundwater at the site. Typical values for the readily soluble fraction of Furnace Bottom Ash (FBA) and Pulverised Fuel Ash (PFA) are shown in Table 2.2. As can be seen, the soluble fraction of FBA and PFA typically contains some heavy metals, notably arsenic, cadmium, lead, selenium, aluminium, and mercury. Levels of heavy metals are low in the groundwater and any leaching of these metals from the placed ash should be limited so as to maintain levels within WHO guidelines.
3 METEOROLOGICAL DATA

3.1 General

Meteorological data for Safi and Casablanca have been collated by the UK Meteorological Office for approximately 20 years. Intermittent data are also available for El Jadida.

The proposed site lies approximately 2 km inland from the Atlantic Coast, with a natural ground elevation of 50 to 60 m AMSL.

3.2 Rainfall

Table 3.1 presents monthly rainfall totals for a 10 year period at the Safi meteorological station, along with an average monthly and annual rainfall. Average total annual rainfall over the 10 year period is about 300 mm but annual totals can reach 500 mm. Rainfall data from 1933 to 1963 have generated average and maximum annual totals of 360 mm and 700 mm, respectively (Ferre & Bruhard, 1975).

The region has a semi-arid climate with a wetter season from October to March and little rainfall between April and September. Maximum levels of rainfall occur in November and December. These conclusions from the Safi data concur with those presented by Ferre & Bruhard (1975).

During the recorded 10 year period, a maximum monthly total of 203 mm was recorded in November 1988. Examination of the daily data confirms that persistent rain is rare, rain typically falling on less than 8 days per month. When rainfall is persistent, this occurs during the months November to January, with a maximum 18 days of rain per month. During the 10 year data period a maximum daily total rainfall of 70 mm was recorded in November 1988.

The arid environment is subject to frequent mists in spring and autumn. Maximum humidity levels are 100 percent during such misty days and are at a minimum (less than 10 percent) during the hot dry Chergui winds. Humidity is at maximum levels during the evening and night with a minimum between 1200 hrs and 1600 hrs (Ferre & Bruhard, 1975).

3.3 Temperature

Table 3.2 presents 3-hourly mean and maximum temperatures for each month of the year, averaged over the period 1983 to 1995. These data indicate extreme maximum temperatures of up to 46 °C may be expected during late afternoons in July, although mean temperatures remain below 30 °C. Mean temperatures do not fall below 8 °C even during winter nights.

Extreme temperatures are typically achieved during easterly Chergui winds which bring hot, dry air from the Sahara (Ferre & Bruhard, 1975).
3.4 Wind

Data on wind speed and direction is available for Safi for the period 1/1/83 to 31/12/95, subdivided into four seasons: December to February; March to May; June to August and September to November. Wind speed and direction is recorded continuously and the percentage frequency calculated over the 12 year period. The following conclusions can be made from these data:

- winds are dominantly from the north and north-east for all seasons, with some westerlies off the Atlantic Ocean
- high wind speeds are rare with 97 percent of recorded winds having speeds below 16 knots (18.4 miles per hour)
- 75 percent of recorded winds are less than 10 knots (11.5 mph)
- calm days are also rare, only 11 percent are less than 4 knots

Limited data (10 minute mean direction and speed recorded at 0900 hrs) are also available for El Jadida over the period July 1984 to December 1988. Although the sampling distribution is skewed towards certain months and years, conclusions on wind speeds and directions concur with those from the Safi data:

- 80 percent of recorded wind speeds are 10 knots or below (11.5 mph)
- higher wind speeds are distributed evenly throughout the year
- maximum wind speeds can reach approximately 22 knots (25 mph)

These wind data indicate that PFA may be readily entrained during emplacement and will necessitate specific measures to counteract this air pollution within and beyond the site.
4 WASTE STREAM

4.1 Waste Stream

Figure 4.1 shows the cumulative volumes of Pulverised Fuel Ash (PFA) and Furnace Bottom Ash (FBA) requiring long term disposal based on projected coal consumption data provided by CMS/ABB. The proportion by mass of dry ash derived from coal can vary and the CMS/ABB expected figure of 11 percent by weight has been adopted in this report. A typical output of 80 percent PFA and 20 percent FBA has been assumed.

Ash may potentially be re-used for construction or other purposes thereby reducing the volume requiring disposal. Figure 4.1(a) shows the life expectancy of the Long Term Site if all ash is disposed within the quarry. Figure 4.1(b) shows the life expectancy of the Long Term Site if all the FBA were re-used from year 10 (phased in from year 5). The figures incorporate the expected four-year life of the Intermediate Site (620 000 m$^3$).

The density of placed ash has been based on compaction to 95 percent of the maximum dry density expected to be achieved by the placement methods proposed in Section 7.3. This has been taken as 1 500 kg/m$^3$ (dry density) for PFA and 1 450 kg/m$^3$ (bulk density) for FBA.
5 SITE END USE

5.1 Site End Use

It is our understanding that the Port Quarry is located within an area intended for industrial development. Given the site situation, it seems that heavy industry would be a likely form of development.

In its current form, the Port Quarry is unfavourable for redevelopment due to access restrictions, safety hazards and poor drainage (groundwater at the surface). Once disposal operations are completed, the landform will have a gently raised dome-like appearance that rises above the level of the surrounding plateau, resulting in much improved surface water drainage characteristics.

The degree of compaction of the ash controls its bearing capacity and, hence, the type of structures that can be economically constructed on it. With adequate controls, light to medium industrial construction on the Long Term Site after disposal operations are completed is entirely feasible. This matter is discussed further in Section 6.3.

Development of the site for heavy industrial use would probably require piled foundations bearing on the underlying bedrock.
6 CONCEPTUAL DESIGN

6.1 General

There is a need to provide a long term controlled land disposal system for the ash which minimises groundwater impacts and is compatible with the required end use. The design concept aims to provide sufficient voidspace for long term purposes whilst being sympathetic to the natural landform. Groundwater sensitivity, drainage and potential land development are also considered by the design.

6.2 Voidspace and Landform

6.2.1 Voidspace

According to the available site surveys (see Section 2.2.3), the Port Quarry is particularly amenable to infilling and provides substantial voidspace.

The proposed new landform would completely infill the Port Quarry to the elevation of the surrounding plateau at its margins, rising to an elevation of about nine metres above the surrounding plateau at its highest (Figure 6.1).

Calculations of the available voidspace, using the topographic map and computerised 3-D volume calculation methods, suggest that there is approximately 5.7 M m$^3$ of available voidspace if the Port Quarry was to be filled to the surrounding ground level. The additional disposal volume available by constructing a domed restoration surface depends upon the gradient of the surface. Typical waste disposal practice is to construct a disposal facility with finished surface slopes of 1 in 25. This provides for effective shedding of rainfall away from the waste so as to minimise infiltration and leaching. The added advantage of such slopes is to increase the available disposal volume. If a 1 in 25 surface were to be used, the additional volume is about 1.6 M m$^3$. In combination, this would result in an available disposal volume of 7.3 M m$^3$.

The use of 1 in 25 slopes at the Long Term Site would result in a landform that rises some 18 m in height at its maximum above the surrounding plateau. With 1 in 25 slopes, future redevelopment of the site would be limited to relatively small plots of land requiring extensive engineering works involving retaining walls and embankments constructed from imported fill. The cost of these works, in combination with the consequent loss of land, would probably make the site uneconomic to redevelop. In addition, access roads to the plots would need to be carefully routed to take into account such slopes.

The use of 1 in 50 slopes to the landform surface would be compatible with the re-use requirement by maximising the surface area of potential building plots while retaining adequate surface drainage of the ash pile. This reduces the disposal volume by 0.8 M m$^3$ to 6.5 M m$^3$. 
6.2.2 Land Form

In order to blend the contours of the restored ash pile surface into the surrounding plateau it will be necessary to extend the disposal area onto the low points surrounding the quarry rim. Also, excavation of materials in the south-west corner of the quarry for use in constructing earthworks for the disposal operation will extend the toe of the restored surface beyond the surveyed break in slope shown on Figure 2.2. Clear definition of the exact final extent of the Long Term Site can only be made following further investigations, additional survey and detailed design. A minimum requirement for the land area is shown in Figure 6.1.

6.3 Settlement and Compaction Requirements

Consideration has been given to the settlement of the placed ash. A maximum expected settlement of the PFA of the order of 25 percent could be expected to occur if the PFA is tipped loose, settles under self-weight and subsequently experiences collapse settlement on wetting by heavy rainfall. Such settlement would damage any future structures on the site and result in surface undulations and ponding.

Since future industrial development at the Long Term Site is envisaged, large settlement is considered unacceptable and the choice of an appropriate method of placement is an important factor in the design. Similarly, the bearing capacity (compressive strength) of the ash, which increases with increased compaction, is an important factor influencing potential land redevelopment by dictating the type of foundation required to support a structure.

Controls on placement thickness and compaction are proposed to reduce settlement to a reasonable level and increase the bearing capacity. Compaction has the added benefit of increasing the disposal volume.

Semi-compaction of PFA will reduce its volume by approximately 20 percent, to an estimated dry density of $1220 \text{ kg/m}^3$, with some further settlement occurring during placement due to self weight. Semi-compaction can be achieved at a moisture content of about 14 percent and layer thicknesses of 500 mm. Although semi-compacted PFA is not recommended for use as a load bearing fill material, past experience of building on old ash dumps in the UK indicates that building on semi-compacted ash would be a possibility.

Published findings on working practice in the UK indicates that compaction of PFA at or near to its optimum moisture content (approximately 20 percent) is required to create a proper load bearing fill for industrial use. In view of the clear intention for industrial end use, the design is based upon this type of compaction. A maximum placed layer thickness of 225 mm is normally recommended for engineered fill; compaction to 95 percent of the maximum dry density would reduce this layer by up to 33 percent to 150 mm, with a dry density of $1500 \text{ kg/m}^3$. However, with the use of heavy, self-propelled vibrating compactors, we consider it is probably feasible to attain 95 percent compaction if ash is placed in layers as thick as 500 mm. Final layer thickness should be confirmed based on field trials using the actual equipment available. An outline operational procedure is developed in Section 7 and costed in Section 8.

Conditioning of the ash with water (see Section 7.3) will provide initial strength due to capillary suction between particles (negative pore pressure), enable some age-hardening to take place due to cementation, and aid compaction. Because of its particle size distribution,
PFA will not consolidate significantly following completion of the disposal operation. FBA is not prone to load induced settlement or consolidation under the conditions envisaged at this site.

The advantages of 95 percent ash compaction, at an estimated differential cost of eight percent higher by comparison with semi-compaction, are that:

- more ash can be disposed of per unit volume of voidspace
- the bearing capacity of the placed ash is greater
- the permeability of the ash is lower, providing additional protection to the groundwater from leaching
- the pozzolanic reaction of PFA between siliceous or aluminous minerals, calcium oxide and water to form calcium silicate hydrate (termed age-hardening or cementation) is maximised. Semi-compacted PFA is unlikely to harden significantly over time.

6.4 Operational Lifetime

With the ash compacted to 95 percent of the maximum dry density, a total scheme life of up to 37 years is potentially achievable, if the FBA is re-used. Should a market for FBA not be found and hence, necessitate disposal of all PFA and FBA, the required minimum 30 year lifetime would still be achieved.

It should be noted that sufficient voidspace would only be available to dispose of ash in a semi-compacted condition and still operate the disposal facility for the required 30 years, if the FBA were to be re-used.

6.5 Site Preparation and Design

6.5.1 General

The Port Quarry contains significant quantities of quarry backfill materials (400,000 m$^3$) and smaller quantities of quarry spoil on the floor (some 50,000 m$^3$) as shown on Figure 2.2. These materials can be used in the operational works, as described in the following section. Some local stabilisation of the quarry faces will be required to create a safe working area. The quarry floor would be cleared of boulders, as necessary, to form a working surface. The site would be set out with markers, perimeter drainage ditches constructed and facilities provided for the operational phase. Long term monitoring facilities would be provided at this time. All such work would be undertaken under a site preparation contract for each phase of operation.

In comparison with many wastes, power station ash is a substance with only minor pollution potential. Nevertheless, it is proposed that the site is operated and restored in a manner which minimises contact of ash with surface water and groundwater.
6.5.2 Filling Sequence

As discussed in Section 3, the Jorf Lasfar region is subject to infrequent but significant rainfall. This is seasonal, with virtually no rain during June, July and August, but with potential heavy rain during November and December. In order to minimise rainfall run-off from the ash during the operation of the site, the site will be filled and restored progressively. A sequence of filling is proposed which sheds water away from the operational area at any time. This sequence is shown in concept in Figures 6.2 and 6.3. A typical section through the filled site is shown in Figure 6.4. Each phase will comprise of three cells, each cell accommodating about one year of ash production.

The base of the ash will be placed at a level which is at least 0.5 m above the maximum groundwater table level. Gravelly sandy silts (backfilled in the south-west corner of the quarry) will be placed and compacted in layers on the floor of the quarry to form a basal layer to provide for a 0.5 m separation from the ash. Further investigations are required to define accurately the groundwater elevation and its seasonal variations. Low spots in the quarry floor will be infilled with this material to create a flat sloping surface. FBA or screened granular quarry waste will be spread in a thin basal layer to drain the base and create a capillary break to prevent the upward flow of water by capillary action.

In the initial few years of operation, prior to establishing the presumed market for FBA, both PFA and FBA will be disposed of at the Long Term Site. The two types of ash need not be segregated and may be co-placed. FBA should not be placed within the outer one metre of the ash pile. This will ensure that the compacted uppermost layers of PFA will form a reduced permeability cap.

6.5.3 Infiltration

The top one metre of ash should be placed in a carefully controlled manner and tested against an end-product specification which sets the required degree of compaction. FBA should not be placed within this upper layer. It is anticipated that the permeability of this compacted ash layer may reduce to approximately $1 \times 10^{-4}$ m/s due to the cementation properties of compacted PFA. (Geol. Soc. Special Publication No. 11, 1991). Consequently, the construction of a low permeability cover is not considered to be necessary.

6.5.4 Drainage

Groundwater seepage into the quarry floor and rainfall run-off should be controlled during disposal operations such that access is maintained for the earth-moving equipment and so that neither the basal fill layer nor the ash is tipped into standing water.

Operating cells should be separated from the rest of the unfilled quarry in order to separate any run-off from the ash from other rainfall entering the site. Run-off from partially completed ash cells and exposed ash side-slopes should be retained by earth bunds. If this run-off is found to be significantly contaminated, it should be diverted to a central lagoon through movable pipework (either gravity fed or pumped) and evaporated. Evaporation of contaminated run-off in this way will reduce the potential for contamination of the groundwater table. The proposed location of the lagoon is presented in Figure 6.2 and a conceptual design of the lagoon in Figure 6.5. During the rainy season, suitable gradients should be maintained on the ash placed in the operational cell to encourage run-off to the bunds.

As discussed in Section 2.3, there is some evidence for the presence of a continuous horizon of marly limestones in the quarry floor which may form a local or regional aquiclude.
aquiticlude may provide a natural low permeability barrier to prevent aquifer contact with the ash. In this case, raising of the placed ash above groundwater will not be required but perimeter drains will be constructed to collect and redirect lateral groundwater inflows. Under these circumstances, a low permeability barrier of clay or compacted marl would be constructed between the ash and the quarry wall around the lowermost two to three metres of the quarry face or as appropriate, incorporating an outer granular drain. The barrier would be keyed into the quarry floor. This alternative design is also shown on Figure 6.4. This solution would remove the need for placement of fill over the entire quarry floor. However, further investigations are required to confirm the presence of the aquiclude.

A perimeter drainage ditch is proposed at normal ground elevation in order to collect surface water running off the completed surface (see Figure 6.4). It should be noted that surface runoff from the site will increase after placement of ash compared with the present situation. It is envisaged that perimeter drainage works will consist of drainage channels leading to soakaways.

6.6 Site Access and Facilities

There are several potential access routes from the Power Plant to the Long Term Site. The most likely alternatives are via the Safi to El Jadida public highway (S.121) and via the OCP Phosphate Plant.

Access via the Safi to El Jadida asphalted highway would require loaded trucks to: join the highway to the south of the Power Plant at the road junction adjacent to the OCP Phosphate Canal; pass beneath railway lines; exit the main highway at the Port junction onto an east-west asphalted public road; pass beneath a rail bridge; leave the highway along an existing gravelled track; and enter the south-east corner of the Port Quarry via a wide cutting.

Alternatively, trucks might be able to avoid the section of the route along the Safi to El Jadida highway and the two railway bridges by travelling via a gravelled road that passes through the OCP Phosphate plant.

Determination of local limitations on the use of public highways to transport ash is outside the scope of this study.

Temporary access roads within the disposal area and ramps up the placed ash itself will need to be developed as the ash is placed. Roads along the site floor will have to be carefully routed to suit the cell phasing plan and incorporate culverts to cross the drainage pipes conveying run-off from working cells and side-slopes to the lagoon. Access to Cell 10 will require the routing of trucks across the restored surface of Cells 8 and 9 and ramping down to the level of the lagoon.

Facilities will be required on site for the operators, for plant security, and to prevent unauthorised tipping or dumping. A controlled entrance, a fenced compound, and a site hut with services are proposed.

A replacement water supply should be provided to mitigate the loss of the primary spring. Some alternative options are: use the abstraction well required for water supply to the disposal site for the purposes of dust control; provide a separate well for local use; or establish a municipal water supply in a suitable location.
A detailed consideration of these alternatives is beyond the scope of this report and should be considered further during the detailed design process.

6.7 Site Restoration

The existing site is degraded and the cliff edges are dangerous to approach. Significant improvement can be achieved if the site is adequately restored.

Between the southern perimeter of the quarry and the east-west highway, an area of flat ground is rock-strewn and traversed by a series of intersecting tracks. The land area at least one kilometre to the south and west of the quarry is presently used for arable farming. The land beyond is occupied by heavy industry, including the OCP Plant and the Port of Jorf Lasfar. It would be entirely appropriate to restore the ash disposal site to be compatible with future development in accordance with Section 5 above.

Reconnaissance of the Long Term Site identified substantial quantities (some 400 000 m³) of "backfill" material within and immediately adjacent to the site. Grading analyses and permeability testing of material adjacent to the quarry indicate that the material is a gravelly, sandy, silt. It is proposed to place a 0.5 m thick compacted cover of this "backfill" material directly over the compacted ash. This cover is designed to reduce the extent to which run-off can leach, or erode, the final ash layer and will also serve to prevent PFA dust generation. The material will be placed as part of the operational work and will proceed as each area of ash is filled to its final level. A final layer of backfill material will be placed to 150 mm and not compacted to enable natural revegetation to occur.

It is envisaged that future development would take place on this surface, possibly with some additional localised fill placement to suit the development layout.

Figure 6.6 shows preliminary perspective views of the surface topography of the Long Term Site before and after ash disposal.
7 OPERATIONAL PROCEDURE

7.1 General

The following sub-sections provide an outline of the operational procedures required to transport, place and cover ash disposed at the Long Term Site. A detailed operational procedure for use by the operators will need to be prepared in the form of an operational plan. Such a plan is not within the scope of this study.

In view of the size of the site, it is envisaged that detailed planning and site preparation will be done on a phase by phase basis within an overall design plan.

As discussed in Section 5, it is desirable that the Long Term Site be suitable for later industrial development in accordance with the local development plan. As such, all fill and ash will be properly compacted at the Long Term Site.

7.2 Bund and Lagoon Construction

Disposal cell bunds should be constructed progressively as each phase and cell is developed using the backfilled marl waste in the south-west corner of the Long Term Site. The marl should be conditioned near to its optimum moisture content and placed and compacted in thin layers to a trapezoidal cross-section as indicated in Figure 6.5.

The lagoon should also be constructed of conditioned and compacted marl waste and should be lined with an impermeable geomembrane. The lagoon has been located in the area designated for ash disposal during Phase 10 as indicated in Figure 6.2. Calculations of runoff, arising from rainfall events during the last 20 years falling on a compacted ash cell, and assuming zero infiltration, indicate that a lagoon size of approximately 50 percent of the exposed ash surface area is required, with a lined depth of 2 m. Subject to monitoring and experience from the Intermediate Site, run-off from the operational cell and exposed ash side slopes that collects in the run-off drains formed behind the bunds will be piped by gravity or pumped to the lagoon and evaporated.

7.3 Ash Conditioning

FBA is wet on output from the hopper and should be transported and placed into the disposal area at its hopper moisture content without any treatment.

Compaction at a moisture content as near to optimum as possible is required. Consequently, a minimum moisture content of 20 percent at the time of disposal is recommended. Properly compacted, this should result in a compacted ash dry density within the disposal area of about 1.5 tonnes/m$^3$. Moisture contents in excess of 20 percent up to a maximum of 25 percent are acceptable.
The moisture content of the PFA, as stored in the ash hoppers on site, is assumed to be close to zero. Therefore, the addition of water (termed "conditioning") is required in order to raise the moisture content to at least 20 percent. The fly ash silo is equipped with a wet unloader for such conditioning.

Periodic sampling and testing of the moisture content of the PFA should be carried out as it is unloaded from the hoppers into the trucks for transport to the Long Term Site and also at the time of compaction so that the conditioning process is controlled within specified limits.

7.4 Placement Method

7.4.1 General

The disposal area will consist of a phased sequence of disposal cells with regular capping. This phasing is designed to minimise the pollution risk to groundwater by limiting the area of ash exposed to rainfall at any time. Also, the run-off will be collected and evaporated from a lined lagoon, as indicated in Figure 6.2.

Cell sizes sufficient to accommodate one year's production of ash should be sufficiently large to allow the division of an operational cell into two working halves, permitting uninterrupted ash disposal. This will allow ash tipping and spreading on one half while the other half is being compacted.

Once a potential market is identified for sale of FBA as a construction material, FBA should no longer be transported to the Long Term Site, but stockpiled adjacent to the Intermediate Site.

To avoid double handling, both the conditioned PFA and FBA should be transported from the hoppers to the disposal site by tipping-truck in preference to conveyor belt systems or rail car. The optimum capacity and hence quantity of trucks is dependant upon many factors both practical and economic, including: the height clearance beneath the hoppers; the bearing capacity of the existing asphalted road surface from the hoppers to the disposal site; and the economics of truck capacity versus cycle distance versus ash stream. The type of truck (whether on-road or off-road) is dictated by: the quality of the access roads and restrictions on their use; by the selected placement method which may require the transport of ash over other uncompacted tipped ash within the disposal area; and by local truck availability. Such an analysis is beyond the scope of this report. Trucks of 25 tonne capacity are assumed for the purposes of this report.

The ash should be placed in the disposal areas in a series of layers of controlled thickness by tipping in adjacent individual truck-loads. The ash should then be spread to approximately 500 mm thickness using a bulldozer. The spacing of the tipped loads should be controlled such that a minimum amount of spreading effort is required by the bulldozer to achieve the 500 mm layer thickness. Each layer should then be compacted with about five passes of a vibrating roller. Succeeding ash layers are then placed over the previous layer, requiring the loaded trucks to ride on the compacted ash.

Periodic sampling and testing should be carried out to monitor the degree of compaction attained. Insufficient compaction would result in a decreased life of the Long Term Site.
7.4.2 Basal Layer Placement

Prior to placing ash, the floor of each disposal cell should be raised to an elevation sufficient to create a minimum 500 mm separation of the groundwater table from the ash. Gravelly sandy silts, (backfill excavated from the south-west corner of the quarry) will be placed on the floor of the quarry in layers of 500 mm thickness and compacted using a vibrating roller. Low spots in the quarry floor will be infilled with this material to create a flat gently sloping surface in preparation for ash placement. Standing water should first be drained away to the lagoon so that fill is not placed into water.

FBA or screened granular quarry waste will be spread thinly to about 250 mm thickness, and compacted over the basal layer to create a capillary break. Basal layer placement may not be necessary if a low permeability natural quarry floor is proven (see Section 2.4.4).

7.4.3 FBA Placement

As stated in Section 6, both PFA and FBA will probably be disposed of at the Long Term Site in the initial years of operation. The two types of ash need not be segregated and may be coplaced.

FBA should not be placed within the top one metre of the ash pile which will ensure that the compacted uppermost layers of PFA will form a reduced permeability cap.

7.4.4 PFA Placement

PFA should be placed on top of the capillary break and in subsequent layers. Since the PFA has been moisture conditioned, the ash should be spread to approximately 500 mm thickness using a bulldozer, immediately after tipping, to avoid drying out. Each layer should then be compacted to about 95 percent of the maximum dry density using a vibrating roller.

7.4.5 Cover Placement

As each cell reaches its restored height, a cover of roller-compacted gravelly, sandy, silt should be placed on top of the compacted PFA to a thickness of 500 mm. This material will be obtained from the stockpiles of material in the south-west corner of the Site.

A further 150 mm of uncompacted gravelly, sandy silt should be placed over the compacted cover.

Restored surfaces should be surveyed to ensure that an adequate slope has been formed so as to ensure that rainfall falling on the restored cell runs off to the perimeter drain.
7.5 Dust Control

The degree to which dust control will be required in the disposal area depends upon:

- prevailing wind speed and direction
- the moisture content and particle size distribution of the ash
- the amount of exposed ash not protected by cover material
- time elapsed between initial placement and spreading (increased turbulence arises due to surface irregularities)

As stated in Section 3, winds are predominantly from the north and north-east and are typically below 16 knots (18.4 miles per hour (mph)). However, calm days are also rare. Wind speeds can reach a maximum of about 22 knots (25 mph). Dust problems will be at their greatest during the easterly Chergui winds which bring hot, dry air from the Sahara and blow on an estimated 10 to 20 days per year. Loose fly ash may be picked up by wind speeds of 5.3 m/s (12 mph) and above, and can cause considerable air pollution both on and off site during bulk handling operations. About two percent of ash particles are hollow. These "cenospheres" build up on the surface of pools or wet spots, and are extremely susceptible to windblow if allowed to dry out. To minimise wind erosion problems, it is necessary for fuel ash to be transported at a moisture content of at least 14 percent. This condition will be met for other reasons as described in Section 7.3.

Dust control in the operational areas will be by the use of water tankers and hand-operated water jets to dampen the material. It is anticipated that this will need to be a continuous operation throughout much of the year. During windy periods, placement of the cover material will need to keep pace closely with the ash placement and may require the use of small cell sizes. The exposed edges of the ash cells will also need wetting down using a hose and pumped water. Pumped groundwater should be used for wetting down.

Normal health and safety guidelines should be followed by the plant operators involved in transporting, placing and covering the ash. Suitable dust masks and washing facilities should be provided.

7.6 Monitoring

Monitoring will serve to identify the level of impact of the scheme and enable some modification of operational methods during the project lifetime, if required.

The site warrants monitoring as follows:

- wells for monitoring of levels and water chemistry of groundwater entering and leaving the site
- surface water runoff quality monitoring
monitoring to check control of moisture content and achieved compaction of the conditioned ash, particularly the top one metre of PFA

Monitoring of the groundwater quality beneath and adjacent to the disposal area should be performed at quarterly intervals. Monitoring wells should be installed. Further details of which are given in Section 10.2. Water levels and samples should be taken from monitoring wells installed on and off-site. Water samples should be collected using standard environmental sampling procedures designed to prevent cross-contamination and pollution of the natural water sample during the sampling process.

Surface water should be collected as grab samples from the perimeter drainage ditches on at least two occasions during the rainy season.

Monitoring of the ash waste stream is a prudent measure which may already be in place. A comparison of the rate of ash production with the rate assumed in designing the Long Term Site (in combination with the achieved degree of compaction) will allow confirmation of the estimated operational life expectancy of the site.

In addition to the above, some baseline and occasional operational dust monitoring is recommended.
8 PRELIMINARY COST ESTIMATE

8.1 General

The following is a preliminary order-of-magnitude estimate of the cost of preparing, operating
and restoring the Long Term Site.

At the time of writing, Moroccan rates for construction materials and earth-moving rates from
contractors are awaited. As a result, cost estimates for the preparatory contracted works
have been estimated on the basis of UK rates and adjusted for the Moroccan market.

The cost estimate is based on the conceptual design presented in Section 6 of this report.
The following assumptions have been made in building up this estimate:

- the Long Term Site will operate for up to 33 years
- CMS/ABB will transport and place all ash at the Long Term Site. Earth-
moving equipment in use at the Intermediate Site will move to the Long Term
Site. CMS/ABB will acquire four additional 25-tonne capacity dump trucks.
Purchasing equipment will offer a significant cost saving over hiring, in the
long term.
- a contractor will be employed by CMS/ABB to implement the following works
to allow Phase I to receive ash:
  - construction of a lagoon
  - placement of a basal layer of compacted fill under Cell 1
  - construction of earth bunds for Phase 1
  - installation of drainage pumps and drainage network
  - installation of an abstraction well and monitoring wells
- preparatory engineering works will also be contracted comprising:
  - a fenced plant compound (containing fuel storage and a
    serviced site hut)
  - a controlled site entrance incorporating a road barrier and
    reception building
  - additional survey and setting out works for the disposal cells
  - a water abstraction well
- four permanent monitoring wells will be installed and a regular groundwater
  quality monitoring programme will be carried out
- a stone-pitched drainage ditch will be installed along the entire perimeter of
  the Long Term Site
- all prices are current, and no allowance has been made for inflation in annual
  operating costs

Initial costs and annual operating costs are presented separately in Table 8.1.
The order-of-magnitude annual cost of ash disposal at the Long Term Site is estimated to be 2.3 million Moroccan Dirhams at 1996 prices. No account has been taken of local taxation.

CMS/ABB annual operating costs are based on the hourly operating cost of the various items of plant, derived from spreading the purchase, financing, operating and maintenance costs over the operating life of the plant in accordance with manufacturer's experience. This hourly rate is then multiplied by the expected annual hours usage of each item of plant.

Earth-moving equipment used by CMS/ABB at the Intermediate Site would be of a sufficient capacity to operate at the Long Term Site. A detailed study of trucking requirements is outside the scope of this study, but briefly considered. The decision remains as to whether or not to purchase trucks that are designed for off-highway use only, with a capacity of 40 tonnes, or to purchase trucks with around half this capacity that can be operated on the highway as well as off highway. While off-highway trucks would be more efficient in terms of cost per tonne of ash transported, a route to the disposal site that avoids public highways would have to be arranged and constructed if this option were taken. Our cost estimate assumes the use of Volvo A25C dump trucks, which are among the largest that can be used both on and off the highway. Their imported cost is approximately £154,000 each.

Other items of earth-moving equipment that our cost estimate is based on, and which would also be used at the Intermediate Site are described below. These items are examples of typical equipment, and not intended to specifically endorse any particular manufacturer.

- **Caterpillar D6 track type bulldozer**
  - 104 kW engine; capable of moving approximately 214 cubic metres per hour
  - Imported cost approximately £94,000

- **Bomag BW219 vibrating roller compactor**
  - 118 kW engine; 20 tonne; capable of compacting 375 square metres an hour with 4 passes.
  - Imported cost approximately £88,000

- **Caterpillar 933 crawler loader**
  - 53 kW engine; 1 cubic metre shovel capacity
  - Imported cost approximately £67,000

Contracted construction costs associated with Phase 1 are shown in Table 8.1 as initial costs. The employment of a Moroccan contractor has been assumed in compiling these costs. Initial costs are estimated at 5.0 million Moroccan Dirhams.

Notes:

(i) Preparatory Engineering Works

Costs associated with setting out of the site are based on survey rates previously charged by LPEE. Estimated costs for constructing a plant compound and securing the site are based on current UK Civil Engineering prices published in 1996.

(ii) Contracted Phase 1 Construction Works

The cost estimate has been compiled using 1996 UK Civil Engineering prices and marking up these prices by 75 percent. This mark-up was obtained by comparing the costs of hiring similar plant in Morocco and the UK. It may be necessary to revise this figure when further information on Moroccan contracting costs is available.
(iii) CMS/ABB Operational Works

It is envisaged that the day to day running of the disposal operation would be performed by CMS/ABB including transporting FBA and conditioned PFA to the Long Term Site; placing and compacting the ash with the aid of a bulldozer and self-propelled vibrating compactor; and spraying the ash surface regularly to reduce dust pollution.

Due to the long term nature of the operational works, purchase of the required earth-moving equipment will be the most economic option, and the cost estimate has been compiled on the assumption that new equipment will be purchased, and used for its entire serviceable life. This has been based on manufacturers data for an average working environment, and is between 14 000 and 20 000 hours, depending on the type of equipment.

Hourly ownership and operating costs for the plant have been calculated by charging the initial capital cost against the serviceable life and adding typical hourly maintenance, fuel and operator costs. The cost of capital is charged at six percent, with taxes and insurance included at two percent of the depreciated value.

(iv) CMS/ABB Annual Cell Construction/Cover Works

The disposal cells have been sized to accommodate approximately one year of ash production. Each cell commences with the placing of a basal layer of fill and the construction of a bund; and is completed with the placing of a cover and perimeter run-off ditch. These costs are presented as annual operational works (sections 5 and 6 of the cost estimate). The use of CMS-owned earth-moving equipment has been assumed in these estimates, other than a grader to form the earth bunds, which has been priced as being hired.

(v) Monitoring

The annual costs of monitoring groundwater quality below the Long Term Site are included in the cost of contracted construction works using rates charged by a local site investigation contractor. Quarterly monitoring visits, at the rate of 4 900 Dirhams per sample tested, are assumed.

(vi) Excluded Costs

Costs associated with further investigation of the Port Quarry, procurement, arranging contracts, and contract supervision have not been included.
9 IMPLEMENTATION SCHEDULE

9.1 General

A schedule showing activities to be accomplished during the preparation contract and prior to placing ash at the Long Term Site is presented in Figure 9.1.

A schedule showing operation of the Long Term Site for the first six years of its life is presented in Figure 9.2.
10 RECOMMENDED FURTHER INVESTIGATIONS

10.1 General

It is recommended that the following investigations be carried out in a further investigation phase prior to a detailed design of the Long Term Site:

- further investigate with boreholes, piezometers and laboratory testing the geology beneath the quarry floor and the hydrogeological regime controlling groundwater seepage into the Long Term Site
- extend topographic survey for 50 m beyond the current surveyed limits of the Port Quarry to enable a refinement of the restored landform profile and ensure the design of a smooth freely draining surface
- investigate and confirm the extent of possible groundwater contamination resulting from the oil spill identified during the reconnaissance survey
- quantify, sample and test the backfill, stockpiled and quarry waste proposed for reuse as a basal layer, capillary break and cover
- use the Intermediate Site as a trial for the Long Term Site i.e. perform compaction trials and attained density measurements of ash during operation
- investigate alternative potable water sources

10.2 Boreholes and Piezometers

A minimum of eight boreholes are proposed in the vicinity of Port Quarry in order to clarify the detailed geological and hydrogeological environment and aid final design of the filling operations and monitoring systems. These investigations should be designed to optimise the long term use of the boreholes for monitoring wells without compromising the initial information required. These investigations will be used for the following purposes:

- to prove, or otherwise, the lateral and vertical continuity of a marly limestone aquiclude below the quarry floor (and thereby clarify the disposal design)
- to provide the thickness of any such marly horizon and details of any underlying aquifer (artesian pressures, water quality)
- to provide hydraulic conductivity measurements for the aquifer and aquiclude
- to monitor groundwater elevations and thus confirm the hydraulic gradient and direction of groundwater flow
- to provide long term monitoring points for groundwater quality, both upstream and downstream of the quarry (locating and tracking of any pollution)
Four boreholes will be drilled within the quarry floor to a depth of approximately 10 to 15 metres to prove the thickness of any aquiclude and to investigate any underlying aquifer. Two of these boreholes will be located to provide long term monitoring points for approximately 20 years. The others may also be used to monitor groundwater levels and quality but for a reduced term of approximately 6 years.

Four further boreholes will be drilled outside the confines of the quarry, each to below the base of any aquiclude (approximately 30 to 35 metres). These boreholes will provide information on the aquifer as well as the aquiclude. The boreholes can be used as water quality monitoring points for the full term of the proposed operation.

Groundwater levels and quality will be monitored in each borehole. In addition, hydrogeological testing will be undertaken to determine the hydraulic conductivity of the aquifer and the aquiclude.

Existing water wells in the area may also be used for long term monitoring of water levels and quality.

The design of the monitoring system and drainage details are necessarily iterative processes which depend upon results of these intrusive investigations. The following factors must be taken into account in the detailed design of any investigations:

- cross-contamination between aquifers (if the aquiclude is present) by virtue of the borehole should be avoided
- contamination of the aquifer by the borehole acting as a conduit from the ground surface should be avoided
- the boreholes within the quarry should be positioned to avoid causing operational problems
- if numerous distinct water bearing horizons are proven, monitoring will be more complex to ensure monitoring of appropriate horizons
DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The studies undertaken have confirmed that the Long Term Site is technically suitable for the disposal of ash from the Power Plant. A landform has been developed in concept which will provide a suitable voidspace and will enable the operation of the site to be handled in a manner which allows phased restoration. This will minimise the environmental impacts which would occur if the site was not to be restored until final completion. Based upon the information available to date and with the proposed engineering and operational measures, no significant impacts on groundwater resources or quality are anticipated.

With the currently expected ash production rate and 95 percent compaction of the deposited material, the available voidspace at the Long Term Site is sufficient for up to 33 years of operation.

The landform, designed in concept in this report, completely fills the current voidspace of Port Quarry. Ash will be placed to a thickness of up to 20 m which will require a well-controlled and managed operation from the outset with appropriate equipment. It is proposed that the landform will be further refined and smoothed for the final design.

The proposed filling will considerably alter the landform but will blend well into the existing topography and restoration will provide an improvement over the existing situation. Materials already available on site will be used as a cover and will enable the restored surface to revegetate naturally or be redeveloped.

Potential access routes to the Long Term Site using existing infrastructure would require the transport of ash along public roads. Consideration of alternative access routes that avoid public roads but involve additional land purchase by CMS/ABB is not included in this report.

The order-of-magnitude annual cost of operation of the site has been estimated as 2.3 million Moroccan Dirhams, excluding transportation of ash to the site. Initial costs are estimated as 5.0 million Moroccan Dirhams. Information from Morocco is awaited to enable further refinement of these figures. A smooth transition from ash disposal at the Intermediate Site to the Long Term Site will be possible given planning and timely preparatory work.

Placement of the planned ash quantities at a site of this size is an operation of significant magnitude. An experienced earthworks foreman should manage the disposal operation. Regular technical review and monitoring should be undertaken.
REFERENCES

Tractebel report, 1989


Gale Common Ash Disposal Scheme. The Embankment Dam. Thomas Telford 1991


<table>
<thead>
<tr>
<th>HEIGHT ABOVE QUARRY FLOOR</th>
<th>GENERAL SEQUENCE</th>
<th>SUMMARY LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.25-14.75</td>
<td></td>
<td>Moderately strong to strong thinly bedded dolomitic marly limestone with closely to medium spaced vertical joints.</td>
</tr>
<tr>
<td>9.25-12.25</td>
<td></td>
<td>Moderately strong to strong massive dolomitic marly limestone with widely spaced joints and abundant unfilled solution cavities up to 100 mm in diameter.</td>
</tr>
<tr>
<td>8.50-9.25</td>
<td>Upper Division</td>
<td>Sequence of variable thickness comprising thinly interbedded dolomitic marly limestone and marl clast horizons.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erosional base and syndepositional slumping, especially within zone from 7.80 to 8.10 m</td>
</tr>
<tr>
<td>7.70-8.50</td>
<td></td>
<td>Massive dolomitic marly limestone with occasional vugs lined with crystalline calcite.</td>
</tr>
<tr>
<td>7.00-7.70</td>
<td>Gradational Boundary</td>
<td>Dolomitic marly limestone containing some fossil moulds and large cavities aligned parallel to bedding from 7.20 to 7.40 m and up to 1 m in width</td>
</tr>
<tr>
<td>7.00</td>
<td>Disconformity</td>
<td>Horizontal bedded overlying undulating bedded limestones</td>
</tr>
<tr>
<td>4.00-7.00</td>
<td></td>
<td>Thinly interbedded unfossiliferous finely crystalline dolomitic limestone and fossiliferous dolomitic limestone planar tilted/undulating at about 5°N.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vertical joints medium spaced striking 20°, 50-70° and 320-340°.</td>
</tr>
<tr>
<td>3.00-4.00</td>
<td></td>
<td>Thinly interbedded finely crystalline dolomitic marly limestone and medium crystalline fossiliferous dolomitic calcarenite.</td>
</tr>
<tr>
<td>2.00-3.00</td>
<td>Lower Division</td>
<td>Massive coarsely crystalline fossiliferous dolomitic limestone with abundant fossil mould of gastropods and lamellibranchs, locally iron-stained</td>
</tr>
<tr>
<td>1.70-2.00</td>
<td></td>
<td>Fossiliferous dolomitic limestone.</td>
</tr>
<tr>
<td>1.50-1.70</td>
<td></td>
<td>Friable fossiliferous dolomitic calcarenite.</td>
</tr>
<tr>
<td>1.00-1.50</td>
<td></td>
<td>Massive fossiliferous dolomitic limestone with abundant fossil moulds parallel to bedding.</td>
</tr>
<tr>
<td>-1.00-1.00</td>
<td>Locally present</td>
<td>Thinly to medium bedded dolomitic marly limestone and fossiliferous dolomitic limestone.</td>
</tr>
</tbody>
</table>
### Table 2.2 Geochemical Summary

<table>
<thead>
<tr>
<th></th>
<th>Spring PQS2</th>
<th>Well PQ4</th>
<th>Well PQS 1999</th>
<th>Typical Carboante</th>
<th>FBA Leachate</th>
<th>PFA Leachate</th>
<th>WHO Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.7</td>
<td>7.75</td>
<td>7.5</td>
<td>7.92</td>
<td>7</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Econ @25 °C</td>
<td>1510</td>
<td>8800</td>
<td>3297</td>
<td>1400</td>
<td>100 - 700</td>
<td>1500¹</td>
<td>(20 °C)</td>
</tr>
<tr>
<td>As μ g/l</td>
<td>&lt;10</td>
<td>0</td>
<td>&lt;10</td>
<td>0</td>
<td>14</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Cd μ g/l</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>0.2</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Cr μ g/l</td>
<td>0.2</td>
<td>1</td>
<td>3.2</td>
<td>4.8</td>
<td>38</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Cu μ g/l</td>
<td>21</td>
<td>&lt;20</td>
<td>39</td>
<td>2.7</td>
<td>17</td>
<td>10</td>
<td>2000</td>
</tr>
<tr>
<td>Pb μ g/l</td>
<td>1</td>
<td>20</td>
<td>9</td>
<td>0</td>
<td>66</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Ni μ g/l</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>0</td>
<td>39</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Se μ g/l</td>
<td>&lt;10</td>
<td>0</td>
<td>&lt;10</td>
<td>0</td>
<td>96</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Zn μ g/l</td>
<td>27</td>
<td>23</td>
<td>22</td>
<td>23.3</td>
<td>10</td>
<td>10</td>
<td>3000</td>
</tr>
<tr>
<td>Al μ g/l</td>
<td>43</td>
<td>16</td>
<td>197</td>
<td>5.5</td>
<td>210</td>
<td>7800</td>
<td>2000</td>
</tr>
<tr>
<td>Hg μ g/l</td>
<td>0.306</td>
<td>0.675</td>
<td>0.329</td>
<td>20</td>
<td>70</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>K m/g/l</td>
<td>18.7</td>
<td>214</td>
<td>12.6</td>
<td>5.5</td>
<td>0 - 5</td>
<td>6.5</td>
<td>16</td>
</tr>
<tr>
<td>Mg²⁺ m/g/l</td>
<td>53.9</td>
<td></td>
<td>0 - 60</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Na + m/g/l</td>
<td>145.5</td>
<td></td>
<td>0 - 25</td>
<td></td>
<td></td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Ca²⁺ m/g/l</td>
<td>665</td>
<td>665</td>
<td>69.4</td>
<td>60 - 70</td>
<td>30</td>
<td>177</td>
<td>100</td>
</tr>
<tr>
<td>NO₃⁻ m/g/l</td>
<td>160</td>
<td></td>
<td>0 - 20</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>HCO₃⁻ m/g/l</td>
<td>244</td>
<td></td>
<td>200 - 500</td>
<td></td>
<td></td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>SO₄²⁻ m/g/l</td>
<td>230</td>
<td>344</td>
<td>67.6</td>
<td>2 - 50</td>
<td>71</td>
<td>24</td>
<td>250</td>
</tr>
<tr>
<td>Cl⁻ m/g/l</td>
<td>318</td>
<td>1551</td>
<td>799</td>
<td>220</td>
<td>0 - 25</td>
<td>280</td>
<td>10</td>
</tr>
<tr>
<td>B m/g/l</td>
<td>0.09</td>
<td>0.55</td>
<td>0.21</td>
<td>0.2</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
</tbody>
</table>

Values for a typical carbonate aquifer are for the dolomite/limestone Lomagundi aquifer, Zimbabwe (Lomagundi Aquifer Study, German Geological Society, 1987)

**Notes:**

1. Shaded boxes in first four columns of data indicate values which exceed WHO guidelines
2. WHO levels not available; European Community (E.C.) maximum admissible concentrations quoted
3. Example leachate obtained by contacting 10 percent (w/w) dry material with de-ionised water overnight
Table 3.1 Monthly Total Rainfall For Safi

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>20.3</td>
<td>17</td>
<td>41</td>
<td>12.7</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>4</td>
<td>26</td>
<td>0.9</td>
<td>124.2</td>
</tr>
<tr>
<td>1987</td>
<td>31.1</td>
<td>39.2</td>
<td>4.4</td>
<td>11</td>
<td>1.6</td>
<td>0.3</td>
<td>0.6</td>
<td>4</td>
<td>16.5</td>
<td>56.6</td>
<td>148</td>
<td>313.3</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>157</td>
<td>23.7</td>
<td>32</td>
<td>4.3</td>
<td>24</td>
<td>8.3</td>
<td>0</td>
<td>0</td>
<td>11.4</td>
<td>203.4</td>
<td>4</td>
<td>468.1</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>80</td>
<td>29.9</td>
<td>27.4</td>
<td>42.1</td>
<td>1.2</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>38.9</td>
<td>152.8</td>
<td>110.2</td>
<td>482.8</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>26</td>
<td>2</td>
<td>22.8</td>
<td>56</td>
<td>10.2</td>
<td>3</td>
<td>0.4</td>
<td>0</td>
<td>24</td>
<td>25</td>
<td>140</td>
<td>309.4</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>13.4</td>
<td>69.4</td>
<td>105.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>187.9</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>0</td>
<td>0</td>
<td>41</td>
<td>1.2</td>
<td>12.7</td>
<td>0</td>
<td>0.9</td>
<td>0</td>
<td>57.3</td>
<td>5</td>
<td>45.1</td>
<td>163.2</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>30</td>
<td>31.5</td>
<td>61.5</td>
<td>16.7</td>
<td>8.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
<td>112.6</td>
<td>109.9</td>
<td>6.8</td>
<td>377.9</td>
</tr>
<tr>
<td>1994</td>
<td>47.7</td>
<td>62.1</td>
<td>16.6</td>
<td>1.1</td>
<td>11.5</td>
<td>2</td>
<td>0.9</td>
<td>0</td>
<td>31.2</td>
<td>16.5</td>
<td>20.2</td>
<td>209.8</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>0.1</td>
<td>35.1</td>
<td>40.7</td>
<td>22.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3.3</td>
<td>13.2</td>
<td>32</td>
<td>154.5</td>
<td>302.7</td>
</tr>
<tr>
<td>Average</td>
<td>40.56</td>
<td>30.99</td>
<td>35.15</td>
<td>20.77</td>
<td>5.82</td>
<td>2.83</td>
<td>0.13</td>
<td>0.25</td>
<td>0.83</td>
<td>30.91</td>
<td>62.72</td>
<td>62.97</td>
<td>294</td>
</tr>
</tbody>
</table>

Monthly totals in millimetres calculated from 24 hour totals (0600 hrs to 0600 hrs) provided by UK Meteorological Office.
Table 3.2 Mean and Maximum Temperatures For Safi

<table>
<thead>
<tr>
<th></th>
<th>00:00 Hrs Mean</th>
<th>00:00 Hrs Max</th>
<th>03:00 Hrs Mean</th>
<th>03:00 Hrs Max</th>
<th>06:00 Hrs Mean</th>
<th>06:00 Hrs Max</th>
<th>09:00 Hrs Mean</th>
<th>09:00 Hrs Max</th>
<th>12:00 Hrs Mean</th>
<th>12:00 Hrs Max</th>
<th>15:00 Hrs Mean</th>
<th>15:00 Hrs Max</th>
<th>18:00 Hrs Mean</th>
<th>18:00 Hrs Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>10</td>
<td>27</td>
<td>9</td>
<td>-</td>
<td>8</td>
<td>17</td>
<td>9</td>
<td>20</td>
<td>16</td>
<td>44</td>
<td>17</td>
<td>31</td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td>Feb</td>
<td>12</td>
<td>26</td>
<td>11</td>
<td>17</td>
<td>10</td>
<td>-</td>
<td>12</td>
<td>20</td>
<td>17</td>
<td>28</td>
<td>18</td>
<td>28</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Mar</td>
<td>13</td>
<td>25</td>
<td>12</td>
<td>24</td>
<td>11</td>
<td>20</td>
<td>14</td>
<td>24</td>
<td>19</td>
<td>28</td>
<td>20</td>
<td>31</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td>Apr</td>
<td>15</td>
<td>29</td>
<td>13</td>
<td>-</td>
<td>13</td>
<td>38</td>
<td>17</td>
<td>31</td>
<td>20</td>
<td>36</td>
<td>21</td>
<td>33</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td>May</td>
<td>16</td>
<td>30</td>
<td>15</td>
<td>27</td>
<td>15</td>
<td>31</td>
<td>19</td>
<td>33</td>
<td>22</td>
<td>36</td>
<td>22</td>
<td>38</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>Jun</td>
<td>19</td>
<td>31</td>
<td>18</td>
<td>30</td>
<td>17</td>
<td>28</td>
<td>21</td>
<td>35</td>
<td>23</td>
<td>42</td>
<td>24</td>
<td>38</td>
<td>23</td>
<td>39</td>
</tr>
<tr>
<td>Jul</td>
<td>21</td>
<td>32</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>30</td>
<td>23</td>
<td>36</td>
<td>26</td>
<td>45</td>
<td>27</td>
<td>46</td>
<td>25</td>
<td>41</td>
</tr>
<tr>
<td>Aug</td>
<td>22</td>
<td>33</td>
<td>21</td>
<td>31</td>
<td>20</td>
<td>36</td>
<td>23</td>
<td>38</td>
<td>27</td>
<td>43</td>
<td>27</td>
<td>43</td>
<td>26</td>
<td>39</td>
</tr>
<tr>
<td>Sep</td>
<td>21</td>
<td>29</td>
<td>20</td>
<td>27</td>
<td>19</td>
<td>28</td>
<td>22</td>
<td>34</td>
<td>26</td>
<td>40</td>
<td>26</td>
<td>42</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>Oct</td>
<td>18</td>
<td>26</td>
<td>17</td>
<td>25</td>
<td>17</td>
<td>23</td>
<td>19</td>
<td>26</td>
<td>23</td>
<td>35</td>
<td>24</td>
<td>37</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Nov</td>
<td>15</td>
<td>26</td>
<td>14</td>
<td>-</td>
<td>14</td>
<td>-</td>
<td>16</td>
<td>28</td>
<td>20</td>
<td>34</td>
<td>21</td>
<td>33</td>
<td>19</td>
<td>-</td>
</tr>
<tr>
<td>Dec</td>
<td>13</td>
<td>21</td>
<td>12</td>
<td>23</td>
<td>11</td>
<td>22</td>
<td>12</td>
<td>22</td>
<td>18</td>
<td>28</td>
<td>19</td>
<td>30</td>
<td>17</td>
<td>24</td>
</tr>
</tbody>
</table>

Average temperatures in (°C) over the period 1/1/83 to 31/12/95 according to UK Meteorological Office.
## Table 8.1 Cost Estimate

<table>
<thead>
<tr>
<th>Description</th>
<th>Initial Cost</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Preparatory Engineering Works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set out site</td>
<td>£10,000</td>
<td>£6,000</td>
</tr>
<tr>
<td>Construct plant compound</td>
<td>£20,800</td>
<td></td>
</tr>
<tr>
<td>Secure site</td>
<td>£2,300</td>
<td></td>
</tr>
<tr>
<td>(ii) Contracted Phase 1 Construction Works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct lagoon with geomembrane liner</td>
<td>£155,500</td>
<td></td>
</tr>
<tr>
<td>Place inert bottom layer (Cell 1)</td>
<td>£102,900</td>
<td></td>
</tr>
<tr>
<td>Construct earth bunds for Phase 1</td>
<td>£31,600</td>
<td></td>
</tr>
<tr>
<td>Install pumps &amp; drainage network</td>
<td>£7,000</td>
<td>£2,500</td>
</tr>
<tr>
<td>Install abstraction well &amp; monitoring wells</td>
<td>£33,600</td>
<td>£1,300</td>
</tr>
<tr>
<td>(iii) CMS/ABB Operational Works *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place ash in 500 mm layers</td>
<td>£35,200</td>
<td></td>
</tr>
<tr>
<td>Compact ash</td>
<td>£39,400</td>
<td></td>
</tr>
<tr>
<td>Moisten ash with bowser</td>
<td>£28,900</td>
<td></td>
</tr>
<tr>
<td>(iv) Annual CMS/ABB Cell Construction Works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place and compact inert bottom layer and capillary break</td>
<td>£32,900</td>
<td></td>
</tr>
<tr>
<td>Construct earth bunds</td>
<td>£14,000</td>
<td></td>
</tr>
<tr>
<td>(v) Annual CMS/ABB Cover Construction Works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place and compact 0.5 m soil overburden layer</td>
<td>£9,700</td>
<td></td>
</tr>
<tr>
<td>Construct perimeter run-off ditch</td>
<td>£1,900</td>
<td></td>
</tr>
<tr>
<td>Total, say</td>
<td>£370,000</td>
<td>£170,000</td>
</tr>
</tbody>
</table>

* Excluding ash transportation costs to the quarry

**Summary of approximate cost estimate:**

(Assuming 13.6 Moroccan Dirhams to a British Pound)

Initial Costs are 5.0 million Moroccan Dirhams
Annual Costs are 2.3 million Moroccan Dirhams

---

J962918
jorf-1as'2bint_r0.doc
November 1996
Revision 0
PORT QUARRY
LONG TERM SITE

LEGEND

- EXISTING WELLS AND SPRINGS
- CONTOURS OF PIEZOMETRIC HEAD
  (Metres above Mean Sea Level)
- 1270 ELECTRICAL CONDUCTIVITY
  \( \mu s/cm \) AT 25\(^\circ\)C

NOTE
Where two values of E.C. are shown, the latter
is from laboratory chemical analysis

GIBB

JORF LASFAR POWER PLANT
ASH DISPOSAL SITE DEVELOPMENT

GROUNDWATER AND ELECTRICAL
CONDUCTIVITY LEVELS

<table>
<thead>
<tr>
<th>Job No:</th>
<th>Date</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>96291B</td>
<td>NOVEMBER 1996</td>
<td>2.4</td>
</tr>
</tbody>
</table>
ASH VOLUME PLACED (Based on all ash produced)

(a)

Cumulative volume of ash in disposal area, m³

Time (Years)

TOTAL

PFA

FBA

ASH VOLUME PLACED (FBA excluded and re-used)

(b)

Cumulative volume of ash in disposal area, m³

Time (Years)

TOTAL

NOTES:
(i) Weight of Dry Ash/weight of Coal = 11%
(ii) Coal consumption data provided by CMS fax of 9-10-96
(iii) PFA compacted to 95% maximum dry density = 1.5 t/m³
(iv) FBA compacted dry density = 1.45 t/m³
(v) Weight of FBA/total weight of ash = 20%
(vi) Assumed life of Intermediate Site = 4 years

* FBA re-used from year 10, increasing linearly from 0% in year 5
NOTES:
1. Fill thickness dependent on groundwater monitoring results collected during future studies.
2. Run off from rainfall to be gravity fed or pumped to Evaporation Lagoon.
3. Evaporation Lagoon area estimated at 50% of active cell area using 20 years of monthly rainfall data and monthly average open water evaporation.
4. Ash and Earth/Rock Bund slopes to be designed.
5. Diagram not to scale.
LAGOON

CONCRETE

GEOMEMBRANE

CONDITIONED AND COMPACTED MARL

PIPE

BUND

SUBMERSIBLE PUMP

PLAN EA

NOT TO SCALE

GIBB

JORF LASFAI POWER PLANT
ASH DISPOSAL SITE DEVELOPMENT

LAGOON CONCEPTUAL DESIGN

NOVEMBER 1985

6.5
A: CURRENT TOPOGRAPHY

B: COMPLETED TOPOGRAPHY

JORF LASFAR POWER PLANT
ASH DISPOSAL SITE DEVELOPMENT

PERSPECTIVE VIEWS OF THE LONG TERM SITE BEFORE AND AFTER DISPOSAL

Job No: 96291B
Date: NOVEMBER 1996
Figure: 6.6
<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Complete Operation of Intermediate Site</td>
<td>0 W</td>
</tr>
<tr>
<td>2</td>
<td>Preparatory Engineering Works</td>
<td>7 W</td>
</tr>
<tr>
<td>2.1</td>
<td>Secure site</td>
<td>3 W</td>
</tr>
<tr>
<td>2.2</td>
<td>Construct compound</td>
<td>3 W</td>
</tr>
<tr>
<td>2.3</td>
<td>Perform additional survey</td>
<td>7 W</td>
</tr>
<tr>
<td>3</td>
<td>Contracted Phase 1 Construction Works</td>
<td>18 W</td>
</tr>
<tr>
<td>3.1</td>
<td>Construct lagoon</td>
<td>9 W</td>
</tr>
<tr>
<td>3.2</td>
<td>Place basal layer under Cell 1</td>
<td>5 W</td>
</tr>
<tr>
<td>3.3</td>
<td>Construct earth bunds for Phase 1</td>
<td>5 W</td>
</tr>
<tr>
<td>3.4</td>
<td>Install drainage pumps and drainage network</td>
<td>4 W</td>
</tr>
<tr>
<td>3.5</td>
<td>Install monitoring wells</td>
<td>4 W</td>
</tr>
<tr>
<td>4</td>
<td>Monitoring</td>
<td>11 W</td>
</tr>
<tr>
<td>5</td>
<td>Commence Phase 1 Operational Works</td>
<td>0 W</td>
</tr>
</tbody>
</table>

Jorf Lasfar Ash Disposal Project
Phase 2b - Long Term Site
Preparation/Construction Schedule

01JAN00
<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Commence Operation of Long Term Site</td>
<td>JAN</td>
</tr>
<tr>
<td>1</td>
<td>PHASE 1</td>
<td>JAN</td>
</tr>
<tr>
<td>1.1</td>
<td>CELL 1</td>
<td>JAN</td>
</tr>
<tr>
<td>1.1.1</td>
<td>Contractor completes base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>1.1.3</td>
<td>Place cover</td>
<td>JAN</td>
</tr>
<tr>
<td>1.2</td>
<td>CELL 2</td>
<td>JAN</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Place base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>1.2.3</td>
<td>Place Cover</td>
<td>JAN</td>
</tr>
<tr>
<td>1.3</td>
<td>CELL 3</td>
<td>JAN</td>
</tr>
<tr>
<td>1.3.1</td>
<td>Place base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>1.3.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>1.3.3</td>
<td>Place cover</td>
<td>JAN</td>
</tr>
<tr>
<td>2</td>
<td>PHASE 2</td>
<td>JAN</td>
</tr>
<tr>
<td>2.1</td>
<td>CELL 1</td>
<td>JAN</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Place base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>2.1.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>2.1.3</td>
<td>Place cover</td>
<td>JAN</td>
</tr>
<tr>
<td>2.2</td>
<td>CELL 2</td>
<td>JAN</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Place base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>2.2.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>2.2.3</td>
<td>Place cover</td>
<td>JAN</td>
</tr>
<tr>
<td>2.3</td>
<td>CELL 3</td>
<td>JAN</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Place base layer</td>
<td>JAN</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Place ash</td>
<td>JAN</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Place cover</td>
<td>JAN</td>
</tr>
</tbody>
</table>
PLATES
GIBB

JORF LASFAR POWER PLANT
ASH DISPOSAL SITE DEVELOPMENT

BACKFILLED SOIL OVERBURDEN ON
WESTERN SIDE OF QUARRY

Job No.: 96291B

Date
NOVEMBER
1996

Plate
2.3
Oil contamination on the northern side of the quarry in November 1996.