KINGDOM OF LESOTHO
MINISTRY OF WATER, ENERGY AND MINING

Oxbow Hydroelectric Project Feasibility Study

Monenco

OXBOW HYDROELECTRIC FEASIBILITY STUDY - MAIN REPORT

CONTENTS

PREFACE

The Oxbow Hydroelectric Project Feasibility Studies were carried out under the terms of an Agreement between the Ministry of Water, Energy and Mining, of the Government of the Kingdom of Lesotho and Monenco Consultants Limited of Montreal, Canada. The Agreement, signed on 18 February 1987, followed a series of events beginning many years earlier.

The Oxbow Scheme had been identified as having one of Lesotho's best opportunities for indigenous independent hydropower development, and it has been the subject of a number of reports prepared between 1955 and 1984. In 1984, studies of the Lesotho Highlands Water Project (LHWP) concluded that Oxbow site and hydro development was no longer an integral part of the LHWP least cost solution. Preliminary studies on the interaction of an independently operated Oxbow scheme and the LHWP concluded that such a scheme merited further study since it was considered it was possible to develop it ahead of LHWP. On this basis, the Government of Lesotho approached the African Development Fund (ADF), and the resulting Terms of Reference for the Oxbow Hydroelectric Project Feasibility Study were based on discussions between GOL and the ADF mission which visited Lesotho in Februrary 1985.

The Government of the Kingdom of Lesotho (GOL) then negotiated a loan for the African Development Fund to assist in financing the feasibility study of the Oxbow Hydroelectric Project in the upper catchment of the Malibamatso river. The scheme, if implemented, would reduce Lesotho's present near 100% dependence on the Electricity Supply Commission (ESCOM) of South Africa for electricity.

The objectives of the study can be summarized as follows:

1. To select and recommend an optimum design option.

2. To establish and define the specific engineering and operation plan for the selected scheme.

3. To determine whether it has engineering and economic feasibility and justification under anticipated economic and financial conditions.

4. To investigate the possibility and extent of using the power house discharges for irrigation and water supply purposes within Lesotho.

The study was to be carried out in two distinct phases:

Phase 1. Preliminary Justification and Selection of layouts for future study.

Phase 2. Detailed Feasibility Study, culminating respectively in a Preliminary Justifcation Report and a Detailed Feasbility Study Report.

The Terms of Reference for the study included the following description of the project.

"Subject to the specific design recommendations of the proposed studies, the Oxbow scheme basically aims at using the regulated flow diverted from the Oxbow reservoir of about 3.3 cumecs with about 700m of head in a 54 MW installed capacity power station at the foot of Mount Khatibe near Tlhaka in the Hololo Valley. The headrace tunnel would run under the mountain ridge north of the Hololo Valley to a saddle west of Khatibe peak. An intermediate adit could be provided adjacent to the existing Oxbow road. The discharge from the power house would flow down the Hololo Valley to the Caledon River and from there to Maseru, the capital. The Oxbow dam would be located high on the Malibamatso River, about 4 km downstream of the confluence with the Tsehlanyane River regulating the runoff from a catchment area of about 277 km^2, with the highest precipitation in Lesotho. A single circuit 132 kV power transmission line would be constructed from the power station switchyard to a terminal 132/88kV sub-station around Maseru, some 135 km away".

Work on Phase I began in Maseru on March 8, 1987 and was completed at the end of June 1987. A two volume report titled "Oxbow Hydroelectric Project - Feasibility Study-Phase I Report, June 1987 was submitted to the Ministry on July 2, 1987."

In accordance with the Terms of Reference the report was reviewed by the Ministry, and by the African Development Fund. On 5 September 1987 an instruction to proceed with Phase II of the study was communicated to Monenco by the Ministry.

The Phase II study team was mobilized and the Project Manager arrived in Lesotho to initiate the Phase II study on 6 October 1987.

The Phase II studies brought the project studies to a full feasibility level, of study and included, at appropriate levels of detail:

- Topographic Surveys and Mapping
- Geological and Geotechnical Investigations
- Hydrological Studies

- Financial Analysis.

Studies of downstream benefits were included at a more preliminary level, reflecting the present lack of any agreement between Lesotho and Republic of South Africa on use of the waters of the international boundary river.

Field Investigations for the various project features began in December 1987 and were completed in March 1988. The draft report on Phase II was submitted on August 23, 1988.

The project development presented in the report essentially fulfills this description with improvements following the study findings as anticipated in the Terms of Reference as quoted above.

Comments on the draft report were discussed at a meeting attended by representatives of the GOL, the Technical Assistance Consultancy of the IHWP and the consultant in Maseru on December 2, 1988. The comments were also discussed with staff of the ADF in Abidjan on December 5, 1988.

As a result of discussions it was agreed that prior to submission of the final report the scope of the study should be extended to take account of:

1. New forecasts of load and energy demand required to be served by the Lesotho electric system.

2. Newly available information on the value of IHWP royalty payments in as far as they even related to the potential benefits of Oxbow releases into the Caledon River.

After review by the ADF and the Ministry an addendum to the original agreement was approved by the ADF and the Ministry and work on the additional scope of study began on May 1, 1989. The studies were completed in August 1989 and the final report, in 5 volumes plus an Executive Summary was then completed.

The five (5) volume set of reports comprises:

Vol. I of V	Main Report
Vol II of V	Appendix A - Hydrology Appendix B - Power Potential
Vol III of V	Appendix C - Geotechnical
Vol IV of V	Appendix D - Hydroelectric Design Studies Appendix E - Transmission Line Optimization

Data

received from the staff of the Ministry of Water, Energy and Mining

20 Construction of the Lesotho Highlands Water Project is planned under a 1986 Treaty between Lesotho and South Africa, with completion of Phase I now expected by the start of 1996. The primary purpose of the project is to supply water to the Vaal Valley in RSA. A secondary purpose is to develop hydropower in Lesotho. The development of Oxbow would reduce the presently planned catchment of the LHWP I. As a result, firm flows from the LHWP I would be reduced by about 12 percent below expectations and thereby reduce the ability of the LHWP to meet scheduled water deliveries to RSA. Power output from the planned 70 MW LHWP I hydro-powerplant would also be reduced. As a consequence of reduced water deliveries from LHWP to the RSA,or of extra costs in scheme modifications to replace the losses, royalty payments to Lesotho would be reduced. A preliminary assessment suggests royalty losses over 50 years may have a 1988 present value of US$ 15 million. Generation losses might possibily be offset by reduced costs associated with a downsized LHWP I powerplant to suit the reduced water flows.

21 If LHWP Phase I is constructed essentially in accordance with the presently planned timetable, there would be an insufficient market initially to successfully exploit the output of LHWP and an Oxbow Project if both were completed in 1995. In addition it is assumed that Oxbow as the second project would be charged with any losses incurred by LHWP due to the Oxbow diversion. In these circumstances, for an Oxbow Project completed in 1995, the internal rate of return based on generation benefits would fall to 3.8 percent per year. Addition of downstream benefits would bring the rate of return up to 4.4 percent per year. The project would not be financially viable.

22 In the event that LHWP proceeds, assuming that the currently accepted load forecast is realized, and assuming that ESCOM rates increase in real terms by 1.5 percent (real) per year, economic analysis indicates that Oxbow returns would reach levels at which the project would again become viable after a delay in construction of about 20 years, i.e. with Oxbow construction completion in 2015. Construction timing would be affected substantially by the actual growth in demand and particularly by the rise in ESCOM rates.

RECOMMENDATIONS

Although it seems most likely that the IHWP Hydro Phase I development will be constructed by 1996, construction has not yet commenced on the major components of the project. In these circumstances, it is deemed advisable to provide recommendations for the Oxbow Project covering the case where IHWP Hydro proceeds to construction as planned, or where, for some unforeseen reason, construction of IHWP Hydro is deferred for some substantial time. Certain recommendations would apply to both cases though maybe with different degrees of urgency.

CASE 1 - IHWP HYDRO CONSTRUCTION DEFERRED

1 If construction of IHWP Hydro Phase I is deferred, planning of Oxbow should be initiated not later than 1 January 1990 to allow the construction of the recommended Oxbow Project by late 1995.

2 To allow for the timely construction of Oxbow, approaches to potential financing agencies to identify suitable financing for the project should commence, as early as possible, in 1990.

3 Preparation of documents inviting proposals for design and project management should be initiated early in 1990 with a view to appointing a consultant for these services by 1 September 1990.

4 Water supply projects presently planned for Maseru and other communities bordered by the Caledon River should be reviewed to take account of possible savings due to increased Caledon River flows, that would result from construction of Oxbow.

CASE 2 - IHWP HYDRO PHASE I OPERATIONAL BY 1996

1 With Phase I of IHWP Hydro operational by 1996, construction of the Oxbow Project should be deferred until energy demand and/or ESCOM rates have grown sufficiently to provide an adequate return on Oxbow generation.

2 While presently expected growth rates for energy demand and ESCOM tariffs suggest that Oxbow would not be financially viable until about 2015, actual differences in one or both of these rates could substantially affect the first date at which Oxbow would become viable. It is therefore recommended that growth of both energy demand and ESCOM rates be reviewed annually, and that the economic returns for Oxbow be recalculated from time to time according to the actual growth rates.

In view of the low and unreliable flow levels naturally

7 At the powerhouse the best economic return on generation would be obtained by the installation of a multi-unit peaking plant of 80 MW total capacity. The four 20 MW generators would be driven by impulse turbines of the Pelton type.

8 A 138 km long, 132 kV, double circuit transmission line from the Oxbow powerhouse, via Maputsoe, to the planned new Mabote sub-station at Maseru, would permit the delivery of an average of over 180 GWh of energy per year, to the electric system.

9 There appear to be no serious environmental problems associated with either the hydroelectric development or the transmission systems.

10 Natural flows in the Hololo and Caledon Rivers frequently fail in the dry season. The natural, 80 percent reliable, flow would only permit the irrigation of about 160 hectares of agricultural lands along the two rivers.

11 Releases of water from Oxbow powerhouse would improve and stabilise low flows in the downstream Hololo and Caledon Rivers allowing for substantial improvements in urban water supply to Maseru, and greatly improved opportunities for river-fed irrigation. Sufficient improvement of low flows would be realized to save M 20 million (1988 values) in construction costs of effecting an improvement of the Maseru water supply, which is planned for the mid-1990's. In addition, Oxbow would permit the irrigation of almost 1000 hectares of agricultural lands in the Hololo and Caledon Valleys of Lesotho. The returns on this new irrigation, when fully developed, would be worth over M 4 million (1988 values) per year.

12 Present estimates indicate that use of the flow improvement in the Hololo/Caledon solely for irrigation would be limited by the availability of suitable land. However, limited soils survey data available at present in the Caledon Valley may underestimate the amount of land suitable for irrigation.

13 Presently there is no formal agreement between Lesotho and RSA covering water extractions from the Caledon River, which forms part of the international boundary between the two countries. The lack of control of water extractions is an inhibiting factor on any plans Lesotho might have for use of Caledon River water, and has contributed to the low priority given to agricultural soils surveys in the Caledon Valley.

14 The Oxbow project would cost US$ 155.5 million (1988 values not including IDC) and would require almost 4 years to construct. Provided a decision to proceed was made by the start of 1990, the project would be completed by late 1995 with commercial generation

15 Present electrical energy consumption in Lesotho is at the rate of 160 GWh per year with an annual peak power demand of 30 MW (1988 calendar year). All electrical energy is presently imported from the South African utility ESCOM. The forecast, accepted by GOL in late 1988, predicts that energy consumption in Lesotho will reach 555 GWh by 2005 with a peak power demand of 45 MW. The extended forecast used in this study assumes a growth rate of 3 percent per year after 2005. The extended forecast is summarised below:

Year	Peak MW	Energy GWh
1996	74.5	256.0
2000	81.1	294.6
2010	106.3	400.6
2020	142.8	538.6
2030	191.9	723.8
2040	258.0	972.7

P 3-22

16 Oxbow generation, when fully exploited, would replace imports of energy from RSA worth almost M 21 million per year at 1988 ESCOM rates.

21/46 = 4.6 · 10^6

17 A review of the average cost of ESCOM electricity shows that, over the period 1980-1986, ESCOM's tariffs increased, on the average, by 1.5 percent more per year than the general Consumer Price Index in South Africa. ESCOM's coal costs, wages and cost of capital are all likely to rise in real terms in the future, making it likely that ESCOM energy costs, though still low by world standards, will rise in real terms at more than the recent average rate of increase. A future increase of 1.5 percent per annum in real terms is considered probable.

18 Assuming a 1.5 percent rise in real terms in ESCOM tariffs, energy demand growing at the forecast rate, and Oxbow as the sole significant generating station in Lesotho, the project would have an internal rate of return of 6.3 percent per year based on generation benefits only. Inclusion of downstream benefits would increase the rate of return to 7.1 percent per year.

19 Under the same conditions as described in Finding 18 above, the Oxbow project completed by late 1995 would be a financially viable project under financing arrangements containing a suitable mixture of commercial export credits, concessionary loans and grants. This viability is based on generation benefits only, and would hold good even if ESCOM tariffs remained constant in real terms. Constant ESCOM tariffs in real terms would, however, increase the

$181 \cdot 10^6 = 125 \cdot 10^6$ Kwh x 15 * R
R = 9.65 c/Kwh x 2.2 (6b) = 21.2 c$/Kwh = 137 cR/Kwh ?

R = 18.24 c$/Kwh

the IHWP in the period before such flow enhancements would be available from Oxbow.

CASE 1 OR CASE 2

1 In preparation for expanded irrigation of agricultural lands in the Hololo and Caledon Valleys a program should be initiated to complete soil mapping of the valley lands within irrigation reach of the two rivers.

2 To ensure that Lesotho is able to plan the reliable exploitation of enhanced flows in the Caledon River for irrigation and/or water supply, approaches should be made as early as possible to the Government of South Africa to secure an agreement on water sharing, and on the control of water abstractions from this boundary river.

Monenco wishes to acknowledge the invaluable assistance received from the staff of the Ministry of Water, Energy and Mining and particularly the help given by the Principal Secretary, Mr. Makhakhe, his deputy Mr. Mohapeloa and the liaison officers, Mr. R.T Mochabelele and Mr. L. Molapo for Phase I and Mr. S. Mochoalibe and Mr. B. Sekoli for Phase II. Thanks is also due to the Commissioner of Mines for his assistance in properly storing the geological core samples for the project, and to LEC, LHDA and their consultants for their cooperation.

Supervision at the ADF was provided initially by Mr. A. Rutta and latterly by Mr. M. Sampara, both under the direction of Mr. Desai Chief, NISI 2, all of whom were always most willing to assist and advice.

Monenco would also like to acknowledge the participation of. Michael Mhlanga, socio-economist, and of Lesotho Consulting Engineers, Ltd. who provided valuable services in survey, geology, engineering assistance, drafting and office services to the project.

FINDINGS

1 Hydrological studies have identified a long term average flow of 4.05 m^3/s in the Malibamatso river at the Oxbow damsite from the 288 km^2 highland drainage basin.

2 Geological conditions are excellent for construction of the Oxbow Project. In the vicinity of the reservoir and dam the rock is sound basalt. Geological investigations indicate there are no major faults. In-situ tests indicate low rock permeability. Consequently water losses and grouting requirements are expected to be minimal. Massive sandstone formations at the powerhouse site should provide excellent foundations and problem-free construction.

3 Optimisation studies indicate that a 92 m high dam at the Oxbow site would permit the most favourable exploitation of the Oxbow water resource. The dam would impound a reservoir with a full pool elevation of 2525 masl and a live storage of 72.8 million cubic metres, and would allow the diversion of an average of some 4 m^3/s to the powerhouse. Siltation of the reservoir should not be a operational problem. Estimates indicate at least a 350 year reservoir life under present and foreseeable drainage basin conditions.

4 A concrete faced rockfill dam would provide the most economical use of the site and available materials. Basalt at the damsite would provide excellent fill material for the dam, but it is not suitable as a source of concrete aggregate. Concrete aggregate would be obtained from a large dolerite dyke about 7 km from the damsite.

5 A natural saddle adjacent to the left abutment of the dam would provide an excellent location for an overflow spillway. A spillway with a 175 m long crest leading to a flip bucket would pass the PMF peak flow of 4430 m^3/s with a one metre freeboard at the dam crest.

6 An 11 km power conduit routed south of the Hololo Valley, would most efficiently convey flows of up to 15 m^3/s from the Oxbow Reservoir to a powerhouse on the right bank of the Malifiloane River in the Hololo Valley. The 3 m inverted "U" section power tunnel would comprise a 6330 m long low pressure tunnel, a short vertical connecting shaft, and a low level 2530 m long high pressure tunnel leading to a steel penstock. The upstream 1050 m of the 2020 m long, 1.75 m diameter steel penstock would be laid inside a non-pressurised section of the lower tunnel. A 3m diameter surge shaft with expansion chambers would be required. Rock conditions are good and the tunnels would not require continuous lining. Tunnel

SUMMARY

SUMMARY

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FIGURES (Cont'd)

SUMMARY

PART 1 - INTRODUCTION

1.1 The Oxbow Hydroelectric Project would involve the diversion of water from 288 km^2 of the upper basin of the Malibamatso River in northern Lesotho to the nearby Hololo River basin. This would allow the development of a multi-purpose scheme with the primary purpose of generating electricity, and the secondary purpose of enhancing flows in the Hololo and the downstream Caledon Rivers, with a view to improving these rivers as a source of irrigation and domestic/industrial water supplies. The arrangement of the project is shown on Figure S1.

1.2 The Malibamatso River is one of the principal headwaters of the Senqu River. After it leaves the southern boundaries of Lesotho, the Senqu River is known as the Orange River, and flows generally westwards across South Africa to the Atlantic Ocean. The Hololo River rises just to the west of the headwaters of the Malibamatso River, and flows generally westwards to enter the south-westerly flowing Caledon River. The Caledon for over 200 kilometres forms Lesotho's north-western border with RSA. About 150 kilometres south-west of the point where it receives the Hololo the Caledon parts from Lesotho, and 150 kilometres further to the south-west enters the Orange River. Further downstream again, the Orange receives the waters of the Vaal River, it's major tributary.

1.3 Schemes for damming the Malibamatso River, just downstream of the confluence of the Tsehlanyane and Tlholohatsi rivers, and diverting its flows to the Hololo Valley for power production and other purposes has been studied for at least 30 years. The notion that economical power generation might be possible from such a project is founded on the proximity of the Malibamatso and Hololo Rivers and the large difference in elevation between them. With a separation of only about 11 kilometres from the Oxbow damsite to the Hololo River in the vicinity of Moteng Store, there is a difference in the existing river levels of about 670 metres. The provision of a dam and reservoir at Oxbow would increase this difference to over 700 metres. The possibility of additional benefits from the scheme arises, as the Malibamatso Valley near Oxbow is largely unsettled, while the Hololo and Caledon Valleys are prime areas of settlement and agriculture, and would benefit from enhanced river flows.

1.4 The Oxbow studies, now completed, were carried out in two phases. During Phase I of the studies, reconnaissance visits were made by engineers, and geological and hydrological specialists to the area. Available data from earlier reports, existing mapping and photography were studied, and cost estimates and economic

of the Phase I studies the basic project arrangement was already closely determined. The Phase I studies were reported in June 1987. The Phase II studies refined and optimized the arrangement and carried the design, costing and benefit evaluations to a level appropriate to a determination of the feasibility of the project.

1.5 At the commencement of Phase II, topographic mapping of the reservoir at a scale of 1:5000 with contour intervals of 5m was produced from existing 1:24000 scale aerial photography by the specialist company of McIlhanney in Ottawa, Canada. These maps enabled an accurate assessment to be made of the storage and surface area characteristics of the potential reservoir. Topographic ground surveys were made at all important project locations including the powerhouse, dam, spillway, power intake, surge shaft, penstock route and critical parts of the tunnel route. Mapping at 1:1000 scale with contour intervals of 1m was produced from these surveys.

1.6 Unless otherwise noted all costs, benefits etc. are expressed at mid-1988 price levels.

PART 2 - HYDROLOGY

2.1 Hydrological studies, which had been commenced in Phase I of the studies, were completed. Particular emphasis was devoted to the preparation of a stationary and dependable flow data base at the reservoir site.

2.2 The Oxbow Reservoir catchment is entirely located in the mountain area of northern Lesotho and measures 288 km^2. The region is characterized by grass and shrub covered mountain slopes, incised by the deep watercourses of the River Malibamatso and its tributaries, with elevations rising from 2400 masl to 3300 masl. Soil cover varies from almost nothing on exposed slopes to 0.5 m in thickness adjacent to the river beds, except where the underlying basalt has been eroded to form scree runs. The physiography can be expected to produce rapid, flashy runoff, from very heavy rainfall, giving high flood peaks, but producing relatively low sediment concentrations.

2.2 The climate in the catchment area is temperate, sub-humid and strongly seasonal, with nearly 80% of the precipitation occurring in the summer months of October to March. Temperature, hours of sunshine ,and hence evaporation, decrease with altitude, while humidity increases. Diurnal temperature variations of 12 °C in summer and 20 °C in winter are common in the area. The following table shows the average monthly variation of climatic parameters at Oxbow climate station .

TABLE S-1

Mean Monthly Climate Factors at Oxbow

Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann
Temperature (°C)	8.7	11.	11.	12.	12.	11.	7.0	4.2	1.1	1.2	3.3	6.8	7.4
Rel Humidity (%)	58	56	61	64	70	71	69	60	61	57	54	48	61
Sunshine (%)	62	44	48	49	53	54	63	73	68	66	59	60	54
Wind Run (km/day)	233	218	207	192	174	172	175	164	179	186	195	217	193
Open Water Evaporation (mm)	105	122	138	149	116	112	78	73	38	34	54	78	1101
Rainfall (mm)	136	156	165	190	138	152	98	59	23	22	33	53	1225

Source : WEMMIN

2.3 The potential of a storage project on the River Malibamatso at Oxbow has been recognized for many years. In 1956 WEMMIN constructed a gauging station (G10), about 2 km upstream of the Oxbow damsite, to provide quantitative flow data. Since then, three additional gauging stations have been built on tributaries to the River Malibamatso above the reach in which the damsite is located. A gauging station has also been constructed on the River Motete, which enters the Malibamatso a few kilometres downstream of the damsite.

2.4 Extensive checks were carried out to find and eliminate any systematic or non-systematic errors in the 56 years of G10 records, and to fill in periods of missing data. After correction, the resulting flow data base was screened using double mass curve analysis and a series of statistical tests, and was found statistically consistent and reliable. The resulting monthly flow data base transposed to the dam site is summarised in the table below, and the long term annual runoff at the damsite can be expressed as :

- an average flow rate of 4.05 m3/s,

- a volume of 128 hm^3 ,or

$\frac{443}{1225}$ = 36% !

$\bar{Q}$ = 7.67 $\bar{R}$=0.69

TABLE S-2

Oxbow Damsite - Historic Inflows

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
						(in m^3/s)							
Max	19.16	18.88	27.71	19.25	17.42	15.83	15.31	16.37	4.29	3.42	10.46	25.73	7.67
Min	0.10	0.20	0.05	0.13	0.43	0.26	0.13	0.04	0.03	0.03	0.00	0.00	1.83
Mean	4.30	6.77	6.71	7.48	7.58	5.49	4.32	1.89	0.75	0.55	1.05	1.72	4.05

Based on 1930-86 record

2.5 Elevation/area/storage curves were prepared for the damsite from the 1:5,000 mapping. The major reservoir characteristics were calculated as follows:

TABLE S-3

Oxbow Reservoir Characteristics

	Elevation	Surface Area	Gross Storage
	(masl)	(ha)	(hm^3)
	2440	0.0	0.0
	2474	-	6.6
L.S.L	2480	67.5	10.1
F.S.L	2525	295	82.9

2.6 Existing studies and sediment measurements on the Malibamatso River were reviewed. This review showed that at Katse, about 60 kilometres downstream from Oxbow, a sediment yield of 80 t/km^2/year could be predicted, with lesser yields further upstream. Although the degree of cultivation above Oxbow reservoir is less than that above Katse reservoir, it was decided to adopt the sediment yield for Katse as a conservative estimate of the average annual yield at Oxbow.

2.7 The deposition of sediment in the reservoir would adversely affect the operation of the hydroelectric power plant when the level of sediment in the reservoir approaches the invert of the power tunnel intake (2474 masl). Three patterns of sediment accumulation were analyzed assuming the 80 t/km^2/year sediment yield, and assuming a deposit density of 1.35 tonnes/m^3. It was calculated that sediment deposition would require at least 385 years to reach the power tunnel invert.

2.8 Flood peaks and volumes were calculated for floods with return periods of up to 1 in 10,000 years. The Probable Maximum Flood (PMF) was also derived. The PMF was estimated to produce a peak flow of 4950 m3/s at the Oxbow damsite. This value is approximately 1.8 times the 10,000-year flood peak and is equivalent to a Creager C value of 140. This value of "C" is higher than previously observed flood "C" values in South Africa and appears quite conservative as a basis for spillway design. It is noteworthy that a value of 2 x 10,000 year peak is sometimes used as a "rule of thumb" estimate of the PMF peak.

PART 3 - POWER POTENTIAL

3.1 As yet Lesotho has no significant indigenous generating capability. Essentially all electrical energy is imported from the South African utility ESCOM, and distributed within Lesotho by LEC. Generation benefits of the Oxbow project were therefore measured in terms of savings resulting from the reduction of imported energy from ESCOM.

3.2 In addition to Oxbow, GOL has plans for a substantial hydropower facility to be constructed as part of the Lesotho Highlands Water Project (LHWP). The LHWP was conceived primarily as a scheme to divert water from the Lesotho Highlands for use in the Vaal River Valley in South Africa. Phase I of the LHWP includes a dam on the Malibamatso River at Katse, downstream of Oxbow, and a dam on the Senqunyane River at Mohale. Water from the Mohale Reservoir will be diverted by a tunnel into Katse reservoir. Water for export to the Vaal will be released from Katse Reservoir to flow north to RSA by gravity flow through a series of two tunnels. The first tunnel will discharge into a reservoir at Muela on the Nqoe River (tributary of the Hololo). The second tunnel will pass flows from Muela directly to the Ash River. Phase I plans include a 70MW underground hydropower facility just upstream of Muela. Figure S2 shows the arrangement of LHWP Phase I, and its relationship to Oxbow in diagrammatic form.

3.3 In early 1988 LHDA estimated generation from the LHWP Phase I powerplant as 150 GWh in 1995, building up to 516 GWh in 2007. However, by late 1988, LHDA plans anticipated that first generation would be delayed until 1996. The generation estimates were based on the availability to LHWP I of all natural inflows to Katse reservoir, including those from the Malibamatso basin above Oxbow. Clearly these upper Malibamatso flows cannot be diverted by Oxbow to the Hololo Valley and at the same time flow into Katse reservoir. Consequently, for the purposes of the Oxbow studies, the LHDA estimates of LHWP generation were reduced to take account of the smaller catchment available to LHWP.

3.4 Lesotho imports electrical energy at four points on it's borders with RSA. The principal connection is at Maseru where 90 per cent of all energy is imported. About 10 per cent of energy enters at Maputsoe, with very small imports at two other points. The import point, which serves the Hololo Valley, was formally of more importance when its prime function was to serve the now-defunct diamond mine at Letseng-la-Terae. The effect of mine demand, between about 1977 and 1983, is very noticeable on curves showing the historic growth of energy and peak power demand in Lesotho (see Figure S3). In the 11 year period between 1976 and 1987 annual energy consumption in Lesotho has increased from 40.4 GWh to 156.2 GWh, equivalent to an average annual growth rate of 13.1 per cent throughout the period. In the 3 year period, 1984 to 1987, annual energy consumption has risen at an average annual rate of 10.9 per cent from 115.2 GWh to 156.2 GWh. During 1988, maybe fuelled by the

3.5 At the commencement of the Oxbow studies an electrical load demand forecast prepared by IMC in 1984 (the IMC Median Forecast) formed the base case by which GOL generation projects were evaluated. During 1988 a new evaluation of future load demand was undertaken by Oskar von Miller as consultants to LHDA. The results of OvM's work were not available during the study period leading to the draft final Oxbow Report of August 1988. However, in late 1988, a new forecast by OvM was accepted by GOL. Consequently, before issue of the present report, generation planning models were rerun using an extended version of the new forecast to redefine Oxbow generation potential. The new generation data was used in the determination of Oxbow generation benefits and in the reported economic and financial evaluations of the project.

3.6 Generation planning studies were carried out initially to optimize various features of the Oxbow Project, and thus enable the selection of an optimum project. For instance, using an assumed installed capacity of 60 MW, computer models were used to simulate and optimize operation of the project with increasing reservoir capacities. The maximum present value of generation benefits was calculated for each increasing reservoir size. Using design and cost data the increasing benefits were compared with the increasing cost levels required for construction and operation. It was found that the optimum benefit would be reached by constructing a reservoir with a full pool elevation of 2525 masl.
Similar analyses were used to calculate an optimum installed capacity of 80MW. The effects of changes in the length, cross section and type of lining of the power conduit were evaluated by the same methods to find the most economic combinations. Present value calculations for all of the alternatives considered were calculated at a discount rate of 6 per cent per annum.

3.7 For the finally recommended arrangement of the Oxbow Project, computer models were used to simulate reservoir operation and power generation, and to calculate the streams of generation benefits which would accrue over a 50 year period of operation. To allow for evaluation of staged installation of the generating plant, generation data and benefit streams were calculated for Oxbow installations of 40MW, 60MW and 80MW. Average annual production of over 180 GWh delivered at the Maseru load centre was calculated. Two cases were evaluated, the first, 'Oxbow Alone', assumed Oxbow to be the only significant generating plant in Lesotho, the second assumed that the planned first stage of LHWP was completed by January 1996, and included a 70MW hydropower plant with output characteristics as advised by LHDA in March of 1988. Oxbow generation in both cases would commence on 1 January 1996. In the second case, as the two projects have overlapping catchment areas, the LHWP energy outputs were reduced to take account of the loss to LHWP of the catchment above Oxbow Dam. Oxbow generation benefits were calculated in each case as the reduction in payments by LEC for imported ESCOM energy which would result from the addition of Oxbow to the system. The growth of Oxbow annual generation benefits over the first 50

flows.

PART 4 - GEOLOGY

4.1 The Oxbow Project is located in an area of high topographic relief, which varies from an elevation of 2440 masl in the riverbed at the damsite to over 2800 masl along the tunnel alignment down to 1800 masl at the powerhouse site. The upper part (dam and intake) of the project lies in an eroded volcanic plateau characterized by steep slopes and deeply incised river valleys. The penstock and powerhouse are located in less extreme topography in the Hololo River Basin.

4.2 Two major rock formations occur in the project area. The Lesotho Formation Basalts are plateau-type basalts consisting of a horizontal succession of flows ranging from elevation 1835 masl to the highest peaks at about elevation 3200 masl. The individual lava flows vary in thickness from 0.5 m to 20 m. Dolerite intrusives occur throughout the basalt as steeply-dipping dykes, or sills concordant to bedding. The Clarens Formation Sandstones underlie the basalt with the contact near the powerhouse site occuring at about elevation 1835 masl. They consist of a uniform, widely jointed, fine grained quartzose sandstone having a calcareous matrix.

4.3 The sites of the dam, diversion works, spillway, power tunnel, and reservoir lie completely within the basalts. The powerhouse site is in the Clarens sandstone. The surface penstock passes over the basalt-sandstone contact en route from the power tunnel to the powerhouse.

4.4 A comprehensive geotechnical investigation program was carried out between January and April 1988 comprising:

airphoto interpretation;
surface geological mapping;
core drilling;
augering, test pitting and trenching;
in-situ testing (permeability and dilatometer);
laboratory testing of soil, rock and water.

4.5 Bedrock and surficial mapping was carried out at the dam, spillway, power intake, tunnel alignment, penstock, powerhouse, prospective rock quarry sites and borrow areas. A total of 1080 linear metres of drilling was completed in 17 borings during the drilling program. Of this total, 301 m was drilled in the area of the dam, 150 m at the spillway, 20 m in a potential quarry area, 99 m in the powerhouse area and the remaining 510 m along the proposed alignment of the power tunnel. A trench was excavated from ground surface to bedrock on both abutments along the dam axis.

4.6 A total of 202 permeability tests were performed in 12 boreholes. Dilatometer testing was carried out at 16 locations in 5 boreholes, to evaluate the strength and deformation

were obtained for laboratory

testing. Dolerite samples were obtained from a large dolerite dyke about 5 km upstream of the damsite.

4.8 A series of laboratory tests were carried out on soil and rock samples. Testing of rock samples was done to determine strength characteristics and evaluate suitability as rockfill and concrete aggregate. Testing on soils was done primarily to assess their properties as fill materials. Samples of river water were also tested.

4.9 The investigations did not reveal any faults or other significant structural features and showed the bedrock to be of high strength and very low permeability. It permitted the following assessments:

- Bedrock of dense and amygdaloidal basalt underlies the dam and cofferdam sites. Rock quality is excellent from the standpoint of high strength and low permeability. Some grouting will be required but grout takes are expected to be low.

- The proposed spillway is located in a saddle of a bedrock ridge which is covered with a veneer of overburden. The basalt bedrock is more permeable at surface than at depth. However, the more permeable rock would be removed by the neccesary spillway excavation. Excavations could be made with vertical slopes. Spillway flows from the flip bucket would discharge onto sound basalt at riverbed level. No significant rock erosion is expected to occur.

- The power tunnel intake portal would be excavated in an exposed rock face which slopes at about 30^0 from the vertical. Bedrock conditions are excellent for developing the portal. Stable rock cuts could be excavated as steeply as vertical.

- The power tunnel would be driven in uniform high-quality basalt for almost its entire length. A minor amount of dolerite would also be encountered, and basalt/dolerite contact zones may be weak and possibly water-bearing. The only other water bearing horizons which may occur are along lava flow contacts. It is not anticipated that a final lining of concrete would be required except in occasional sections of faulted, sheared, fractured or altered rock. For most of the tunnel, shaft and surge shaft, rock reinforcement in the form of rock bolting would be adequate for long term stability. Shotcrete would also be necessary where rock conditions warrant, for instance in amygdaloidal basalt which may tend to weaken in time because of mineralogical alteration and erosion of soluble minerals.
- A transition from pressure tunnel to steel penstock would be made 1150 m upstream of the tunnel outlet portal. At this

pedestals inside the tunnel. From the tunnel portal to the powerhouse the penstock supports would also be taken to bedrock.

- The powerhouse would be founded on uniform, high strength and very widely-jointed, massive sandstone. Excavation conditions would be ideal and smooth rock walls could be blasted vertically to the required depth. Seepage into the excavation through rock would be very low due to the low rock permeability.

4.10 A survey was made of the reservoir rim. This work consisted of airphoto interpretation and ground traversing from the damsite to the upstream limit of the reservoir. An assessment was made of potential slope instability of rock and soil, and seepage from the reservoir.There is too little soil on the slopes surrounding the reservoir to pose any danger from slumping into the reservoir. The rock is composed of flat-lying layers of basalt which do not have any prominent structural weaknesses along which a major rock slide could develop. The rock is essentially impervious, a characteristic which precludes the possibility of significant water seepage from the reservoir.

4.11 The investigation for construction materials focussed on locating the required volumes of suitable, impervious fill, granular fill, rockfill, and fine and coarse concrete aggregates. The results were as follows:

- It is estimated that the required impervious fill could be obtained from the excavation of alluvium on the left bank of the damsite supplemented by material from a downstream borrow pit.

- An abundance of sound basalt is available for rockfill for the dam and cofferdam. The recommended quarry site is located about 800 km downstream of the dam axis.

- Natural deposits of sand and gravel suitable for concrete aggregates and filter material were not found in useful quantities in the project area and must be produced by crushing of basalt or dolerite. Based on results of laboratory tests and petrographic analyses it was concluded that dolerite would make durable concrete aggregates while similar tests for basalt were less conclusive. Dolerite would also produce a superior quality of granular or filter materials. It is recommended that concrete aggregates and granular material to be used in the dam be obtained from dolerite, while that required for the cofferdam and access

organic impurities, and soluble salts.

PART 5 - HYDROELECTRIC DEVELOPMENT

5.1 During Phase I of the studies the general arrangement and sizing of the project components was completed in outline. During Phase II the data provided by topographic surveys, reservoir mapping, geological investigations and cost studies were used, in conjunction with generation planning studies and more detailed design, to further define and optimize the layout. Generation planning studies were used to estimate the generation benefits which could be realized by a series of options. These benefits were then compared with the costs of the options on an incremental present value basis to permit selection of the option offering the best economic returns.

5.2 The recommended project arrangement is shown on Figure S1. A reservoir on the Malibamatso River would be impounded by a 92 m high concrete faced rockfill dam. The reservoir would cover an area of 295 hectares and have a live storage of 72.8 hm^3 at it's full supply level of 2525 masl. A free overflow spillway would be set in a natural depression on the left abutment of the dam. A powerhouse, housing four 20 MW generators, would be sited on the right bank of the Malefiloane River about 600 m upstream of it's confluence with the Hololo River near Moteng Store. A power tunnel would be driven from the left side of the reservoir to a point about one kilometre from the powerhouse site and would be connected to the powerhouse by a 1.75m diameter steel penstock.

5.3 Reservoir full pool elevation was selected at 2525 masl on the basis of economic studies which compared the calculated present value of generation benefits for different reservoir full supply levels with the present value of the costs of construction. The low supply level at elevation 2480 masl ensures adequate submergence of the power tunnel intake (invert elevation 2474 masl) while allowing reservoir storage space below the intake level for over 350 years of sediment accumulation.

5.4 The free overflow spillway would include a reinforced concrete overflow weir, chute slab and flip bucket. A flip bucket exit angle of 45^{o} was selected to throw the jet directly into the river channel for all discharges in excess of 1,000 m^3/s. The length of the spillway overflow weir was determined as a result of optimization of spillway and dam costs. For the selected 175 m long spillway, dam freeboard of 6 m over the full supply level of El. 2525 masl allows passage of the Probable Maximum Flood with peak discharge of 4430 m^3/s at one metre freeboard. A combination of surcharge from the 1000 year flood, and set up and wave effects from a 100 year wind was checked to ensure adequate freeboard and found to be satisfactory.

5.5 A concrete faced rockfill dam (CFRD) with symmetrical upstream and [illegible] selected as the preferred type because

[illegible]

also unfavourable for economic arch dam construction. [illegible] of impervious fill precluded the earth-rockfill type dam from serious consideration. The CFRD is a well proven design and numerous examples, many of which exceed Oxbow's proposed height of 92 m, have been constructed around the world, and have given excellent performance.

5.6 The CFRD design adopted for Oxbow is considered to have the highest fundamental conservatism against earthquake of any dam type. No rockfill dam has ever been recorded as having failed due to inadequate stability. Nevertheless, earthquake studies were made and analyses were performed to evaluate the stability of the dam under conditions of seismic loading. Using Newmark's method of analysis it was determined that the embankment would not be expected to deform when subjected to the calculated design horizontal acceleration of 0.1g. Based on the observed behaviour of other rockfill dams during seismic loading, the CRFD at Oxbow could be expected to safely withstand much higher seismic loading than that produced by the Maximum Credible Earthquake, of Richter Magnitude 6.0, predicted for the project area.

5.7 Permeability tests showed that bedrock at the dam site is relatively impervious, and it is considered that a grout curtain based on a single line of holes would be adequate for the concrete faced rockfill dam. This grout curtain, would extend to a depth equal to half the reservoir head and would be constructed by drilling through the toe slab of the dam.

5.8 The river would be diverted from its present course to allow construction of the dam. Topographic conditions make a left bank tunnel arrangement easily the most practical and economic form of diversion. A 475 m long diversion tunnel, of 6.2 m inverted-U section would be driven through the left abutment. The dam foundation area would be isolated by an upstream cofferdam with crest elevation of 2468 masl, and kept dry by pumping. The fall in river level between the dam site and the tunnel outlet is sufficient to prevent flood stage backwater reaching the dam foundation, so obviating the need for a downstream cofferdam. The tunnel and cofferdam sizes were optimized to safely handle the 1:25 year diversion design flood in the most economical manner. After completion of the dam the diversion tunnel would be closed with a concrete plug which would incorporate a sealed low level outlet. The outlet could easily be put into service if future developments and policies determine a need for downstream releases, and would allow for discharge rates of up to 500 litres per second.

5.9 The power tunnel intake would be constructed some 1.5 km upstream of the dam on the right bank of the reservoir. The intake would be protected by trashracks. A concrete lined transition tunnel section would lead to a steel lined gate section. At the gate section a bonnetted hydraulically operated high pressure slide gate would be provided to allow closure and dewatering of the conduit for inspection and maintenance. A guard gate would also be installed, in tandem, to allow servicing of the operating gate.

required the shaft be carried to El. 2538.5 masl. Overspill of surge water was not accepted. The 3 m diameter, unlined surge shaft was designed for a 100% load-off and a 50% load-on condition. To improve the stability of operation, three expansion chambers would be provided to limit upsurge and downsurge, and to control harmonic surges.

5.11 The power tunnel system would consist of an upstream, 6330 m long, high level tunnel connected by a 353m deep vertical shaft, to a 3680 m long low level tunnel which would emerge about 900m from the powerhouse in the Malefiloane River Valley. The unlined tunnels would be of 3m x 3m inverted "U" section. The vertical shaft, also unlined, would have a 3 m diameter circular section. Tunnel size was initially selected at 3 m as the practical minimum (for construction purposes) for tunnels of this length. Later optimization studies indicated economic disadvantages would result if the tunnels were either enlarged or lined. Tunnel gradients, not exceeding 2 percent, were selected on constructional grounds. The route of the upper tunnel was chosen to provide sufficient rock cover to safely contain the high pressure water flows, and is the most direct route to the surge shaft location. To ensure ease of construction, the tunnelling layout has been arranged so that the vertical shaft, which would connect the upper power tunnel to the lower power tunnel, would lie directly below the surge shaft.

5.12 The surge shaft and power tunnel system would be driven entirely in basalt. The excellent condition of the rock obviates the need for continuous protective linings. However, allowance has been made for support systems identified in geotechnical studies.

5.13 In the final 1150m of the lower tunnel, because of insufficient rock cover to resist hydraulic pressures, a 35m long concrete transition plug would be in installed. From this point a 1.75m diameter steel penstock would lead to the ground surface. The penstock would be carried down the hillside on concrete supports founded on bedrock. In order to limit the wall thickness of the penstock to that suitable for field welding without stress relief, the penstock would be fabricated from high strength steel.

5.14 The powerhouse would ultimately include four generating units with an installed capacity of 80 MW. It would be 65m long, including an erection bay, and have an overall width of 16m. The superstructure would be of steel frame construction. A separate frame would support the rails of a 50 tonne overhead crane. Administration offices would be provided adjacent to the generating hall. A small retarding basin just below the powerhouse would protect downstream river users from sudden flow changes when the units were started up.

5.15 Each of the four vertical shaft, Pelton-type impulse turbines would have a rated full load capacity of 20 MW at a net head of 626m and a discharge of 3.73 m^3/s. At full supply level, with a net head of some 700m the unit turbine output would be 23.0 MW. The turbine governors

percent. The generators would be grouped bus through individual circuit breakers. Two 11 kV feeders would connect the 11kV bus to the two step-up generator transformers.

5.17 The two step-up transformers would be of the Delta-Wye type. The transformer rating is sufficient for each to handle all four generator units, if necessary, so that the need for a spare transformer is obviated. The transformers would be located adjacent to the powerhouse between the switchyard and the hillside and would be separated one from another by concrete fire walls. The transformers would be connected to each switchgear section via circuit breakers and to the switchyard via 132 kV overhead lines.

5.18 The generator station bus would provide power supplies to the unit and station auxiliaries stepped down to 415/240 Volts. Standby and start-up power would be provided by means of a 415 V diesel generator set connected to the station essential service board.

5.19 Powerline carrier (PLC) equipment would be used to tie-in with the existing PLC system to provide telephone links, teleprotection and supervisory control if required.

5.20 Project Access roads, leading to the dam, spillway, intake and powerhouse ,would initially be constructed in gravel and towards the end of construction these roads would be upgraded to permanent project service roads when a bitumen surface would be added to keep future maintenance of the roads to a minimum. The existing A1 road from Butha-Buthe to Mokhotlong would be flooded by the project reservoir for an approximate distance of two kilometres near to the Oxbow Lodge. It would be relocated to a location above the reservoir maximum water level.

PART 6 - TRANSMISSION SYSTEM

6.1 An 11/132 kV switchyard to connect the Oxbow Powerhouse output to the Lesotho system would be located adjacent to the powerhouse. A double circuit 132 kV transmission line would connect the substation to the LEC system.

6.2 The equipment and bus work in the switchyard would meet the following system characteristics :

Nominal voltage	132kV
Maximum operating voltage	145kV
BIL	650kV
Frequency	50Hz
Rated nominal current	600A
System grounding	Effective.

6.3 The proposed switching scheme comprises a single bus single breaker with one bus sectionalizing circuit breaker to provide the flexibility of removing one bus section without affecting the other or its connected feeders.

6.4 The 132 kV circuit breakers would be of the SF6 type. The breakers would be rated at 600A, 25kA symmetrical short circuit interrupting capacity(this value should be confirmed by short circuit studies at the design phase), 3 cycles suitable for high speed single-pole and three-pole tripping and reclosing.

6.5 Surge arresters would be installed in the switchyard to provide prime protection to the power transformers and also general protection for the entire switchyard. The arresters used would be station class gapless type. All outgoing lines would be equipped with line traps rated at 600 A for use with power line carrier equipment.

6.6 Switchyard protection would include:

(i) Transmission Lines :

Main -Multi-zone distance protection
Back-up -Directional ground overcurrent protection
-Breaker-fail protection
Auto-reclosing -Automatic, fast, single or 3 pole reclosing.

(ii) Bus bars -Differential protection

6.7 The transmission line route from Oxbow, via Maputsoe, to the proposed new LEC substation at Mabote near Maseru was chosen after field reconnaisance. It would generally follow the main road for ease of access and, as much as is practical, would avoid mountainous terrain. The line length from Oxbow to Maputsoe is 73km and from Maputsoe to Mabote it is 65km. The total route length is 138km. The selected right of way width is 22 meters.

6.8 The 132 kV double circuit transmission line was designed taking account of local wind, snow and ice conditions. The following overload factors were utilized, and were equated against the maximum applied loads.

Structural steel (towers)	1.25
Conductors, shieldwires, insulators, hardware and foundation	2.00

- The limiting tensions for the conductors and overhead shield wires, expressed as a percentage of the ultimate tensile strength (UTS), were selected as follows to avoid overstressing the cables and to avoid problems with wire fatigue due to aeolian vibration.

  a) Maximum gust, temperature 0°C, tension not to exceed 50 percent UTS.

  b) No wind, temperature 10°C, tension not to exceed 18 percent UTS with the conductor in its final condition,and tension not to exceed 30 percent UTS at 0°C with the conductor in its initial (stringing) condition.

6.9 After analysis of local thunderstorm conditions which show a relatively high isokeronic level of 63 to 100, a shield wire coverage angle of 12 degrees was selected, which would require two overhead shield wires on the transmission lines.

6.10 While the initial output of the Oxbow plant may be less than 80MW, the ultimate capacity of the plant is presently planned to be 80 MW. The transmission line parameters were selected therefore on the basis of their ability to carry the full 80 MW plant output.

6.11 The Monenco in-house computer program TROP (Transmission Line Optimization Program) was used to undertake an economic analysis to determine the optimum conductor. For this analysis the following four conductors were investigated.

Code Name	Aluminum Area
Lynx	183.4 mm^2

economic average span of between 300 and 350 metres. The transmission line design was therefore based on the use of the ACSR "Bear" conductor and an average span of 350 metres. The two circuits would be supported on a single line of galvanized steel towers.

6.12 Data for the ESCOM and Lesotho system now, and as currently planned, was gathered from LEC, ESCOM, and LHDA consultants. The proposed transmission system was then checked by simulating the system on Monenco's in-house computer facilities.

6.13 Steady state load flow studies of the system were carried out under peak and minimum load conditions and for outages at peak load to ensure there would be no loadings in excess of normal rating in any transmission component. Cases were simulated both with Oxbow as the sole Lesotho generating station, and with Oxbow and LHWP Phase I generating. The following criteria were used in evaluating the system performance :

Bus Voltages

- acceptable range under normal conditions: 95% to 105%
- acceptable range under short-time emergency conditions : 90% to 105%
- acceptable range for equipment : 90% to 105%.

Transmission Line Loadings

- limited to the conductor thermal rating, unless restricted to lower values by voltage drop limitations.

Transformer and Generator Loadings

- limited to the maximum MVA ratings under all system conditions
- generator reactive power loading limits based on generator reactive capability characteristics of similar generators.

6.14 A transient stability simulation was carried out to verify the successful operation of the network during and after faults. The transmission system was tested by applying three phase faults on the system which were successfully cleared in 7 cycles.

6.13 The results of the system analyses were satisfactory. However, as so many changes to the system are currently planned, both in Lesotho and RSA, it will be important to repeat the study during the design phase when many of the present proposals will have been implemented, or at least will be in a more advanced stage of design.

PART 7 - DOWNSTREAM BENEFITS

7.1 A prefeasibility level study of the possible downstream benefits of the Oxbow project was included in the Oxbow studies. Downstream of the powerhouse there will be an increase in river flows in the Malefiloane, Hololo and Caledon Rivers. These enhanced flows have the potential to bring positive benefits in the Hololo and Caledon Valleys.

7.2 The studies indicate that increased reliable flow in the Hololo River would increase land potentially irrigable from the river from an estimated 60 hectares, under present conditions, to 526 hectares, an increase of 466 hectares. However, the irrigation limit in the Hololo Valley is due to a restraint on suitable land within economical reach of the river. Due to this, increased flows, surplus to the needs of irrigation in the Hololo Valley, would enter the downstream Caledon River.

7.3 As the Caledon is an International Boundary River it has been assumed that the use of increased flows in the Caledon would be equally divided between Lesotho and RSA. If devoted entirely to irrigation, Lesotho's share of the enhanced Caledon River flows would have the potential for irrigating over 2400 ha. However, as on the Hololo, the availability of suitable land presently appears to be a restraint, with a total of only 1300 hectares of suitable land identified on the Lesotho bank of the Caledon in these studies. To date only limited soil surveys have been made in Lesotho along the Caledon Valley, and it is possible that more land may be identified by future surveys. Irrigation potential from the Caledon River without the flow enhancement was estimated at 97 ha.

7.4 If part of the improved Caledon flows were devoted to municipal water supply, the whole of Lesotho's share of the flow increase could be utilized. In this case, by allocating 1 m^3/s to an increase in river water supplies to Maseru and connected towns, it would be possible to save an estimated M 20 million by removing the need for a proposed Maseru water supply reservoir on the Korokoro River near Mazenod. The remainder of the increased river flows would allow development of the previously mentioned 466 ha on the Hololo, and of 478 ha on the Lesotho bank of the Caledon. The irrigation benefits on this newly available area of 944 hectares would build up to over 4 million Maloti annually over a 12 year development period.

7.5 In addition to the benefits to Lesotho, there would also be benefits to RSA by an increase in their share of Caledon River flows. The flow improvements have the potential to irrigate over 2300 ha. of land in RSA, or provide improved municipal or industrial supplies.

7.6 At present there is no formal agreement between Lesotho and RSA regarding the sharing of Caledon river water, and consequently no waters would be required to permit the secure and full development of Lesotho's potential benefits.

7.7 By diverting the catchment of the upper Malibamatso River the Oxbow Project would reduce firm flows available to LHWP by 3.5 m^3/s. There would be conseqential losses to LHWP in the form of reduced royalty payments for water deliveries to RSA. Using Treaty data to estimate the possible increase in cost of LHWP, if it was enlarged to compensate for the loss of Oxbow water, indicated that this could lead to a loss of royalties from LHWP of about US$ 15 million (present value 1988, at 6 percent discount rate) over a 50 year period. At best, this could only be taken as a very preliminary estimate. Changes in the LHWP and the adjustment of royalties would likely involve engineering studies to identify and evaluate the cost of any change, and negotiations between Lesotho and RSA to assess the effect on royalties.

PART 8 - ENVIRONMENTAL CONSIDERATIONS

8.1 A study of the environmental impacts of the project indicate that there would be little lasting environmental impact from the project. The reservoir would flood only 300 hectares of summer grazing land, require the relocation of about 2 km of the highway, and require compensation for the loss of Oxbow Lodge, a small inn located on the highway near the upper end of the reservoir. Other land requirements would be small. Bio-physically the biggest impact expected would be the loss of trout fishing in the reaches of the Malibamatso River just downstream of the dam. However, it is expected that a new trout fishery in the reservoir would more than offset the river losses.

8.2 The major socio-economic impacts would occur during the 4 year construction period when local short term benefits due to increased incomes, and some short term social disruption would be encountered. To minimize the latter it is recommended that proper control measures must be adopted during the construction stage to mitigate possible detrimental effects, and that a liaison committee be set up to promote good public relations between the project and affected communities, as well as the effectiveness of mitigative measures. The existence of the reservoir may present the opportunity for increased tourism and related activities in the area.

PART 9 - CONSTRUCTION PLANNING AND COST ESTIMATES

9.1 Construction of the project would take four years. The construction schedule is governed by the progress rates which can be achieved on the critical activities, as well as on the natural river flows, which prescribe specific dates for diversion and reservoir impounding.

9.2 Access to the site, both from within Lesotho and from other countries, is excellent. The ports, highways and railways which would be used are in good condition and, by the time the project commenced, the ongoing paving of the Moteng Pass road would have been completed, leaving only short sections to be built, in order to reach the powerhouse, dam and tunnel adits. A period of five months is considered to be sufficient for the development of this access, as well as to allow for contractor mobilization.

9.3 The low flow season in the Malibamatso lasts from the beginning of April to the end of September. The best time for river diversion is, therefore, around the first of April. The highest flows are experienced during the summer months (Oct-Mar). From an analysis of reservoir filling times it appears that reservoir impounding should start between October and December, to allow generation to commence about 10 months later.

9.4 The principal project milestones are shown below:

Table S-4

Project Milestones

Event	Date
Award of Main Civil Contract	1 February, 1992
River Diversion	1 April, 1993
Reservoir Impounding begins	31 December, 1994
First Power	1 October, 1995

9.5 After the initial mobilization period, the project schedule features two distinct critical sequences of activities.

The first is:

- Diversion Tunnel;
- Dam Foundation excavation;
- Dam Embankment placing;
- Concrete Face Slab completion;

The second runs through the following activities:

- Lower Power Tunnel construction;
- Underground Penstock installation.

The electro-mechanical plant contracts are not on the critical path and their award can, therefore, be delayed for up to 10 months.

9.6 The Oxbow capital cost estimate at mid-1988 price levels is summarized as follows:

Table S-5

Summary Cost Estimate
(US$ x 1000)

Code	Description	Total Amount	Local	Foreign
1.	Direct Costs			
1.1	Land & Environment	825.30	304.08	521.22
1.2	Dam and Reservoir	40382.84	4134.79	36248.05
1.3	Power Generating Facilities	64880.02	6101.16	58778.86
1.4	Power Transmission Facilities	13452.20	1871.17	11581.03
	Total Direct Costs	119540.36	12963.82	106576.54
2.	Indirect Costs	1761.75	420.52	1341.23
	Total Base Costs	121302.11	13384.34	107917.77
	Physical Contingencies	20057.74	2398.52	17659.23
	Total Construction Costs	141359.85	15782.86	125577.00
	Engineering & Project Management At 8 percent construction cost	11300.00	3560.00	7740.00
	Owner's Expenses At 2 percent construction cost	2850.00	2850.00	
	Capital Cost	155509.85	22192.86	133317.00

PART 10 - ECONOMICS

10.1 The project, would generate more than 180 GWh annually from an installation varying from 40-80 MW (2-4 units of 20 MW each). Project optimisation referred to in Parts 3 and 5 indicate that the full supply level of the reservoirs is optimum at 2525 masl and that the benefits do not warrant an installation of more than 80 MW. The investment cost for an 80 MW plant, excluding interest during construction and excluding financial contingencies, is US $ 155 million (For comparative purposes the costs for a 40 MW and a 60 MW plant were determined to be US $ 137 million and US $ 147 million, respectively).Costs and benefits throughout are expressed in constant prices of mid 1988.

10.2 The life of the plant and associated transmission facilities has been assumed to be 100 years. This is a common assumption for the life of the main civil components of a hydroproject. Provision has been made for overhaul and replacement of mechanical, electrical and transmission facilities during this plant life. The cost of operation and normal maintenance, not including the major overhaul/replacement noted has been set at 1 percent of the total investment cost, annually.

10.3 An examination of ESCOM operating conditions and likely future trends indicates that it is unlikely that ESCOM can avoid increased costs for electricity production which exceed the general rate of inflation. It is considered that a real increase in ESCOM rates of 1.5 per cent per annum is probable. Thus base case economic evaluations were calculated assuming a 1.5 per cent p.a. real increase in ESCOM rates. Major indicators were also calculated for rate increases of zero and 2.5 per cent p.a. real.

10.4 At the time of preparing this report, engineering for the LHWP is well advanced and the Government is committed to its execution. However, as long as major components of the scheme are not yet under actual construction, there remains a possibility that the LHWP may not proceed. Thus two scenarios were analysed, one scenario provides for completion of the Oxbow Project in late 1995, with full operation during 1996, without consideration of the LHWP. The other scenario provides for operation of the Oxbow plant from 1996 with the LHWP Phase I also completed and operational by the start of 1996. The current design of the LHWP does not allow for the existence of the Oxbow plant. However, if the Oxbow plant is built, it would divert water from the system which feeds the LHWP, resulting in a decrease of energy generation and a loss of water supply royalties to LHDA.

10.5 For the case of Oxbow operating without LHWP, and as the sole significant generating station in Lesotho (Oxbow Alone), the findings are presented in Table S-6.

Table S-6

Oxbow Alone - Findings of Economic Analysis

Installed Capacity	Load Growth	ESCOM Rate Increase (real)	Internal Rate of Return	Remarks
		% p.a.	% p.a.	
A Base Case				
80MW	As F'cst	1.5	6.3	Generation benefits only.
B Variations from Base Case				
B-1 Capacity:				
60MW	As F'cst	1.5	6.2	Generation benefits
40MW	As F'cst	1.5	5.6	Generation benefits
B-2 Load Growth:				
80MW	15% Above Forecast	1.5	6.5	
80MW	15% Below Forecast	1.5	6.0	
B-3 ESCOM Tariffs:				
80MW	As F'cst	2.5	7.7	
80MW	As F'cst	0.0	4.0	
B-4 With Dowstream Benefits:				
80MW	As F'cst	1.5	7.1	With Downstream Benefits *
B-5 Staged Installation:				
80MW	As F'cst	1.5	6.5	Staged installation 1995 - 60MW 2015 - 20MW added
80MW	As F'cst	1.5	7.0	Staged installation ** + Export 1995 - 60MW 1999 - 20MW added

* Assumes increased municipal water supply to Maseru from the Caledon River plus irrigation to 944 hectares of land in the Hololo and Caledon Valleys.

10.6 For the case of Oxbow co-generating with LHWP from the start of 1996, charging royalty losses against Oxbow, and assuming LHWP generation losses offset by construction savings, the following findings were obtained:

Table S-7

Oxbow with LHWP - Findings of Economic Analysis

Installed Capacity	Load Growth	ESCOM Rate Increase (real)	Internal Rate of Return	Remarks
		% p.a.	% p.a.	
A Base Case				
80MW	As F'cst	1.5	3.8	Generation benefits only.
B Variations from Base Case				
B-1 Capacity:				
60MW	As F'cst	1.5	3.6	Generation benefits
40MW	As F'cst	1.5	3.2	Generation benefits
B-2 Load Growth:				
80MW	15% Above Forecast	1.5	4.2	
80MW	15% Below Forecast	1.5	3.2	
B-3 ESCOM Tariffs:				
80MW	As F'cst	2.5	5.1	
80MW	As F'cst	0.0	1.5	
B-4 With Dowstream Benefits:				
80MW	As F'cst	1.5	4.4	With Downstream Benefits *
B-5 Staged Installation:				
80MW	As F'cst	1.5	3.9	Staged installation 1995 - 40MW 2020 - 20MW added 2030 - 20MW added
80MW	As F'cst	1.5	5.5	Staged installation ** + Export 1995 - 40MW 1999 - 40 MW added

* Assumes increased municipal water supply to Maseru from the Caledon River plus irrigation to 944 hectares of land in the Hololo and Caledon Valleys.

** Assumes that ESCOM's present surplus of capacity ends in 2000, and that subsequently ESCOM would pay Lesotho for firm power purchased from Lesotho at a rate of 90 percent of the

10.7 In determining the internal rates of return for Oxbow in 10.7 above, Oxbow was not penalised for generation losses of LHWP I due to the Oxbow diversion of the upper LHWP catchment. It was assumed that early construction of Oxbow, which would result in a reduction of flows through LHWP I of over 12 percent, should lead to a downsizing of LHWP I to suit the lower flows, and that consequent construction savings would be sufficient to offset the generation losses. In this regard, economic analyses indicate that a cost saving in the construction of LHWP of only US$ 6 million (present value 1988, discounting at 6 percent p.a.) would be sufficient to balance the loss of generation benefits due to the Oxbow diversion. At a discount rate of 10 percent, a construction saving of US$ 2 million would be sufficient to balance the loss of generation benefits.

PART 11 - FINANCIAL ANALYSIS

11.1 At the time of the studies it was not clear how Oxbow power would be marketed. For the purposes of the financial analysis it therefore was assumed that the completed project would be operated by a so-called "stand-alone" company. Thus, a special company, such as a government owned corporation, would assume responsibility for the project. The company was assumed to sell the power generated to LEC at their substation in Maseru at LEC's "avoided cost". For the purpose of this analysis, this assumption had the advantage that the analysis focussed on the financial viability of the project, irrespective of extraneous elements which would be incorporated if the project were to be handed over to an existing agency or company, such as LEC. It was further assumed that the company would start operation on the first of January 1996. The company would then enter the project in its books at the full cost as accumulated to December 31, 1995, including interest during construction. The company would assume the obligation for repayment of the loans obtained to finance construction of the project, on the terms and conditions as applicable to each loan. Any grants obtained for the construction of the project would be entered in the books as initial equity of the Government in the company.

11.2 The project was considered viable if it met two conditions simultaneously:

- There should be no need to increase tariffs of power sold by LEC in Lesotho beyond the levels which would be applicable if LEC purchased the power from ESCOM rather than from the Oxbow project.

- The company which operates the project should meet its obligations from its own resources and would, therefore, not become a drain on Lesotho's operational budget. Deficits might accrue during one or more years if it was reasonable to assume that the company could obtain short term loans from commercial banks, at commercial rates, to cover such deficits.

11.3 The estimated economic rates of return, though solidly positive under the most probable of the alternative assumptions made, are not high. This implies that the financial margin of safety is likely to be relatively small and that the project could run into financial problems, particularly if actual future conditions are less favourable to the project than presently considered most likely. Prudence is an essential element in a financial analysis, requiring that assumptions regarding future conditions should give appropriate weight to relatively unfavourable conditions which could develop. The financial analysis accordingly focussed on the terms of funding which would be necessary to assure financial viability under conditions which would not be very favourable to the project.

- The life of the plant was assumed reduced to 50 years with a 1.5 percent p.a. operation and maintainance charge, but without the specific charges for major replacements as used in the economic analysis.

- The estimated basic cost of the project, US $ 155.5 million in prices of mid-1988, was increased by a general financial contingency of 10 percent, to provide protection against contingencies such as contractor's bids in excess of the estimated costs. The effects of inflationary cost increases were dealt with separately, as a variable assumption.

- Past experience indicates that likely financiers of the project would probably insist on reducing purchases in South Africa to a minimum. The project cost estimate, used in the economic analysis, reflects world-prices with the proviso that equipment and materials are purchased from the cheapest source, subject to satisfactory quality. In many cases, the cheapest source is South Africa, and purchases in South Africa amount to about 36 percent of the basic cost. To allow reduction of such purchases to the minimum the cost was increased by 7 percent.

Thus in the financial analyses the total financial cost of the project, with the base 80 MW plant, was increased from US $ 155.5 million to US $ 181 million, in 1988 prices, not including interest during construction (IDC). IDC was taken into account within the analyses, and varied according to the particular funding package considered.

11.4 The analyses considered financing packages consisting of five standard components. The terms for these components are shown In Table S-8.

Table S-8

Loan Terms

Type of Loan	Grace Period from Year of Completion		Repayment Period After Last Year of Grace Period	
	No. of Years	Rate of Interest	No. of Years	Rate of Interest
		% p.a.		% p.a.
Commercial Loan	1	12	10	12
Normal Export Credit	1	8	12	8
Extended Export Credit	11	8	12	8
Soft Loan	11	1.25	30	3
Grant	-	-	-	-

11.5 For each of 15 cases a complete year by year financial history was calculated, reported and assessed. The cases covered the two principal situations which might arise:

Oxbow operating from the start of 1996 as the sole Lesotho generating plant;

Oxbow and LHWP I co-generating from the start of 1996.

The base parameters under which the project was considered most likely to operate were as follows:

Oxbow installed capacity 80 MW, completed in 1995, fully operational in 1996;

Load growth corresponding to the OvM forecast as extended by Monenco;

Rates for imported energy from ESCOM growing at 1.5 percent real per year;

Foreign inflation growing at 5 percent per year;

Initial analysis was made to assess viability under the base parameters and purely commercial financing. Failing this a financing package was identified, if possible, which would result in a viable project. Then, adjustments required in the financing package were investigated to retain viability under conditions varying from the base parameters. A summary of the financial analyses follows.

Table S-9

Summary of Financial Cases Analysed

Case	Installation Oxbow MW	Installation LHWP I MW	Ann. Load Growth (F=Forecast Rate)	Escom Tariff Escalation 1.5%	Escom Tariff Escalation 0 %	Inflation Percent per Year Foreign	Inflation Percent per Year Local	Financial Package (mlns of US$ of 1988)[1] Comm.	Normal Export	Extended Export	Soft	Grant	Viability
Oxbow Alone													
1	80 in 95		F	x		5	15	181					No
2	80 in 95		F	x		5	15		35	30	50	66	Yes
3	80 in 95		F	x		5-10[6]	15-10[6]		35	30	50	66	Yes
4	80 in 95		F	x		5	15-5[6]		35	30	50	66	Yes
5	80 in 95		F		x	5	15		35	30	50	66	No
6	80 in 95		F		x	5	15		30		95	56	Yes
7	80 in 95		F-15%	x		5	15		35	30	50	66	Marginal
8	80 in 95		F-15%		x	5	15		30		95	56	Yes
9(2)	40/80		F-15%		x	5	15		27		86	50	Yes
Oxbow + LHWP I													
10(3)	80 in 95	70 in 95	F	x		5	15					181	No
11(4)	80 in 95	70 in 95	F	x		5	15					181	Marginal
12(3)	80 in 95	70 in 95	F+15%	2.5%		5	15					181	Marginal
13(2,3)	40/80	70 in 95	F	x		5	15			32	72	59	Marginal
14(2,3)	40/80	70 in 95	F-15%		x	5	15				104	59	No
15(3,5)	80 in 99	70 in 95	F	x		5	15		35	30	50	66	Yes

Notes: 1. Loan terms for components of financing packages are shown in 11.4 above.

2. 40 MW in 1995 and another 40 MW in 1999. Temporary export of surplus from the year 2000. Initial cost US$ 163 mln, plus US$ 20.5 mln at commercial rates in 1999(prices of 1988).

3. Incorporates a payment of compensation for assumed losses of royalties from the LHWP scheme to the Government of Lesotho.

4. Excludes the payment of compensation for assumed losses of royalties from the LHWP scheme to the Government of Lesotho.

11.6 The first 9 cases analysed assumed that Oxbow was the sole significant generation station in Lesotho. The first result of these analyses was to show that Oxbow would not be financially viable if financed solely by commercial loans. However, the project would be financially viable under the base conditions with a financing package consisting of about one third Export credit, one third Soft Loans and one third Grants. Viability under less favourable conditions than assumed, such as no escalation of ESCOM tariffs in real terms, or 15 percent lower growth rate in energy demand, could be achieved by reducing Export credits to about one sixth of the total amount. If ESCOM were prepared to purchase capacity at a reasonable rate when capacity is again needed in RSA an easier loan package would suffice.

11.7 The remaining analyses cover the alternate scenario in which Oxbow and IHWP I co-generate from the start of 1996. Financial viability under commercial financing was not considered, as even without IHWP I sharing the load it had been shown that the project be successful. The analyses showed that even with all financing by grants the project would not be viable under the base conditions. Assuming load growth rates 15 percent above those forecast were coupled with ESCOM rates increasing at 2.5 percent real per year, analyses showed full grant financing still achieved only marginal viability. Project viability in the near future was demonstrated only under conditions in which Oxbow's surplus energy and capacity could be exported at reasonable rates to ESCOM. The case analysed assumed that ESCOM experienced a shortage of capacity by the year 2000, and was prepared to purchase energy from Lesotho at a rate of 90 percent of the tariff applied to power sold by ESCOM to Lesotho. Analysis under these conditions showed construction of Oxbow with an 80 MW capacity available in 2000 would be viable with a loan package of one third Export credit, one third Soft Loans and one third Grants.

11.8 Although no financial analyses were made for delayed Oxbow construction, improving economic returns for delayed Oxbow construction dates indicate that, if IHWP I is constructed as planned, a delay in Oxbow construction of about 15 to 20 years would be required to enable Oxbow to become financially viable under similar conditions to those now applying to construction of Oxbow without IHWP I. Higher than anticipated rates of growth in either energy demand or ESCOM tariffs, or both, could reduce this delay period.

PART 12 - PROJECT PLANNING

12.1 Based on a schedule which would make Oxbow power generation available by the end of 1995, the timing of critical activities which would need to be undertaken by WEMMIN to execute the project are as follows:

- Decision to Proceed	1 Jan 1990
- Call for Engineering Proposals	1 Mar 1990
- Award Engineering Contract	1 Sep 1990
- Call for Civil Construction Bids	1 Jul 1991
- Award Civil Construction Contract	1 Feb 1992
- Call Equipment Bids	1 Jun 1992
- Award Equipment Contracts	1 Jan 1993

12.2 Arrangements for financing the construction of the project should be in place by the time bids are called for the civil construction contract. To this end it would be neccesary to establish a program to investigate sources of funding, and to arrange preliminary meetings with potential donors, as soon as a decision to proceed is taken.

KINGDOM OF LESOTHO
MINISTRY OF WATER, ENERGY AND MINING

Oxbow Hydroelectric Project Feasibility Study

Monenco

OXBOW HYDROELECTRIC FEASIBILITY STUDY - MAIN REPORT

CONTENTS

PREFACE

The Oxbow Hydroelectric Project Feasibility Studies were carried out under the terms of an Agreement between the Ministry of Water, Energy and Mining, of the Government of the Kingdom of Lesotho and Monenco Consultants Limited of Montreal, Canada. The Agreement, signed on 18 February 1987, followed a series of events beginning many years earlier.

The Oxbow Scheme had been identified as having one of Lesotho's best opportunities for indigenous independent hydropower development, and it has been the subject of a number of reports prepared between 1955 and 1984. In 1984, studies of the Lesotho Highlands Water Project (LHWP) concluded that Oxbow site and hydro development was no longer an integral part of the LHWP least cost solution. Preliminary studies on the interaction of an independently operated Oxbow scheme and the LHWP concluded that such a scheme merited further study since it was considered it was possible to develop it ahead of LHWP. On this basis, the Government of Lesotho approached the African Development Fund (ADF), and the resulting Terms of Reference for the Oxbow Hydroelectric Project Feasibility Study were based on discussions between GOL and the ADF mission which visited Lesotho in Februrary 1985.

The Government of the Kingdom of Lesotho (GOL) then negotiated a loan for the African Development Fund to assist in financing the feasibility study of the Oxbow Hydroelectric Project in the upper catchment of the Malibamatso river. The scheme, if implemented, would reduce Lesotho's present near 100% dependence on the Electricity Supply Commission (ESCOM) of South Africa for electricity.

The objectives of the study can be summarized as follows:

1. To select and recommend an optimum design option.

2. To establish and define the specific engineering and operation plan for the selected scheme.

3. To determine whether it has engineering and economic feasibility and justification under anticipated economic and financial conditions.

4. To investigate the possibility and extent of using the power house discharges for irrigation and water supply purposes within Lesotho.

The study was to be carried out in two distinct phases:

Phase 1. Preliminary Justification and Selection of layouts for future study.

Phase 2. Detailed Feasibility Study, culminating respectively in a Preliminary Justifcation Report and a Detailed Feasbility Study Report.

The Terms of Reference for the study included the following description of the project.

"Subject to the specific design recommendations of the proposed studies, the Oxbow scheme basically aims at using the regulated flow diverted from the Oxbow reservoir of about 3.3 cumecs with about 700m of head in a 54 MW installed capacity power station at the foot of Mount Khatibe near Tlhaka in the Hololo Valley. The headrace tunnel would run under the mountain ridge north of the Hololo Valley to a saddle west of Khatibe peak. An intermediate adit could be provided adjacent to the existing Oxbow road. The discharge from the power house would flow down the Hololo Valley to the Caledon River and from there to Maseru, the capital. The Oxbow dam would be located high on the Malibamatso River, about 4 km downstream of the confluence with the Tsehlanyane River regulating the runoff from a catchment area of about 277 km^2, with the highest precipitation in Lesotho. A single circuit 132 kV power transmission line would be constructed from the power station switchyard to a terminal 132/88kV sub-station around Maseru, some 135 km away".

Work on Phase I began in Maseru on March 8, 1987 and was completed at the end of June 1987. A two volume report titled "Oxbow Hydroelectric Project - Feasibility Study-Phase I Report, June 1987 was submitted to the Ministry on July 2, 1987."

In accordance with the Terms of Reference the report was reviewed by the Ministry, and by the African Development Fund. On 5 September 1987 an instruction to proceed with Phase II of the study was communicated to Monenco by the Ministry.

The Phase II study team was mobilized and the Project Manager arrived in Lesotho to initiate the Phase II study on 6 October 1987.

The Phase II studies brought the project studies to a full feasibility level, of study and included, at appropriate levels of detail:

- Topographic Surveys and Mapping
- Geological and Geotechnical Investigations
- Hydrological Studies

- Financial Analysis.

Studies of downstream benefits were included at a more preliminary level, reflecting the present lack of any agreement between Lesotho and Republic of South Africa on use of the waters of the international boundary river.

Field Investigations for the various project features began in December 1987 and were completed in March 1988. The draft report on Phase II was submitted on August 23, 1988.

The project development presented in the report essentially fulfills this description with improvements following the study findings as anticipated in the Terms of Reference as quoted above.

Comments on the draft report were discussed at a meeting attended by representatives of the GOL, the Technical Assistance Consultancy of the LHWP and the consultant in Maseru on December 2, 1988. The comments were also discussed with staff of the ADF in Abidjan on December 5, 1988.

As a result of discussions it was agreed that prior to submission of the final report the scope of the study should be extended to take account of:

1. New forecasts of load and energy demand required to be served by the Lesotho electric system.

2. Newly available information on the value of LHWP royalty payments in as far as they even related to the potential benefits of Oxbow releases into the Caledon River.

After review by the ADF and the Ministry an addendum to the original agreement was approved by the ADF and the Ministry and work on the additional scope of study began on May 1, 1989. The studies were completed in August 1989 and the final report, in 5 volumes plus an Executive Summary was then completed.

The five (5) volume set of reports comprises:

Vol. I of V	Main Report
Vol II of V	Appendix A - Hydrology Appendix B - Power Potential
Vol III of V	Appendix C - Geotechnical
Vol IV of V	Appendix D - Hydroelectric Design Studies Appendix E - Transmission Line Optimization

Data

received from the staff of the Ministry of Water, Energy and Mining

20 Construction of the Lesotho Highlands Water Project is planned under a 1986 Treaty between Lesotho and South Africa, with completion of Phase I now expected by the start of 1996. The primary purpose of the project is to supply water to the Vaal Valley in RSA. A secondary purpose is to develop hydropower in Lesotho. The development of Oxbow would reduce the presently planned catchment of the LHWP I. As a result, firm flows from the LHWP I would be reduced by about 12 percent below expectations and thereby reduce the ability of the LHWP to meet scheduled water deliveries to RSA. Power output from the planned 70 MW LHWP I hydro-powerplant would also be reduced. As a consequence of reduced water deliveries from LHWP to the RSA,or of extra costs in scheme modifications to replace the losses, royalty payments to Lesotho would be reduced. A preliminary assessment suggests royalty losses over 50 years may have a 1988 present value of US$ 15 million. Generation losses might possibily be offset by reduced costs associated with a downsized LHWP I powerplant to suit the reduced water flows.

21 If LHWP Phase I is constructed essentially in accordance with the presently planned timetable, there would be an insufficient market initially to successfully exploit the output of LHWP and an Oxbow Project if both were completed in 1995. In addition it is assumed that Oxbow as the second project would be charged with any losses incurred by LHWP due to the Oxbow diversion. In these circumstances, for an Oxbow Project completed in 1995, the internal rate of return based on generation benefits would fall to 3.8 percent per year. Addition of downstream benefits would bring the rate of return up to 4.4 percent per year. The project would not be financially viable.

22 In the event that LHWP proceeds, assuming that the currently accepted load forecast is realized, and assuming that ESCOM rates increase in real terms by 1.5 percent (real) per year, economic analysis indicates that Oxbow returns would reach levels at which the project would again become viable after a delay in construction of about 20 years, i.e. with Oxbow construction completion in 2015. Construction timing would be affected substantially by the actual growth in demand and particularly by the rise in ESCOM rates.

RECOMMENDATIONS

Although it seems most likely that the LHWP Hydro Phase I development will be constructed by 1996, construction has not yet commenced on the major components of the project. In these circumstances, it is deemed advisable to provide recommendations for the Oxbow Project covering the case where LHWP Hydro proceeds to construction as planned, or where, for some unforeseen reason, construction of LHWP Hydro is deferred for some substantial time. Certain recommendations would apply to both cases though maybe with different degrees of urgency.

CASE 1 - LHWP HYDRO CONSTRUCTION DEFERRED

1 If construction of LHWP Hydro Phase I is deferred, planning of Oxbow should be initiated not later than 1 January 1990 to allow the construction of the recommended Oxbow Project by late 1995.

2 To allow for the timely construction of Oxbow, approaches to potential financing agencies to identify suitable financing for the project should commence, as early as possible, in 1990.

3 Preparation of documents inviting proposals for design and project management should be initiated early in 1990 with a view to appointing a consultant for these services by 1 September 1990.

4 Water supply projects presently planned for Maseru and other communities bordered by the Caledon River should be reviewed to take account of possible savings due to increased Caledon River flows, that would result from construction of Oxbow.

CASE 2 - LHWP HYDRO PHASE I OPERATIONAL BY 1996

1 With Phase I of LHWP Hydro operational by 1996, construction of the Oxbow Project should be deferred until energy demand and/or ESCOM rates have grown sufficiently to provide an adequate return on Oxbow generation.

2 While presently expected growth rates for energy demand and ESCOM tariffs suggest that Oxbow would not be financially viable until about 2015, actual differences in one or both of these rates could substantially affect the first date at which Oxbow would become viable. It is therefore recommended that growth of both energy demand and ESCOM rates be reviewed annually, and that the economic returns for Oxbow be recalculated from time to time according to the actual growth rates.

In view of the low and unreliable flow levels naturally

7 At the powerhouse the best economic return on generation would be obtained by the installation of a multi-unit peaking plant of 80 MW total capacity. The four 20 MW generators would be driven by impulse turbines of the Pelton type.

8 A 138 km long, 132 kV, double circuit transmission line from the Oxbow powerhouse, via Maputsoe, to the planned new Mabote sub-station at Maseru, would permit the delivery of an average of over 180 GWh of energy per year, to the electric system.

9 There appear to be no serious environmental problems associated with either the hydroelectric development or the transmission systems.

10 Natural flows in the Hololo and Caledon Rivers frequently fail in the dry season. The natural, 80 percent reliable, flow would only permit the irrigation of about 160 hectares of agricultural lands along the two rivers.

11 Releases of water from Oxbow powerhouse would improve and stabilise low flows in the downstream Hololo and Caledon Rivers allowing for substantial improvements in urban water supply to Maseru, and greatly improved opportunities for river-fed irrigation. Sufficient improvement of low flows would be realized to save M 20 million (1988 values) in construction costs of effecting an improvement of the Maseru water supply, which is planned for the mid-1990's. In addition, Oxbow would permit the irrigation of almost 1000 hectares of agricultural lands in the Hololo and Caledon Valleys of Lesotho. The returns on this new irrigation, when fully developed, would be worth over M 4 million (1988 values) per year.

12 Present estimates indicate that use of the flow improvement in the Hololo/Caledon solely for irrigation would be limited by the availability of suitable land. However, limited soils survey data available at present in the Caledon Valley may underestimate the amount of land suitable for irrigation.

13 Presently there is no formal agreement between Lesotho and RSA covering water extractions from the Caledon River, which forms part of the international boundary between the two countries. The lack of control of water extractions is an inhibiting factor on any plans Lesotho might have for use of Caledon River water, and has contributed to the low priority given to agricultural soils surveys in the Caledon Valley.

14 The Oxbow project would cost US$ 155.5 million (1988 values not including IDC) and would require almost 4 years to construct. Provided a decision to proceed was made by the start of 1990, the project could be completed by late 1995 with commercial generation

15 Present electrical energy consumption in Lesotho is at the rate of 160 GWh per year with an annual peak power demand of 30 MW (1988 calendar year). All electrical energy is presently imported from the South African utility ESCOM. The forecast, accepted by GOL in late 1988, predicts that energy consumption in Lesotho will reach 555 GWh by 2005 with a peak power demand of 45 MW. The extended forecast used in this study assumes a growth rate of 3 percent per year after 2005. The extended forecast is summarised below:

Year	Peak MW	Energy GWh
1996	74.5	256.0
2000	81.1	294.6
2010	106.3	400.6
2020	142.8	538.6
2030	191.9	723.8
2040	258.0	972.7

P 3-22

16 Oxbow generation, when fully exploited, would replace imports of energy from RSA worth almost M 21 million per year at 1988 ESCOM rates.

21/46 = 4.6 · 10^6

17 A review of the average cost of ESCOM electricity shows that, over the period 1980-1986, ESCOM's tariffs increased, on the average, by 1.5 percent more per year than the general Consumer Price Index in South Africa. ESCOM's coal costs, wages and cost of capital are all likely to rise in real terms in the future, making it likely that ESCOM energy costs, though still low by world standards, will rise in real terms at more than the recent average rate of increase. A future increase of 1.5 percent per annum in real terms is considered probable.

18 Assuming a 1.5 percent rise in real terms in ESCOM tariffs, energy demand growing at the forecast rate, and Oxbow as the sole significant generating station in Lesotho, the project would have an internal rate of return of 6.3 percent per year based on generation benefits only. Inclusion of downstream benefits would increase the rate of return to 7.1 percent per year.

19 Under the same conditions as described in Finding 18 above, the Oxbow project completed by late 1995 would be a financially viable project under financing arrangements containing a suitable mixture of commercial export credits, concessionary loans and grants. This viability is based on generation benefits only, and would hold good even if ESCOM tariffs remained constant in real terms. Constant ESCOM tariffs in real terms would, however, increase the

$181 \cdot 10^6 = 125 \cdot 10^6$ Kwh × 15 * R

R = 9.65 c/Kwh × 2.2 (6b)(ix) = 21.2 c$/Kwh = 137 cR/Kwh ?

R = 18.24 c$/Kwh

the IHWP in the period before such flow enhancements would be available from Oxbow.

CASE 1 OR CASE 2

1 In preparation for expanded irrigation of agricultural lands in the Hololo and Caledon Valleys a program should be initiated to complete soil mapping of the valley lands within irrigation reach of the two rivers.

2 To ensure that Lesotho is able to plan the reliable exploitation of enhanced flows in the Caledon River for irrigation and/or water supply, approaches should be made as early as possible to the Government of South Africa to secure an agreement on water sharing, and on the control of water abstractions from this boundary river.

Monenco wishes to acknowledge the invaluable assistance received from the staff of the Ministry of Water, Energy and Mining and particularly the help given by the Principal Secretary, Mr. Makhakhe, his deputy Mr. Mohapeloa and the liaison officers, Mr. R.T Mochabelele and Mr. L. Molapo for Phase I and Mr. S. Mochoalibe and Mr. B. Sekoli for Phase II. Thanks is also due to the Commissioner of Mines for his assistance in properly storing the geological core samples for the project, and to LEC, LHDA and their consultants for their cooperation.

Supervision at the ADF was provided initially by Mr. A. Rutta and latterly by Mr. M. Sampara, both under the direction of Mr. Desai Chief, NISI 2, all of whom were always most willing to assist and advice.

Monenco would also like to acknowledge the participation of. Michael Mhlanga, socio-economist, and of Lesotho Consulting Engineers, Ltd. who provided valuable services in survey, geology, engineering assistance, drafting and office services to the project.

FINDINGS

1 Hydrological studies have identified a long term average flow of 4.05 m^3/s in the Malibamatso river at the Oxbow damsite from the 288 km^2 highland drainage basin.

2 Geological conditions are excellent for construction of the Oxbow Project. In the vicinity of the reservoir and dam the rock is sound basalt. Geological investigations indicate there are no major faults. In-situ tests indicate low rock permeability. Consequently water losses and grouting requirements are expected to be minimal. Massive sandstone formations at the powerhouse site should provide excellent foundations and problem-free construction.

3 Optimisation studies indicate that a 92 m high dam at the Oxbow site would permit the most favourable exploitation of the Oxbow water resource. The dam would impound a reservoir with a full pool elevation of 2525 masl and a live storage of 72.8 million cubic metres, and would allow the diversion of an average of some 4 m^3/s to the powerhouse. Siltation of the reservoir should not be a operational problem. Estimates indicate at least a 350 year reservoir life under present and foreseeable drainage basin conditions.

4 A concrete faced rockfill dam would provide the most economical use of the site and available materials. Basalt at the damsite would provide excellent fill material for the dam, but it is not suitable as a source of concrete aggregate. Concrete aggregate would be obtained from a large dolerite dyke about 7 km from the damsite.

5 A natural saddle adjacent to the left abutment of the dam would provide an excellent location for an overflow spillway. A spillway with a 175 m long crest leading to a flip bucket would pass the PMF peak flow of 4430 m^3/s with a one metre freeboard at the dam crest.

6 An 11 km power conduit routed south of the Hololo Valley, would most efficiently convey flows of up to 15 m^3/s from the Oxbow Reservoir to a powerhouse on the right bank of the Malifiloane River in the Hololo Valley. The 3 m inverted "U" section power tunnel would comprise a 6330 m long low pressure tunnel, a short vertical connecting shaft, and a low level 2530 m long high pressure tunnel leading to a steel penstock. The upstream 1050 m of the 2020 m long, 1.75 m diameter steel penstock would be laid inside a non-pressurised section of the lower tunnel. A 3m diameter surge shaft with expansion chambers would be required. Rock conditions are good and the tunnels would not require continuous lining. Tunnel

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SUMMARY

PART 1 - INTRODUCTION

1.1 The Oxbow Hydroelectric Project would involve the diversion of water from 288 km^2 of the upper basin of the Malibamatso River in northern Lesotho to the nearby Hololo River basin. This would allow the development of a multi-purpose scheme with the primary purpose of generating electricity, and the secondary purpose of enhancing flows in the Hololo and the downstream Caledon Rivers, with a view to improving these rivers as a source of irrigation and domestic/industrial water supplies. The arrangement of the project is shown on Figure S1.

1.2 The Malibamatso River is one of the principal headwaters of the Senqu River. After it leaves the southern boundaries of Lesotho, the Senqu River is known as the Orange River, and flows generally westwards across South Africa to the Atlantic Ocean. The Hololo River rises just to the west of the headwaters of the Malibamatso River, and flows generally westwards to enter the south-westerly flowing Caledon River. The Caledon for over 200 kilometres forms Lesotho's north-western border with RSA. About 150 kilometres south-west of the point where it receives the Hololo the Caledon parts from Lesotho, and 150 kilometres further to the south-west enters the Orange River. Further downstream again, the Orange receives the waters of the Vaal River, it's major tributary.

1.3 Schemes for damming the Malibamatso River, just downstream of the confluence of the Tsehlanyane and Tlholohatsi rivers, and diverting its flows to the Hololo Valley for power production and other purposes has been studied for at least 30 years. The notion that economical power generation might be possible from such a project is founded on the proximity of the Malibamatso and Hololo Rivers and the large difference in elevation between them. With a separation of only about 11 kilometres from the Oxbow damsite to the Hololo River in the vicinity of Moteng Store, there is a difference in the existing river levels of about 670 metres. The provision of a dam and reservoir at Oxbow would increase this difference to over 700 metres. The possibility of additional benefits from the scheme arises, as the Malibamatso Valley near Oxbow is largely unsettled, while the Hololo and Caledon Valleys are prime areas of settlement and agriculture, and would benefit from enhanced river flows.

1.4 The Oxbow studies, now completed, were carried out in two phases. During Phase I of the studies, reconnaissance visits were made by engineers, and geological and hydrological specialists to the area. Available data from earlier reports, existing mapping and photography were studied, and cost estimates and economic

of the Phase I studies the basic project arrangement was already closely determined. The Phase I studies were reported in June 1987. The Phase II studies refined and optimized the arrangement and carried the design, costing and benefit evaluations to a level appropriate to a determination of the feasibility of the project.

1.5 At the commencement of Phase II, topographic mapping of the reservoir at a scale of 1:5000 with contour intervals of 5m was produced from existing 1:24000 scale aerial photography by the specialist company of McIlhanney in Ottawa, Canada. These maps enabled an accurate assessment to be made of the storage and surface area characteristics of the potential reservoir. Topographic ground surveys were made at all important project locations including the powerhouse, dam, spillway, power intake, surge shaft, penstock route and critical parts of the tunnel route. Mapping at 1:1000 scale with contour intervals of 1m was produced from these surveys.

1.6 Unless otherwise noted all costs, benefits etc. are expressed at mid-1988 price levels.

PART 2 - HYDROLOGY

2.1 Hydrological studies, which had been commenced in Phase I of the studies, were completed. Particular emphasis was devoted to the preparation of a stationary and dependable flow data base at the reservoir site.

2.2 The Oxbow Reservoir catchment is entirely located in the mountain area of northern Lesotho and measures 288 km^2. The region is characterized by grass and shrub covered mountain slopes, incised by the deep watercourses of the River Malibamatso and its tributaries, with elevations rising from 2400 masl to 3300 masl. Soil cover varies from almost nothing on exposed slopes to 0.5 m in thickness adjacent to the river beds, except where the underlying basalt has been eroded to form scree runs. The physiography can be expected to produce rapid, flashy runoff, from very heavy rainfall, giving high flood peaks, but producing relatively low sediment concentrations.

2.2 The climate in the catchment area is temperate, sub-humid and strongly seasonal, with nearly 80% of the precipitation occurring in the summer months of October to March. Temperature, hours of sunshine ,and hence evaporation, decrease with altitude, while humidity increases. Diurnal temperature variations of 12 °C in summer and 20 °C in winter are common in the area. The following table shows the average monthly variation of climatic parameters at Oxbow climate station .

TABLE S-1

Mean Monthly Climate Factors at Oxbow

Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann
Temperature (°C)	8.7	11.	11.	12.	12.	11.	7.0	4.2	1.1	1.2	3.3	6.8	7.4
Rel Humidity (%)	58	56	61	64	70	71	69	60	61	57	54	48	61
Sunshine (%)	62	44	48	49	53	54	63	73	68	66	59	60	54
Wind Run (km/day)	233	218	207	192	174	172	175	164	179	186	195	217	193
Open Water Evaporation (mm)	105	122	138	149	116	112	78	73	38	34	54	78	1101
Rainfall (mm)	136	156	165	190	138	152	98	59	23	22	33	53	1225

Source : WEMMIN

2.3 The potential of a storage project on the River Malibamatso at Oxbow has been recognized for many years. In 1956 WEMMIN constructed a gauging station (G10), about 2 km upstream of the Oxbow damsite, to provide quantitative flow data. Since then, three additional gauging stations have been built on tributaries to the River Malibamatso above the reach in which the damsite is located. A gauging station has also been constructed on the River Motete, which enters the Malibamatso a few kilometres downstream of the damsite.

2.4 Extensive checks were carried out to find and eliminate any systematic or non-systematic errors in the 56 years of G10 records, and to fill in periods of missing data. After correction, the resulting flow data base was screened using double mass curve analysis and a series of statistical tests, and was found statistically consistent and reliable. The resulting monthly flow data base transposed to the dam site is summarised in the table below, and the long term annual runoff at the damsite can be expressed as :

- an average flow rate of 4.05 m3/s,
- a volume of 128 hm^3 ,or

$\frac{443}{1225}$ – 36%

$\bar{Q}$ = 7.67 $\bar{R}$=0.69

TABLE S-2

Oxbow Damsite - Historic Inflows

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
						(in m^3/s)							
Max	19.16	18.88	27.71	19.25	17.42	15.83	15.31	16.37	4.29	3.42	10.46	25.73	7.67
Min	0.10	0.20	0.05	0.13	0.43	0.26	0.13	0.04	0.03	0.03	0.00	0.00	1.83
Mean	4.30	6.77	6.71	7.48	7.58	5.49	4.32	1.89	0.75	0.55	1.05	1.72	4.05

Based on 1930-86 record

2.5 Elevation/area/storage curves were prepared for the damsite from the 1:5,000 mapping. The major reservoir characteristics were calculated as follows:

TABLE S-3

Oxbow Reservoir Characteristics

	Elevation	Surface Area	Gross Storage
	(masl)	(ha)	(hm^3)
	2440	0.0	0.0
	2474	-	6.6
L.S.L	2480	67.5	10.1
F.S.L	2525	295	82.9

2.6 Existing studies and sediment measurements on the Malibamatso River were reviewed. This review showed that at Katse, about 60 kilometres downstream from Oxbow, a sediment yield of 80 t/km²/year could be predicted, with lesser yields further upstream. Although the degree of cultivation above Oxbow reservoir is less than that above Katse reservoir, it was decided to adopt the sediment yield for Katse as a conservative estimate of the average annual yield at Oxbow.

2.7 The deposition of sediment in the reservoir would adversely affect the operation of the hydroelectric power plant when the level of sediment in the reservoir approaches the invert of the power tunnel intake (2474 masl). Three patterns of sediment accumulation were analyzed assuming the 80 t/km^2/year sediment yield, and assuming a deposit density of 1.35 tonnes/m^3. It was calculated that sediment deposition would require at least 385 years to reach the power tunnel invert.

2.8 Flood peaks and volumes were calculated for floods with return periods of up to 1 in 10,000 years. The Probable Maximum Flood (PMF) was also derived. The PMF was estimated to produce a peak flow of 4950 m3/s at the Oxbow damsite. This value is approximately 1.8 times the 10,000-year flood peak and is equivalent to a Creager C value of 140. This value of "C" is higher than previously observed flood "C" values in South Africa and appears quite conservative as a basis for spillway design. It is noteworthy that a value of 2 x 10,000 year peak is sometimes used as a "rule of thumb" estimate of the PMF peak.

PART 3 - POWER POTENTIAL

3.1 As yet Lesotho has no significant indigenous generating capability. Essentially all electrical energy is imported from the South African utility ESCOM, and distributed within Lesotho by LEC. Generation benefits of the Oxbow project were therefore measured in terms of savings resulting from the reduction of imported energy from ESCOM.

3.2 In addition to Oxbow, GOL has plans for a substantial hydropower facility to be constructed as part of the Lesotho Highlands Water Project (LHWP). The LHWP was conceived primarily as a scheme to divert water from the Lesotho Highlands for use in the Vaal River Valley in South Africa. Phase I of the LHWP includes a dam on the Malibamatso River at Katse, downstream of Oxbow, and a dam on the Senqunyane River at Mohale. Water from the Mohale Reservoir will be diverted by a tunnel into Katse reservoir. Water for export to the Vaal will be released from Katse Reservoir to flow north to RSA by gravity flow through a series of two tunnels. The first tunnel will discharge into a reservoir at Muela on the Nqoe River (tributary of the Hololo). The second tunnel will pass flows from Muela directly to the Ash River. Phase I plans include a 70MW underground hydropower facility just upstream of Muela. Figure S2 shows the arrangement of LHWP Phase I, and its relationship to Oxbow in diagrammatic form.

3.3 In early 1988 LHDA estimated generation from the LHWP Phase I powerplant as 150 GWh in 1995, building up to 516 GWh in 2007. However, by late 1988, LHDA plans anticipated that first generation would be delayed until 1996. The generation estimates were based on the availability to LHWP I of all natural inflows to Katse reservoir, including those from the Malibamatso basin above Oxbow. Clearly these upper Malibamatso flows cannot be diverted by Oxbow to the Hololo Valley and at the same time flow into Katse reservoir. Consequently, for the purposes of the Oxbow studies, the LHDA estimates of LHWP generation were reduced to take account of the smaller catchment available to LHWP.

3.4 Lesotho imports electrical energy at four points on it's borders with RSA. The principal connection is at Maseru where 90 per cent of all energy is imported. About 10 per cent of energy enters at Maputsoe, with very small imports at two other points. The import point, which serves the Hololo Valley, was formally of more importance when its prime function was to serve the now-defunct diamond mine at Letseng-la-Terae. The effect of mine demand, between about 1977 and 1983, is very noticeable on curves showing the historic growth of energy and peak power demand in Lesotho (see Figure S3). In the 11 year period between 1976 and 1987 annual energy consumption in Lesotho has increased from 40.4 GWh to 156.2 GWh, equivalent to an average annual growth rate of 13.1 per cent throughout the period. In the 3 year period, 1984 to 1987, annual energy consumption has risen at an average annual rate of 10.9 per cent from 115.2 GWh to 156.2 GWh. During 1988, maybe fuelled by the

3.5 At the commencement of the Oxbow studies an electrical load demand forecast prepared by IMC in 1984 (the IMC Median Forecast) formed the base case by which GOL generation projects were evaluated. During 1988 a new evaluation of future load demand was undertaken by Oskar von Miller as consultants to LHDA. The results of OvM's work were not available during the study period leading to the draft final Oxbow Report of August 1988. However, in late 1988, a new forecast by OvM was accepted by GOL. Consequently, before issue of the present report, generation planning models were rerun using an extended version of the new forecast to redefine Oxbow generation potential. The new generation data was used in the determination of Oxbow generation benefits and in the reported economic and financial evaluations of the project.

3.6 Generation planning studies were carried out initially to optimize various features of the Oxbow Project, and thus enable the selection of an optimum project. For instance, using an assumed installed capacity of 60 MW, computer models were used to simulate and optimize operation of the project with increasing reservoir capacities. The maximum present value of generation benefits was calculated for each increasing reservoir size. Using design and cost data the increasing benefits were compared with the increasing cost levels required for construction and operation. It was found that the optimum benefit would be reached by constructing a reservoir with a full pool elevation of 2525 masl.
Similar analyses were used to calculate an optimum installed capacity of 80MW. The effects of changes in the length, cross section and type of lining of the power conduit were evaluated by the same methods to find the most economic combinations. Present value calculations for all of the alternatives considered were calculated at a discount rate of 6 per cent per annum.

3.7 For the finally recommended arrangement of the Oxbow Project, computer models were used to simulate reservoir operation and power generation, and to calculate the streams of generation benefits which would accrue over a 50 year period of operation. To allow for evaluation of staged installation of the generating plant, generation data and benefit streams were calculated for Oxbow installations of 40MW, 60MW and 80MW. Average annual production of over 180 GWh delivered at the Maseru load centre was calculated. Two cases were evaluated, the first, 'Oxbow Alone', assumed Oxbow to be the only significant generating plant in Lesotho, the second assumed that the planned first stage of LHWP was completed by January 1996, and included a 70MW hydropower plant with output characteristics as advised by LHDA in March of 1988. Oxbow generation in both cases would commence on 1 January 1996. In the second case, as the two projects have overlapping catchment areas, the LHWP energy outputs were reduced to take account of the loss to LHWP of the catchment above Oxbow Dam. Oxbow generation benefits were calculated in each case as the reduction in payments by LEC for imported ESCOM energy which would result from the addition of Oxbow to the system. The growth of Oxbow annual generation benefits over the first 50

flows.

PART 4 - GEOLOGY

4.1 The Oxbow Project is located in an area of high topographic relief, which varies from an elevation of 2440 masl in the riverbed at the damsite to over 2800 masl along the tunnel alignment down to 1800 masl at the powerhouse site. The upper part (dam and intake) of the project lies in an eroded volcanic plateau characterized by steep slopes and deeply incised river valleys. The penstock and powerhouse are located in less extreme topography in the Hololo River Basin.

4.2 Two major rock formations occur in the project area. The Lesotho Formation Basalts are plateau-type basalts consisting of a horizontal succession of flows ranging from elevation 1835 masl to the highest peaks at about elevation 3200 masl. The individual lava flows vary in thickness from 0.5 m to 20 m. Dolerite intrusives occur throughout the basalt as steeply-dipping dykes, or sills concordant to bedding. The Clarens Formation Sandstones underlie the basalt with the contact near the powerhouse site occuring at about elevation 1835 masl. They consist of a uniform, widely jointed, fine grained quartzose sandstone having a calcareous matrix.

4.3 The sites of the dam, diversion works, spillway, power tunnel, and reservoir lie completely within the basalts. The powerhouse site is in the Clarens sandstone. The surface penstock passes over the basalt-sandstone contact en route from the power tunnel to the powerhouse.

4.4 A comprehensive geotechnical investigation program was carried out between January and April 1988 comprising:

- airphoto interpretation;
- surface geological mapping;
- core drilling;
- augering, test pitting and trenching;
- in-situ testing (permeability and dilatometer);
- laboratory testing of soil, rock and water.

4.5 Bedrock and surficial mapping was carried out at the dam, spillway, power intake, tunnel alignment, penstock, powerhouse, prospective rock quarry sites and borrow areas. A total of 1080 linear metres of drilling was completed in 17 borings during the drilling program. Of this total, 301 m was drilled in the area of the dam, 150 m at the spillway, 20 m in a potential quarry area, 99 m in the powerhouse area and the remaining 510 m along the proposed alignment of the power tunnel. A trench was excavated from ground surface to bedrock on both abutments along the dam axis.

4.6 A total of 202 permeability tests were performed in 12 boreholes. Dilatometer testing was carried out at 16 locations in 5 boreholes, to evaluate the strength and

were obtained for laboratory

testing. Dolerite samples were obtained from a large dolerite dyke about 5 km upstream of the damsite.

4.8 A series of laboratory tests were carried out on soil and rock samples. Testing of rock samples was done to determine strength characteristics and evaluate suitability as rockfill and concrete aggregate. Testing on soils was done primarily to assess their properties as fill materials. Samples of river water were also tested.

4.9 The investigations did not reveal any faults or other significant structural features and showed the bedrock to be of high strength and very low permeability. It permitted the following assessments:

- Bedrock of dense and amygdaloidal basalt underlies the dam and cofferdam sites. Rock quality is excellent from the standpoint of high strength and low permeability. Some grouting will be required but grout takes are expected to be low.

- The proposed spillway is located in a saddle of a bedrock ridge which is covered with a veneer of overburden. The basalt bedrock is more permeable at surface than at depth. However, the more permeable rock would be removed by the neccesary spillway excavation. Excavations could be made with vertical slopes. Spillway flows from the flip bucket would discharge onto sound basalt at riverbed level. No significant rock erosion is expected to occur.

- The power tunnel intake portal would be excavated in an exposed rock face which slopes at about 30^0 from the vertical. Bedrock conditions are excellent for developing the portal. Stable rock cuts could be excavated as steeply as vertical.

- The power tunnel would be driven in uniform high-quality basalt for almost its entire length. A minor amount of dolerite would also be encountered, and basalt/dolerite contact zones may be weak and possibly water-bearing. The only other water bearing horizons which may occur are along lava flow contacts. It is not anticipated that a final lining of concrete would be required except in occasional sections of faulted, sheared, fractured or altered rock. For most of the tunnel, shaft and surge shaft, rock reinforcement in the form of rock bolting would be adequate for long term stability. Shotcrete would also be necessary where rock conditions warrant, for instance in amygdaloidal basalt which may tend to weaken in time because of mineralogical alteration and erosion of soluble minerals.
- A transition from pressure tunnel to steel penstock would be made 1150 m upstream of the tunnel outlet portal. At this

pedestals inside the tunnel. From the tunnel portal to the powerhouse the penstock supports would also be taken to bedrock.

- The powerhouse would be founded on uniform, high strength and very widely-jointed, massive sandstone. Excavation conditions would be ideal and smooth rock walls could be blasted vertically to the required depth. Seepage into the excavation through rock would be very low due to the low rock permeability.

4.10 A survey was made of the reservoir rim. This work consisted of airphoto interpretation and ground traversing from the damsite to the upstream limit of the reservoir. An assessment was made of potential slope instability of rock and soil, and seepage from the reservoir.There is too little soil on the slopes surrounding the reservoir to pose any danger from slumping into the reservoir. The rock is composed of flat-lying layers of basalt which do not have any prominent structural weaknesses along which a major rock slide could develop. The rock is essentially impervious, a characteristic which precludes the possibility of significant water seepage from the reservoir.

4.11 The investigation for construction materials focussed on locating the required volumes of suitable, impervious fill, granular fill, rockfill, and fine and coarse concrete aggregates. The results were as follows:

- It is estimated that the required impervious fill could be obtained from the excavation of alluvium on the left bank of the damsite supplemented by material from a downstream borrow pit.

- An abundance of sound basalt is available for rockfill for the dam and cofferdam. The recommended quarry site is located about 800 km downstream of the dam axis.

- Natural deposits of sand and gravel suitable for concrete aggregates and filter material were not found in useful quantities in the project area and must be produced by crushing of basalt or dolerite. Based on results of laboratory tests and petrographic analyses it was concluded that dolerite would make durable concrete aggregates while similar tests for basalt were less conclusive. Dolerite would also produce a superior quality of granular or filter materials. It is recommended that concrete aggregates and granular material to be used in the dam be obtained from dolerite, while that required for the cofferdam and access

organic impurities, and soluble salts.

PART 5 - HYDROELECTRIC DEVELOPMENT

5.1 During Phase I of the studies the general arrangement and sizing of the project components was completed in outline. During Phase II the data provided by topographic surveys, reservoir mapping, geological investigations and cost studies were used, in conjunction with generation planning studies and more detailed design, to further define and optimize the layout. Generation planning studies were used to estimate the generation benefits which could be realized by a series of options. These benefits were then compared with the costs of the options on an incremental present value basis to permit selection of the option offering the best economic returns.

5.2 The recommended project arrangement is shown on Figure S1. A reservoir on the Malibamatso River would be impounded by a 92 m high concrete faced rockfill dam. The reservoir would cover an area of 295 hectares and have a live storage of 72.8 hm^3 at it's full supply level of 2525 masl. A free overflow spillway would be set in a natural depression on the left abutment of the dam. A powerhouse, housing four 20 MW generators, would be sited on the right bank of the Malefiloane River about 600 m upstream of it's confluence with the Hololo River near Moteng Store. A power tunnel would be driven from the left side of the reservoir to a point about one kilometre from the powerhouse site and would be connected to the powerhouse by a 1.75m diameter steel penstock.

5.3 Reservoir full pool elevation was selected at 2525 masl on the basis of economic studies which compared the calculated present value of generation benefits for different reservoir full supply levels with the present value of the costs of construction. The low supply level at elevation 2480 masl ensures adequate submergence of the power tunnel intake (invert elevation 2474 masl) while allowing reservoir storage space below the intake level for over 350 years of sediment accumulation.

5.4 The free overflow spillway would include a reinforced concrete overflow weir, chute slab and flip bucket. A flip bucket exit angle of 45° was selected to throw the jet directly into the river channel for all discharges in excess of 1,000 m^3/s. The length of the spillway overflow weir was determined as a result of optimization of spillway and dam costs. For the selected 175 m long spillway, dam freeboard of 6 m over the full supply level of El. 2525 masl allows passage of the Probable Maximum Flood with peak discharge of 4430 m^3/s at one metre freeboard. A combination of surcharge from the 1000 year flood, and set up and wave effects from a 100 year wind was checked to ensure adequate freeboard and found to be satisfactory.

5.5 A concrete faced rockfill dam (CFRD) with symmetrical upstream and [illegible] was selected as the preferred type because

also unfavourable for economic arch dam construction. [illegible]
impervious fill precluded the earth-rockfill type dam from serious

consideration. The CFRD is a well proven design and numerous examples, many of which exceed Oxbow's proposed height of 92 m, have been constructed around the world, and have given excellent performance.

5.6 The CFRD design adopted for Oxbow is considered to have the highest fundamental conservatism against earthquake of any dam type. No rockfill dam has ever been recorded as having failed due to inadequate stability. Nevertheless, earthquake studies were made and analyses were performed to evaluate the stability of the dam under conditions of seismic loading. Using Newmark's method of analysis it was determined that the embankment would not be expected to deform when subjected to the calculated design horizontal acceleration of 0.1g. Based on the observed behaviour of other rockfill dams during seismic loading, the CRFD at Oxbow could be expected to safely withstand much higher seismic loading than that produced by the Maximum Credible Earthquake, of Richter Magnitude 6.0, predicted for the project area.

5.7 Permeability tests showed that bedrock at the dam site is relatively impervious, and it is considered that a grout curtain based on a single line of holes would be adequate for the concrete faced rockfill dam. This grout curtain, would extend to a depth equal to half the reservoir head and would be constructed by drilling through the toe slab of the dam.

5.8 The river would be diverted from its present course to allow construction of the dam. Topographic conditions make a left bank tunnel arrangement easily the most practical and economic form of diversion. A 475 m long diversion tunnel, of 6.2 m inverted-U section would be driven through the left abutment. The dam foundation area would be isolated by an upstream cofferdam with crest elevation of 2468 masl, and kept dry by pumping. The fall in river level between the dam site and the tunnel outlet is sufficient to prevent flood stage backwater reaching the dam foundation, so obviating the need for a downstream cofferdam. The tunnel and cofferdam sizes were optimized to safely handle the 1:25 year diversion design flood in the most economical manner. After completion of the dam the diversion tunnel would be closed with a concrete plug which would incorporate a sealed low level outlet. The outlet could easily be put into service if future developments and policies determine a need for downstream releases, and would allow for discharge rates of up to 500 litres per second.

5.9 The power tunnel intake would be constructed some 1.5 km upstream of the dam on the right bank of the reservoir. The intake would be protected by trashracks. A concrete lined transition tunnel section would lead to a steel lined gate section. At the gate section a bonnetted hydraulically operated high pressure slide gate would be provided to allow closure and dewatering of the conduit for inspection and maintenance. A guard gate would also be installed, in tandem, to allow servicing of the operating gate.

requires the shaft be carried to El. 2538.5 masl. Overspill of surge water was not accepted. The 3 m diameter, unlined surge shaft was designed for a 100% load-off and a 50% load-on condition. To improve the stability of operation, three expansion chambers would be provided to limit upsurge and downsurge, and to control harmonic surges.

5.11 The power tunnel system would consist of an upstream, 6330 m long, high level tunnel connected by a 353m deep vertical shaft, to a 3680 m long low level tunnel which would emerge about 900m from the powerhouse in the Malefiloane River Valley. The unlined tunnels would be of 3m x 3m inverted "U" section. The vertical shaft, also unlined, would have a 3 m diameter circular section. Tunnel size was initially selected at 3 m as the practical minimum (for construction purposes) for tunnels of this length. Later optimization studies indicated economic disadvantages would result if the tunnels were either enlarged or lined. Tunnel gradients, not exceeding 2 percent, were selected on constructional grounds. The route of the upper tunnel was chosen to provide sufficient rock cover to safely contain the high pressure water flows, and is the most direct route to the surge shaft location. To ensure ease of construction, the tunnelling layout has been arranged so that the vertical shaft, which would connect the upper power tunnel to the lower power tunnel, would lie directly below the surge shaft.

5.12 The surge shaft and power tunnel system would be driven entirely in basalt. The excellent condition of the rock obviates the need for continuous protective linings. However, allowance has been made for support systems identified in geotechnical studies.

5.13 In the final 1150m of the lower tunnel, because of insufficient rock cover to resist hydraulic pressures, a 35m long concrete transition plug would be in installed. From this point a 1.75m diameter steel penstock would lead to the ground surface. The penstock would be carried down the hillside on concrete supports founded on bedrock. In order to limit the wall thickness of the penstock to that suitable for field welding without stress relief, the penstock would be fabricated from high strength steel.

5.14 The powerhouse would ultimately include four generating units with an installed capacity of 80 MW. It would be 65m long, including an erection bay, and have an overall width of 16m. The superstructure would be of steel frame construction. A separate frame would support the rails of a 50 tonne overhead crane. Administration offices would be provided adjacent to the generating hall. A small retarding basin just below the powerhouse would protect downstream river users from sudden flow changes when the units were started up.

5.15 Each of the four vertical shaft, Pelton-type impulse turbines would have a rated full load capacity of 20 MW at a net head of 626m and a discharge of 3.73 m^3/s. At full supply level, with a net head of some 700m the unit turbine output would be 23.0 MW. The turbine governors

percent. The generators would be grouped adjacent bus through individual circuit breakers. Two 11 kV feeders would connect the 11kV bus to the two step-up generator transformers.

5.17 The two step-up transformers would be of the Delta-Wye type. The transformer rating is sufficient for each to handle all four generator units, if necessary, so that the need for a spare transformer is obviated. The transformers would be located adjacent to the powerhouse between the switchyard and the hillside and would be separated one from another by concrete fire walls. The transformers would be connected to each switchgear section via circuit breakers and to the switchyard via 132 kV overhead lines.

5.18 The generator station bus would provide power supplies to the unit and station auxiliaries stepped down to 415/240 Volts. Standby and start-up power would be provided by means of a 415 V diesel generator set connected to the station essential service board.

5.19 Powerline carrier (PLC) equipment would be used to tie-in with the existing PLC system to provide telephone links, teleprotection and supervisory control if required.

5.20 Project Access roads, leading to the dam, spillway, intake and powerhouse ,would initially be constructed in gravel and towards the end of construction these roads would be upgraded to permanent project service roads when a bitumen surface would be added to keep future maintenance of the roads to a minimum. The existing A1 road from Butha-Buthe to Mokhotlong would be flooded by the project reservoir for an approximate distance of two kilometres near to the Oxbow Lodge. It would be relocated to a location above the reservoir maximum water level.

PART 6 - TRANSMISSION SYSTEM

6.1 An 11/132 kV switchyard to connect the Oxbow Powerhouse output to the Lesotho system would be located adjacent to the powerhouse. A double circuit 132 kV transmission line would connect the substation to the LEC system.

6.2 The equipment and bus work in the switchyard would meet the following system characteristics :

Nominal voltage	132kV
Maximum operating voltage	145kV
BIL	650kV
Frequency	50Hz
Rated nominal current	600A
System grounding	Effective.

6.3 The proposed switching scheme comprises a single bus single breaker with one bus sectionalizing circuit breaker to provide the flexibility of removing one bus section without affecting the other or its connected feeders.

6.4 The 132 kV circuit breakers would be of the SF6 type. The breakers would be rated at 600A, 25kA symmetrical short circuit interrupting capacity(this value should be confirmed by short circuit studies at the design phase), 3 cycles suitable for high speed single-pole and three-pole tripping and reclosing.

6.5 Surge arresters would be installed in the switchyard to provide prime protection to the power transformers and also general protection for the entire switchyard. The arresters used would be station class gapless type. All outgoing lines would be equipped with line traps rated at 600 A for use with power line carrier equipment.

6.6 Switchyard protection would include:

(i) Transmission Lines :

Main -Multi-zone distance protection
Back-up -Directional ground overcurrent protection
-Breaker-fail protection
Auto-reclosing -Automatic, fast, single or 3 pole reclosing.

(ii) Bus bars -Differential protection

6.7 The transmission line route from Oxbow, via Maputsoe, to the proposed new LEC substation at Mabote near Maseru was chosen after field reconnaisance. It would generally follow the main road for ease of access and, as much as is practical, would avoid mountainous terrain. The line length from Oxbow to Maputsoe is 73km and from Maputsoe to Mabote it is 65km. The total route length is 138km. The selected right of way width is 22 meters.

6.8 The 132 kV double circuit transmission line was designed taking account of local wind, snow and ice conditions. The following overload factors were utilized, and were equated against the maximum applied loads.

Structural steel (towers)	1.25
Conductors, shieldwires, insulators, hardware and foundation	2.00

- The limiting tensions for the conductors and overhead shield wires, expressed as a percentage of the ultimate tensile strength (UTS), were selected as follows to avoid overstressing the cables and to avoid problems with wire fatigue due to aeolian vibration.

  a) Maximum gust, temperature 0°C, tension not to exceed 50 percent UTS.

  b) No wind, temperature 10°C, tension not to exceed 18 percent UTS with the conductor in its final condition,and tension not to exceed 30 percent UTS at 0°C with the conductor in its initial (stringing) condition.

6.9 After analysis of local thunderstorm conditions which show a relatively high isokeronic level of 63 to 100, a shield wire coverage angle of 12 degrees was selected, which would require two overhead shield wires on the transmission lines.

6.10 While the initial output of the Oxbow plant may be less than 80MW, the ultimate capacity of the plant is presently planned to be 80 MW. The transmission line parameters were selected therefore on the basis of their ability to carry the full 80 MW plant output.

6.11 The Monenco in-house computer program TROP (Transmission Line Optimization Program) was used to undertake an economic analysis to determine the optimum conductor. For this analysis the following four conductors were investigated.

Code Name	Aluminum Area
Lynx	183.4 mm^2

economic average span of between 300 and 350 metres. The transmission line design was therefore based on the use of the ACSR "Bear" conductor and an average span of 350 metres. The two circuits would be supported on a single line of galvanized steel towers.

6.12 Data for the ESCOM and Lesotho system now, and as currently planned, was gathered from LEC, ESCOM, and LHDA consultants. The proposed transmission system was then checked by simulating the system on Monenco's in-house computer facilities.

6.13 Steady state load flow studies of the system were carried out under peak and minimum load conditions and for outages at peak load to ensure there would be no loadings in excess of normal rating in any transmission component. Cases were simulated both with Oxbow as the sole Lesotho generating station, and with Oxbow and LHWP Phase I generating. The following criteria were used in evaluating the system performance :

Bus Voltages

- acceptable range under normal conditions: 95% to 105%
- acceptable range under short-time emergency conditions : 90% to 105%
- acceptable range for equipment : 90% to 105%.

Transmission Line Loadings

- limited to the conductor thermal rating, unless restricted to lower values by voltage drop limitations.

Transformer and Generator Loadings

- limited to the maximum MVA ratings under all system conditions
- generator reactive power loading limits based on generator reactive capability characteristics of similar generators.

6.14 A transient stability simulation was carried out to verify the successful operation of the network during and after faults. The transmission system was tested by applying three phase faults on the system which were successfully cleared in 7 cycles.

6.13 The results of the system analyses were satisfactory. However, as so many changes to the system are currently planned, both in Lesotho and RSA, it will be important to repeat the study during the design phase when many of the present proposals will have been implemented, or at least will be in a more advanced stage of design.

PART 7 - DOWNSTREAM BENEFITS

7.1 A prefeasibility level study of the possible downstream benefits of the Oxbow project was included in the Oxbow studies. Downstream of the powerhouse there will be an increase in river flows in the Malefiloane, Hololo and Caledon Rivers. These enhanced flows have the potential to bring positive benefits in the Hololo and Caledon Valleys.

7.2 The studies indicate that increased reliable flow in the Hololo River would increase land potentially irrigable from the river from an estimated 60 hectares, under present conditions, to 526 hectares, an increase of 466 hectares. However, the irrigation limit in the Hololo Valley is due to a restraint on suitable land within economical reach of the river. Due to this, increased flows, surplus to the needs of irrigation in the Hololo Valley, would enter the downstream Caledon River.

7.3 As the Caledon is an International Boundary River it has been assumed that the use of increased flows in the Caledon would be equally divided between Lesotho and RSA. If devoted entirely to irrigation, Lesotho's share of the enhanced Caledon River flows would have the potential for irrigating over 2400 ha. However, as on the Hololo, the availability of suitable land presently appears to be a restraint, with a total of only 1300 hectares of suitable land identified on the Lesotho bank of the Caledon in these studies. To date only limited soil surveys have been made in Lesotho along the Caledon Valley, and it is possible that more land may be identified by future surveys. Irrigation potential from the Caledon River without the flow enhancement was estimated at 97 ha.

7.4 If part of the improved Caledon flows were devoted to municipal water supply, the whole of Lesotho's share of the flow increase could be utilized. In this case, by allocating 1 m^3/s to an increase in river water supplies to Maseru and connected towns, it would be possible to save an estimated M 20 million by removing the need for a proposed Maseru water supply reservoir on the Korokoro River near Mazenod. The remainder of the increased river flows would allow development of the previously mentioned 466 ha on the Hololo, and of 478 ha on the Lesotho bank of the Caledon. The irrigation benefits on this newly available area of 944 hectares would build up to over 4 million Maloti annually over a 12 year development period.

7.5 In addition to the benefits to Lesotho, there would also be benefits to RSA by an increase in their share of Caledon River flows. The flow improvements have the potential to irrigate over 2300 ha. of land in RSA, or provide improved municipal or industrial supplies.

7.6 At present there is no formal agreement between Lesotho and RSA regarding the sharing of Caledon river water, and consequently no waters would be required to permit the secure and full development of Lesotho's potential benefits.

7.7 By diverting the catchment of the upper Malibamatso River the Oxbow Project would reduce firm flows available to LHWP by 3.5 m^3/s. There would be conseqential losses to LHWP in the form of reduced royalty payments for water deliveries to RSA. Using Treaty data to estimate the possible increase in cost of LHWP, if it was enlarged to compensate for the loss of Oxbow water, indicated that this could lead to a loss of royalties from LHWP of about US$ 15 million (present value 1988, at 6 percent discount rate) over a 50 year period. At best, this could only be taken as a very preliminary estimate. Changes in the LHWP and the adjustment of royalties would likely involve engineering studies to identify and evaluate the cost of any change, and negotiations between Lesotho and RSA to assess the effect on royalties.

PART 8 - ENVIRONMENTAL CONSIDERATIONS

8.1 A study of the environmental impacts of the project indicate that there would be little lasting environmental impact from the project. The reservoir would flood only 300 hectares of summer grazing land, require the relocation of about 2 km of the highway, and require compensation for the loss of Oxbow Lodge, a small inn located on the highway near the upper end of the reservoir. Other land requirements would be small. Bio-physically the biggest impact expected would be the loss of trout fishing in the reaches of the Malibamatso River just downstream of the dam. However, it is expected that a new trout fishery in the reservoir would more than offset the river losses.

8.2 The major socio-economic impacts would occur during the 4 year construction period when local short term benefits due to increased incomes, and some short term social disruption would be encountered. To minimize the latter it is recommended that proper control measures must be adopted during the construction stage to mitigate possible detrimental effects, and that a liaison committee be set up to promote good public relations between the project and affected communities, as well as the effectiveness of mitigative measures. The existence of the reservoir may present the opportunity for increased tourism and related activities in the area.

PART 9 - CONSTRUCTION PLANNING AND COST ESTIMATES

9.1 Construction of the project would take four years. The construction schedule is governed by the progress rates which can be achieved on the critical activities, as well as on the natural river flows, which prescribe specific dates for diversion and reservoir impounding.

9.2 Access to the site, both from within Lesotho and from other countries, is excellent. The ports, highways and railways which would be used are in good condition and, by the time the project commenced, the ongoing paving of the Moteng Pass road would have been completed, leaving only short sections to be built, in order to reach the powerhouse, dam and tunnel adits. A period of five months is considered to be sufficient for the development of this access, as well as to allow for contractor mobilization.

9.3 The low flow season in the Malibamatso lasts from the beginning of April to the end of September. The best time for river diversion is, therefore, around the first of April. The highest flows are experienced during the summer months (Oct-Mar). From an analysis of reservoir filling times it appears that reservoir impounding should start between October and December, to allow generation to commence about 10 months later.

9.4 The principal project milestones are shown below:

Table S-4

Project Milestones

Event	Date
Award of Main Civil Contract	1 February, 1992
River Diversion	1 April, 1993
Reservoir Impounding begins	31 December, 1994
First Power	1 October, 1995

9.5 After the initial mobilization period, the project schedule features two distinct critical sequences of activities.

The first is:

- Diversion Tunnel;
- Dam Foundation excavation;
- Dam Embankment placing;
- Concrete Face Slab completion;

The second runs through the following activities:

- Lower Power Tunnel construction;
- Underground Penstock installation.

The electro-mechanical plant contracts are not on the critical path and their award can, therefore, be delayed for up to 10 months.

9.6 The Oxbow capital cost estimate at mid-1988 price levels is summarized as follows:

Table S-5

Summary Cost Estimate
(US$ x 1000)

Code	Description	Total Amount	Local	Foreign
1.	Direct Costs			
1.1	Land & Environment	825.30	304.08	521.22
1.2	Dam and Reservoir	40382.84	4134.79	36248.05
1.3	Power Generating Facilities	64880.02	6101.16	58778.86
1.4	Power Transmission Facilities	13452.20	1871.17	11581.03
	Total Direct Costs	119540.36	12963.82	106576.54
2.	Indirect Costs	1761.75	420.52	1341.23
	Total Base Costs	121302.11	13384.34	107917.77
	Physical Contingencies	20057.74	2398.52	17659.23
	Total Construction Costs	141359.85	15782.86	125577.00
	Engineering & Project Management At 8 percent construction cost	11300.00	3560.00	7740.00
	Owner's Expenses At 2 percent construction cost	2850.00	2850.00	
	Capital Cost	155509.85	22192.86	133317.00

PART 10 - ECONOMICS

10.1 The project, would generate more than 180 GWh annually from an installation varying from 40-80 MW (2-4 units of 20 MW each). Project optimisation referred to in Parts 3 and 5 indicate that the full supply level of the reservoirs is optimum at 2525 masl and that the benefits do not warrant an installation of more than 80 MW. The investment cost for an 80 MW plant, excluding interest during construction and excluding financial contingencies, is US $ 155 million (For comparative purposes the costs for a 40 MW and a 60 MW plant were determined to be US $ 137 million and US $ 147 million, respectively).Costs and benefits throughout are expressed in constant prices of mid 1988.

10.2 The life of the plant and associated transmission facilities has been assumed to be 100 years. This is a common assumption for the life of the main civil components of a hydroproject. Provision has been made for overhaul and replacement of mechanical, electrical and transmission facilities during this plant life. The cost of operation and normal maintenance, not including the major overhaul/replacement noted has been set at 1 percent of the total investment cost, annually.

10.3 An examination of ESCOM operating conditions and likely future trends indicates that it is unlikely that ESCOM can avoid increased costs for electricity production which exceed the general rate of inflation. It is considered that a real increase in ESCOM rates of 1.5 per cent per annum is probable. Thus base case economic evaluations were calculated assuming a 1.5 per cent p.a. real increase in ESCOM rates. Major indicators were also calculated for rate increases of zero and 2.5 per cent p.a. real.

10.4 At the time of preparing this report, engineering for the IHWP is well advanced and the Government is committed to its execution. However, as long as major components of the scheme are not yet under actual construction, there remains a possibility that the IHWP may not proceed. Thus two scenarios were analysed, one scenario provides for completion of the Oxbow Project in late 1995, with full operation during 1996, without consideration of the IHWP. The other scenario provides for operation of the Oxbow plant from 1996 with the IHWP Phase I also completed and operational by the start of 1996. The current design of the IHWP does not allow for the existence of the Oxbow plant. However, if the Oxbow plant is built, it would divert water from the system which feeds the IHWP, resulting in a decrease of energy generation and a loss of water supply royalties to IHDA.

10.5 For the case of Oxbow operating without IHWP, and as the sole significant generating station in Lesotho (Oxbow Alone), the findings are presented in Table S-6.

Table S-6

Oxbow Alone - Findings of Economic Analysis

Installed Capacity	Load Growth	ESCOM Rate Increase (real)	Internal Rate of Return	Remarks
		% p.a.	% p.a.	
A Base Case				
80MW	As F'cst	1.5	6.3	Generation benefits only.
B Variations from Base Case				
B-1 Capacity:				
60MW	As F'cst	1.5	6.2	Generation benefits
40MW	As F'cst	1.5	5.6	Generation benefits
B-2 Load Growth:				
80MW	15% Above Forecast	1.5	6.5	
80MW	15% Below Forecast	1.5	6.0	
B-3 ESCOM Tariffs:				
80MW	As F'cst	2.5	7.7	
80MW	As F'cst	0.0	4.0	
B-4 With Dowstream Benefits:				
80MW	As F'cst	1.5	7.1	With Downstream Benefits *
B-5 Staged Installation:				
80MW	As F'cst	1.5	6.5	Staged installation 1995 - 60MW 2015 - 20MW added
80MW	As F'cst	1.5	7.0	Staged installation ** + Export 1995 - 60MW 1999 - 20MW added

* Assumes increased municipal water supply to Maseru from the Caledon River plus irrigation to 944 hectares of land in the Hololo and Caledon Valleys.

10.6 For the case of Oxbow co-generating with LHWP from the start of 1996, charging royalty losses against Oxbow, and assuming LHWP generation losses offset by construction savings, the following findings were obtained:

Table S-7

Oxbow with LHWP - Findings of Economic Analysis

Installed Capacity	Load Growth	ESCOM Rate Increase (real)	Internal Rate of Return	Remarks
		% p.a.	% p.a.	
A Base Case				
80MW	As F'cst	1.5	3.8	Generation benefits only.
B Variations from Base Case				
B-1 Capacity:				
60MW	As F'cst	1.5	3.6	Generation benefits
40MW	As F'cst	1.5	3.2	Generation benefits
B-2 Load Growth:				
80MW	15% Above Forecast	1.5	4.2	
80MW	15% Below Forecast	1.5	3.2	
B-3 ESCOM Tariffs:				
80MW	As F'cst	2.5	5.1	
80MW	As F'cst	0.0	1.5	
B-4 With Dowstream Benefits:				
80MW	As F'cst	1.5	4.4	With Downstream Benefits *
B-5 Staged Installation:				
80MW	As F'cst	1.5	3.9	Staged installation 1995 - 40MW 2020 - 20MW added 2030 - 20MW added
80MW	As F'cst	1.5	5.5	Staged installation ** + Export 1995 - 40MW 1999 - 40 MW added

* Assumes increased municipal water supply to Maseru from the Caledon River plus irrigation to 944 hectares of land in the Hololo and Caledon Valleys.

** Assumes that ESCOM's present surplus of capacity ends in 2000, and that subsequently ESCOM would pay Lesotho for firm power purchased from Lesotho at a rate of 90 percent of the

10.7 In determining the internal rates of return for Oxbow in 10.7 above, Oxbow was not penalised for generation losses of IHWP I due to the Oxbow diversion of the upper IHWP catchment. It was assumed that early construction of Oxbow, which would result in a reduction of flows through IHWP I of over 12 percent, should lead to a downsizing of IHWP I to suit the lower flows, and that consequent construction savings would be sufficient to offset the generation losses. In this regard, economic analyses indicate that a cost saving in the construction of IHWP of only US$ 6 million (present value 1988, discounting at 6 percent p.a.) would be sufficient to balance the loss of generation benefits due to the Oxbow diversion. At a discount rate of 10 percent, a construction saving of US$ 2 million would be sufficient to balance the loss of generation benefits.

PART 11 - FINANCIAL ANALYSIS

11.1 At the time of the studies it was not clear how Oxbow power would be marketed. For the purposes of the financial analysis it therefore was assumed that the completed project would be operated by a so-called "stand-alone" company. Thus, a special company, such as a government owned corporation, would assume responsibility for the project. The company was assumed to sell the power generated to LEC at their substation in Maseru at LEC's "avoided cost". For the purpose of this analysis, this assumption had the advantage that the analysis focussed on the financial viability of the project, irrespective of extraneous elements which would be incorporated if the project were to be handed over to an existing agency or company, such as LEC. It was further assumed that the company would start operation on the first of January 1996. The company would then enter the project in its books at the full cost as accumulated to December 31, 1995, including interest during construction. The company would assume the obligation for repayment of the loans obtained to finance construction of the project, on the terms and conditions as applicable to each loan. Any grants obtained for the construction of the project would be entered in the books as initial equity of the Government in the company.

11.2 The project was considered viable if it met two conditions simultaneously:

- There should be no need to increase tariffs of power sold by LEC in Lesotho beyond the levels which would be applicable if LEC purchased the power from ESCOM rather than from the Oxbow project.

- The company which operates the project should meet its obligations from its own resources and would, therefore, not become a drain on Lesotho's operational budget. Deficits might accrue during one or more years if it was reasonable to assume that the company could obtain short term loans from commercial banks, at commercial rates, to cover such deficits.

11.3 The estimated economic rates of return, though solidly positive under the most probable of the alternative assumptions made, are not high. This implies that the financial margin of safety is likely to be relatively small and that the project could run into financial problems, particularly if actual future conditions are less favourable to the project than presently considered most likely. Prudence is an essential element in a financial analysis, requiring that assumptions regarding future conditions should give appropriate weight to relatively unfavourable conditions which could develop. The financial analysis accordingly focussed on the terms of funding which would be necessary to assure financial viability under conditions which would not be very favourable to the project.

- The life of the plant was assumed reduced to 50 years with a 1.5 percent p.a. operation and maintainance charge, but without the specific charges for major replacements as used in the economic analysis.

- The estimated basic cost of the project, US $ 155.5 million in prices of mid-1988, was increased by a general financial contingency of 10 percent, to provide protection against contingencies such as contractor's bids in excess of the estimated costs. The effects of inflationary cost increases were dealt with separately, as a variable assumption.

- Past experience indicates that likely financiers of the project would probably insist on reducing purchases in South Africa to a minimum. The project cost estimate, used in the economic analysis, reflects world-prices with the proviso that equipment and materials are purchased from the cheapest source, subject to satisfactory quality. In many cases, the cheapest source is South Africa, and purchases in South Africa amount to about 36 percent of the basic cost. To allow reduction of such purchases to the minimum the cost was increased by 7 percent.

Thus in the financial analyses the total financial cost of the project, with the base 80 MW plant, was increased from US $ 155.5 million to US $ 181 million, in 1988 prices, not including interest during construction (IDC). IDC was taken into account within the analyses, and varied according to the particular funding package considered.

11.4 The analyses considered financing packages consisting of five standard components. The terms for these components are shown In Table S-8.

Table S-8

Loan Terms

Type of Loan	Grace Period from Year of Completion		Repayment Period After Last Year of Grace Period	
	No. of Years	Rate of Interest	No. of Years	Rate of Interest
		% p.a.		% p.a.
Commercial Loan	1	12	10	12
Normal Export Credit	1	8	12	8
Extended Export Credit	11	8	12	8
Soft Loan	11	1.25	30	3
Grant	-	-	-	-

11.5 For each of 15 cases a complete year by year financial history was calculated, reported and assessed. The cases covered the two principal situations which might arise:

Oxbow operating from the start of 1996 as the sole Lesotho generating plant;

Oxbow and LHWP I co-generating from the start of 1996.

The base parameters under which the project was considered most likely to operate were as follows:

Oxbow installed capacity 80 MW, completed in 1995, fully operational in 1996;

Load growth corresponding to the OvM forecast as extended by Monenco;

Rates for imported energy from ESCOM growing at 1.5 percent real per year;

Foreign inflation growing at 5 percent per year;

Initial analysis was made to assess viability under the base parameters and purely commercial financing. Failing this a financing package was identified, if possible, which would result in a viable project. Then, adjustments required in the financing package were investigated to retain viability under conditions varying from the base parameters. A summary of the financial analyses follows.

<u>Table S-9</u>

Summary of Financial Cases Analysed

Case	Installation Oxbow MW	Installation LHWP I MW	Ann. Load Growth (F=Forecast Rate)	Escom Tariff Escalation 1.5%	Escom Tariff Escalation 0 %	Inflation Percent per Year Foreign	Inflation Percent per Year Local	Financial Package (mlns of US$ of 1988)[1] Comm.	Normal Export	Extended Export	Soft	Grant	Viability
<u>Oxbow Alone</u>													
1	80 in 95		F	x		5	15	181					No
2	80 in 95		F	x		5	15		35	30	50	66	Yes
3	80 in 95		F	x		5-10[6]	15-10[6]		35	30	50	66	Yes
4	80 in 95		F	x		5	15-5[6]		35	30	50	66	Yes
5	80 in 95		F		x	5	15		35	30	50	66	No
6	80 in 95		F		x	5	15		30		95	56	Yes
7	80 in 95		F-15%	x		5	15		35	30	50	66	Marginal
8	80 in 95		F-15%		x	5	15		30		95	56	Yes
9(2)	40/80		F-15%		x	5	15		27		86	50	Yes
<u>Oxbow + LHWP I</u>													
10(3)	80 in 95	70 in 95	F	x		5	15					181	No
11(4)	80 in 95	70 in 95	F	x		5	15					181	Marginal
12(3)	80 in 95	70 in 95	F+15%	2.5%		5	15					181	Marginal
13(2,3)	40/80	70 in 95	F	x		5	15			32	72	59	Marginal
14(2,3)	40/80	70 in 95	F-15%		x	5	15				104	59	No
15(3,5)	80 in 99	70 in 95	F	x		5	15		35	30	50	66	Yes

Notes: 1. Loan terms for components of financing packages are shown in 11.4 above.

2. 40 MW in 1995 and another 40 MW in 1999. Temporary export of surplus from the year 2000. Initial cost US$ 163 mln, plus US$ 20.5 mln at commercial rates in 1999(prices of 1988).

3. Incorporates a payment of compensation for assumed losses of royalties from the LHWP scheme to the Government of Lesotho.

4. Excludes the payment of compensation for assumed losses of royalties from the LHWP scheme to the Government of Lesotho.

11.6 The first 9 cases analysed assumed that Oxbow was the sole significant generation station in Lesotho. The first result of these analyses was to show that Oxbow would not be financially viable if financed solely by commercial loans. However, the project would be financially viable under the base conditions with a financing package consisting of about one third Export credit, one third Soft Loans and one third Grants. Viability under less favourable conditions than assumed, such as no escalation of ESCOM tariffs in real terms, or 15 percent lower growth rate in energy demand, could be achieved by reducing Export credits to about one sixth of the total amount. If ESCOM were prepared to purchase capacity at a reasonable rate when capacity is again needed in RSA an easier loan package would suffice.

11.7 The remaining analyses cover the alternate scenario in which Oxbow and LHWP I co-generate from the start of 1996. Financial viability under commercial financing was not considered, as even without LHWP I sharing the load it had been shown that the project be successful. The analyses showed that even with all financing by grants the project would not be viable under the base conditions. Assuming load growth rates 15 percent above those forecast were coupled with ESCOM rates increasing at 2.5 percent real per year, analyses showed full grant financing still achieved only marginal viability. Project viability in the near future was demonstrated only under conditions in which Oxbow's surplus energy and capacity could be exported at reasonable rates to ESCOM. The case analysed assumed that ESCOM experienced a shortage of capacity by the year 2000, and was prepared to purchase energy from Lesotho at a rate of 90 percent of the tariff applied to power sold by ESCOM to Lesotho. Analysis under these conditions showed construction of Oxbow with an 80 MW capacity available in 2000 would be viable with a loan package of one third Export credit, one third Soft Loans and one third Grants.

11.8 Although no financial analyses were made for delayed Oxbow construction, improving economic returns for delayed Oxbow construction dates indicate that, if LHWP I is constructed as planned, a delay in Oxbow construction of about 15 to 20 years would be required to enable Oxbow to become financially viable under similar conditions to those now applying to construction of Oxbow without LHWP I. Higher than anticipated rates of growth in either energy demand or ESCOM tariffs, or both, could reduce this delay period.

PART 12 - PROJECT PLANNING

12.1 Based on a schedule which would make Oxbow power generation available by the end of 1995, the timing of critical activities which would need to be undertaken by WEMMIN to execute the project are as follows:

- Decision to Proceed	1 Jan 1990
- Call for Engineering Proposals	1 Mar 1990
- Award Engineering Contract	1 Sep 1990
- Call for Civil Construction Bids	1 Jul 1991
- Award Civil Construction Contract	1 Feb 1992
- Call Equipment Bids	1 Jun 1992
- Award Equipment Contracts	1 Jan 1993

12.2 Arrangements for financing the construction of the project should be in place by the time bids are called for the civil construction contract. To this end it would be neccesary to establish a program to investigate sources of funding, and to arrange preliminary meetings with potential donors, as soon as a decision to proceed is taken.