Department of Water Affairs
Republic of Botswana

MOTLOUTSE DAM
FEASIBILITY/PRELIMINARY DESIGN STUDY.

ANNEX B

WATER RESOURCES DRAFT

July 1989

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D.WA

Department of Water Affairs
Republic of Botswana

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[redacted]

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This report consists of a

MAIN REPORT
ALBUM OF DRAWINGS

Accompanied by thirteen Annexes :

Annex A: Hydrology

Annex B: Water Resources

Annex C: Geology and Site Investigations

Annex D: Dam Studies

Annex E: Water Supply

Annex F: Soils and Land Suitability

Annex G: Agriculture

Annex H: Markets and Prices

Annex I: Irrigation Engineering

Annex J: Economic and Financial Analysis of Irrigation Development

Annex K: Environmental Impact Studies

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ABBREVIATIONS

AGC	Australian Groundwater Consultants
BCL	Bamangwato Concessions Limited
DWA	Department of Water Affairs
Eo	Open water evaporation
ETo	Potential reference crop evapotranspiration
MAP	Mean annual precipitation
MAR	Mean annual runoff
NSC	North – South Carrier
SMEC	Snowy Mountains Engineering Corporation

CHAPTER B1

INTRODUCTION

B1.1 General

The water resource studies for the Motloutse Dam Feasibility/Preliminary Design Study were carried out between June 1988 and June 1989. The work was carried out in three phases. The first two phases were reported on as part of the Scheme Identification Report (MacDonald 1988) and the Interim Report (MacDonald 1989). This annex briefly summarises and updates the earlier work as well as presenting the results obtained during the last few months of the study.

The primary aim of this study has been to evaluate the water resource potential of a dam on the Motloutse river. To this end five dam sites on the Motloutse have been considered, their locations are given in Figure B1.1. A wider goal of the study has been a more general assessment of the water resource potential of the Middle Motloutse valley. This has served a number of purposes, namely:

- to identify further resources as part of a general improvement of the quality of information for the national water resource inventory
- to identify shortcomings in existing data and provide direction for future studies
- to evaluate the impact of a major dam on other resources, particularly to establish the potential benefits of conjunctive use and the implications on the most appropriate design for each component

Three other water resources have been considered in some detail:

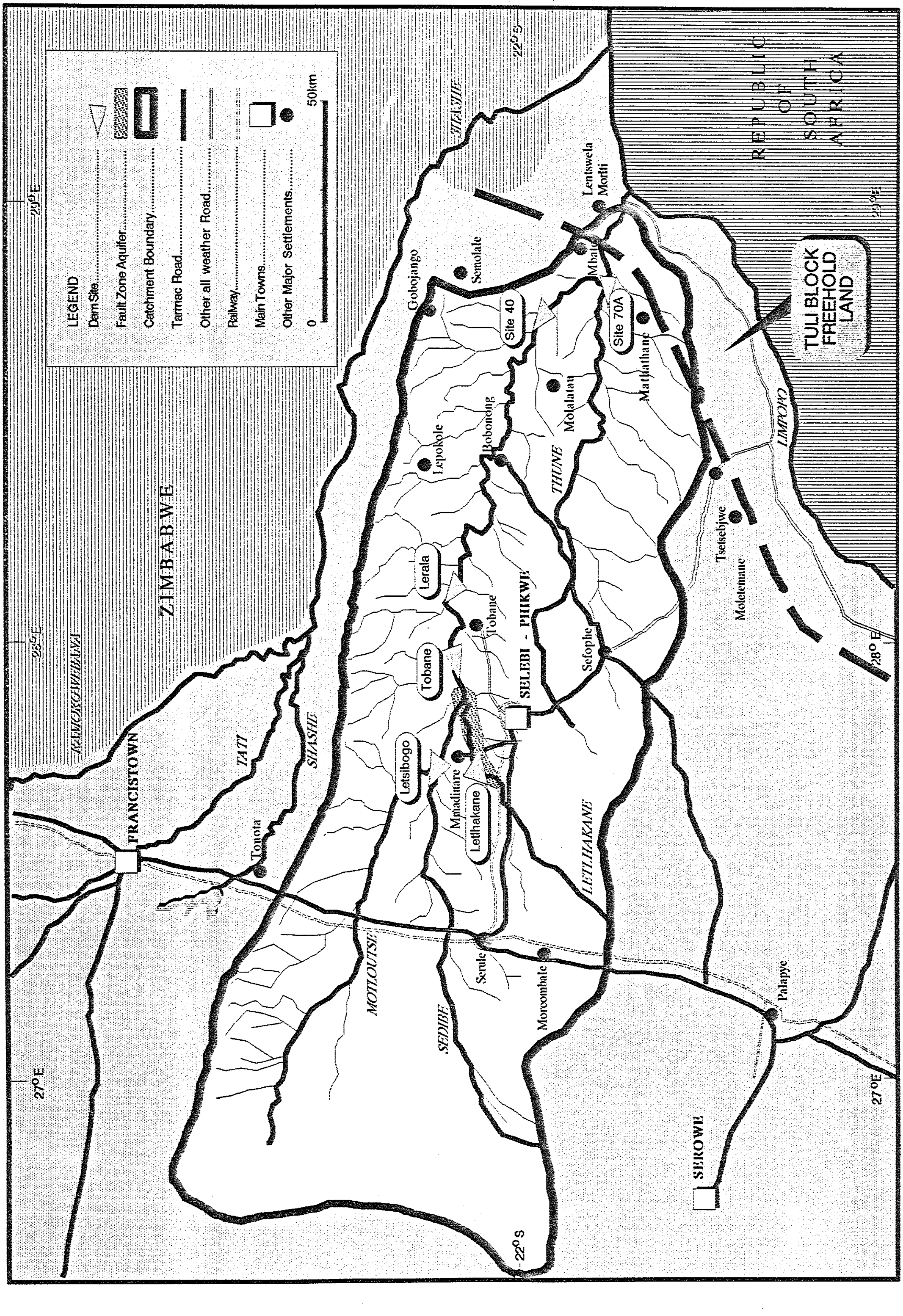
- a small dam on the Letlhakane tributary
- the Letlhakane Fault Zone groundwater resource
- storage within the sand river

The earlier phases of the study have progressively reduced the range of main dam options under consideration, leading to the selection of the Letsibogo dam site as the most economic source of water. Further refinement led to the identification of an optimum reservoir capacity between 100 and 125 $m^3 10^6$. Subsequent work has confirmed these findings. The quality of data available has enabled a thorough assessment of the Letsibogo dam to be completed. Lack of adequate data has, however, limited the level of confidence that can be placed on the conclusions relating to the Letlhakane dam and groundwater resources, which are only considered to have been studied to a pre-feasibility level.

This annex follows from the basic hydrological studies presented in Annex A.

Figure B1.1

Potential Water Resources



CHAPTER B2

RESERVOIR YIELD ANALYSIS

B2.1 Reservoir Operation Modelling

B2.1.1 General

Reservoir yield analysis has been based on a monthly simulation of reservoir operation. For each month the components of the water balance are established, namely river inflow, evaporation loss, direct rainfall and releases from the reservoir. Evaporation and rainfall are dependent on the surface area of the reservoir which is taken as the average of the condition at the start and end of each month. Reservoir releases may be controlled by various operational rules, depending on the prescribed reliability criterion, as discussed below. The reservoir yield is established by a trial and error process using repeated simulations for the 66 year period from 1922/23 to 1987/88, based on the hydrological year, starting in October.

B2.1.2 Reservoir Inflow Sequence

The inflow sequence for each reservoir site has been based on the flow recorded for Tobane gauge. The 66 years of data includes 19 years of actual record, which has been substantially revised by reprocessing during this study. The remaining 47 years of synthesised data has been produced by the Pitman model for the catchment, which was calibrated against the 19 years of reprocessed record, see Annex A, Chapter A4. The basic inflow record is given Appendix B – A.

To establish the inflow record for each dam site a correction factor has been applied to the basic Tobane record. This correction factor is based on the catchment area. A previous assessment of river flows had been made as part of the wide ranging Limpopo Water Utilization Study (MacDonald 1987) which considered the Motloutse catchment in two halves, upstream and downstream of the Tobane gauge. In terms of unit runoff the MAR of these two subcatchments was 8.8 mm/km^2 and 5.3 mm/km^2 for the upstream and downstream catchments, respectively, using the revised catchment areas established by this study. As a result of the reprocessing of the Tobane level records, and subsequent work, the MAR of the upper catchment is now considered to be 94 m^{3}10^6, or 11.8 mm/km^2. As the Letsibogo dam, which is entirely located in the upstream subcatchment, has been identified as the most economic source of water, no attempt has been made to improve the estimate of runoff from the lower subcatchment.

During the first phase of the study the sensitivity of yield to variations in unit runoff was considered (MacDonald 1988). This showed the economic advantage of Letsibogo to be reasonably insensitive to small variations in the split of the gauged flow between the catchment upstream and downstream of the Letsibogo site. For planning purposes it is considered that a split based entirely on catchment area is the only sensible approach. As the Letsibogo catchment covers a significant proportion of the gauged catchment it is unlikely that significant errors will arise, this can only be confirmed when some information is available from the newly installed water level gauging station at the dam site.

The Letlhakane site is somewhat different. The MAR of the Letlhakane catchment could be significantly different from that derived from the assumption of a constant unit runoff, but as it represents a small proportion of the gauged catchment any effect is obscured by runoff from the other areas. It is for this reason that the study of the Letlhakane dam site can only be considered as a pre-feasibility level investigation.

The correction factor for each catchment is based on the proportion within each of the subcatchments, as shown in Table B2.1.

Table B2.1
Derivation of Catchment Correction Factors for Inflow Sequences

Dam Site	Total catchment (km^2)	Area in each subcatchment (km^2) Upper (MAR 11.85mm/km^2)	Lower (MAR 5.3mm/km^2)	Derived MAR ($m^3 10^6$)	Factor for Tobane record
Letlhakane	1 320	1 320	–	15.6	0.166
Letsibogo	5 480	5 480	–	64.9	0.690
Tobane	7 760	7 760	–	92.0	0.978
Lerala	8 510	7 930	580	97.1	1.033
Site 40	11 000	7 930	3 070	110.3	1.173
Site 70A	14 690	7 930	6 760	129.8	1.381

It is possible that the runoff from the lower catchment has been underestimated. Currently there is no gauging station between the Tobane gauge and the Limpopo confluence, 155 km downstream. This makes the task of estimating runoff very unreliable. In Annex A the recommendation is made that a flow gauging station should be installed in the lower subcatchment. Table B2.1 shows the MAR for the lower dam sites to be considerably higher than the Letsibogo site. The preliminary economic analysis (MacDonald 1988) showed the lower dam sites to be economically uncompetitive with those of the upper catchment, nonetheless it is apparent that considerable untapped resource remains for possible exploitation at a later date. No attempt has been made to assess the yields of Site 40 or 70A with the Letsibogo dam in operation.

B2.1.3 Rainfall on the Reservoir

Direct rainfall onto the reservoir provides a significant contribution to the water balance, being equivalent to about 20% of the evaporation loss. The catchment rainfall data derived for the Pitman modelling has been used for this component of the reservoir simulations, with a suitable adjustment made to bring the MAP into line with the regional isohyets, see Figure A2.4, in Annex A. The MAP at the various sites is given in Table B2.2.

Table B2.2
MAP for each Dam Site

Dam Site	MAP (mm)	Factor for catchment average
Letlhakane	430	1.00
Letsibogo	430	1.00
Tobane	410	0.95
Lerala	405	0.94
Site 40	350	0.81
Site 70A	345	0.80

Monthly rainfall figures are given in Appendix B-A.

B2.1.4 Evaporation

Estimates of open water evaporation (Eo) have been taken from the recently completed national study (SMEC, 1987). An annual total of 2 000 mm has been assumed, distributed as for the existing Shashe dam. No account has been taken of any inter-annual variation. The annual total of 2 000 mm is strictly only applicable to the Letsibogo site, although variations between the four upstream sites would be small. As the Letsibogo site has been selected no more detailed consideration has been given to Eo for other sites and the same values have been used throughout. An assessment has, however, been made of the sensitivity of Letsibogo yield to variations in estimates of Eo, see section B2.2.3.

B2.1.5 Initial Conditions

For each simulation the initial conditions have been set by assuming a three year initial period throughout which inflow is set to the average for each month. The reservoir is taken as empty at the beginning of the three year initialisation. This process was adopted because the range of reservoir sizes under consideration was large (from 50 to 200 $m^3 10^6$) and the larger reservoirs benefitted from an initial condition based on a fixed proportion of volume.

The exception to this general procedure is the study relating to reservoir filling. For this analysis the reservoir is taken as initially empty with the simulation used to monitor the rate of filling under a range of inflow sequences, see Section B7.

B2.1.6 Sedimentation

The recently completed sedimentation survey of Shashe dam has confirmed the initial estimates of an annual rate of siltation of 0.33% of MAR. Adopting this proportion for the Letsibogo site results in an annual average influx of 0.21 $m^3 10^6$. The economic analysis has been based on a 45 year operational period of the dam, over which time the expected silt build up would amount to 9.6 $m^3 10^6$. This silt will tend to be deposited at the upstream end of the reservoir. However, for the purpose of reservoir simulation it has been assumed that the silt will be deposited over the entire area of the reservoir. It has also been assumed that the initial value of 'dead' storage (i.e. volume below the lowest point of offtake) of 1.0 $m^3 10^6$ will not be reduced. As reservoir yields would be higher with a smaller volume of dead storage this constitutes a marginally conservative assumption.

The sensitivity of long term yield to variations in the assumed rate of siltation has also been assessed, see Section B2.2.3.

B2.1.7 Reliability Criteria

A number of reliability criteria have been used in assessing the yield of the reservoirs. The main one is the 95/99% criterion required for urban supply. This specifies that the established demand should be met for 95% of months and 60% of demand should be met for a further 4% of months. The point at which releases are cut back to 60% of demand is set by a trigger level in the reservoir, established by a trial and error process. The operation of the trigger rule is such that a decision on the release for each month is based on the level at the beginning of that month. To provide compatibility with previous work the yield of Letsibogo dam has also been assessed at 95% reliability in terms of months, years and volume of water supplied. The results are presented in Section B2.2.2.

Consideration is being given to irrigation as part of a multi-use scheme. As discussed in Chapter B6 it is considered that a 90% reliability criterion should be adopted for irrigation supplies. To assess the quantity of irrigation water available with a predefined primary demand the simulation has been run for a 90/95/99% reliability. This requires two trigger levels, the first controlling the cessation of irrigation and the second dictating the reduction of release to 60% of full demand. The trigger level for irrigation operates in two key months, representing the timing of the decision to plant a crop. If the reservoir level is below the trigger level at the start of October or May then the crop is cancelled and no irrigation water is released for the following six months. Should the level drop below the irrigation trigger level after the decision to plant has been taken then irrigation water is supplied for as many months as possible unless primary demand cannot be met. Once a shortfall in irrigation supplies has been experienced the crop is assumed to have been lost, and no further supplies are released for the remainder of the six month period.

The conjunctive use of the Letsibogo dam with a dam on the Letlhakane or groundwater from the Letlhakane Fault Zone has been considered. With the two surface resources there is an option of controlling releases from both, to minimize combined surface area at the end of the month (to minimize evaporation loss) or the total quantity of spill. This has been accomplished by repeating the simulation each month, with and without supply from the secondary source and selecting the better alternative.

To achieve optimum use of groundwater in a conjunctive use programme a 'pumping' trigger level has been incorporated. This establishes a level in Letsibogo reservoir such that when the level is lower the wellfield is operational. This has the effect of delaying the extraction of groundwater until it is most needed.

Throughout the analysis the primary demand has been held constant, with no inter-annual fluctuation. The demands for irrigation have been varied in accordance with water requirements for the selected cropping pattern.

B2.1.8 Dam Operation in the Early Years after Commissioning

The general method of analysis has been based on establishing the long term steady-state yield for the respective operational reliability. The method establishes a set of operating criteria, which achieve the desired results when applied to the 66 years of inflow record. The growth in demand is such that the Letsibogo reservoir would not be fully committed to meeting urban supply for a number of years after its commissioning. The operation of the dam in these early years, when low demand means it is relatively under-utilized, is critical in assessing both the timing of the next resource and the amount of 'spare' water available for irrigation. Superimposed on this picture of a growing demand is the factor of the reliability of the dam initially filling. The growth in demand is such that by the thirteenth year after commissioning the required yield from the 'northern sources' would be considerably in excess of the yield of Letsibogo dam. The method of analysis has been to select every thirteen consecutive years of record (1922 to 1934, 1923 to 1935, etc) and to assess the performance of the dam in attempting to meet specified demands. The 66 year record allows for 53 such simulations, representing the performance of a dam commissioned in each year from 1922 to 1974. Treating the first year after commissioning as year 1, it is possible to express the chance of failure in the first year of operation as the total number of failure months in year 1 for all runs, divided by the maximum possible number of failure months. Repeating the process for years 2 to 13 enables the reliability of supply in the early years of operation to be established. The results of this analysis are presented in

B2.2 Reservoir Yields for Urban Supply.

B2.2.1 Various Dam Sites

The yields for the range of dam sites considered in phase 1 of the study have been reprocessed using the revised inflow sequence. This has been done to complete the record of analysis for these sites. The phase 1 studies identified the Letsibogo dam as the most economic, and this site is considered in more detail in the following section. The Letlhakane dam site is also considered separately, see Chapter B3. Sample printouts for each site are given in Appendix B – B, these give all the details of reservoir characteristics and subsidiary details of releases, total rainfall contribution, etc.

Table B2.3
95/99% Yield for Various Sites

Dam Site	Reservoir Capacity ($m^3 10^6$)		
	100	150	200
Letsibogo	29.9	32.0	33.0
Tobane	39.2	*	*
Lerala	39.4	45.5	48.1
Site 40	47.4	55.8	59.5
Site 70A	59.9	68.8	73.0

Note * Excluded by topographic limitations

The conclusions reached in phase 1 of the study was that Letsibogo site offered the cheapest source of water. These conclusions were based on the previous estimate of inflow sequence (MacDonald 1988). Subsequent analysis has resulted in a 36% increase in MAR for the Tobane record, see Annex A, Section A4.5. The general conclusions reached in phase 1 are still considered to be valid, for the following reasons:

- In terms of unit cost of water, phase 1 studies identified the Tobane dam as the second most promising, after Letsibogo. The topographic limitations of the Tobane site effectively imposed a limit on storage of approximately 100 $m^3 10^6$. The revised MAR for Tobane site is 92 $m^3 10^6$. Typically, optimum storage for reservoirs in Botswana are of the order of twice MAR, hence the topographic limitations represent an even greater constraint than foreseen in phase 1.

- The third most competitive dam site was Lerala. The margin between Lerala and Letsibogo, as demonstrated in phase 1, is considered sufficiently large to have been unaffected by the revised inflow figures.

- Either of the two dam sites on the lower Motloutse (Sites 40 and 70A) are considered to offer a potential for future development. In this respect the choice of Letsibogo, with its limited catchment, maximises this potential. The findings of the parallel study on the Shashe river (SMEC, 1989) show a Lower Shashe dam to be cheaper than a Lower Motloutse dam, thus setting the benchmark for the marginal cost analysis (see Annex M). Hence, it is considered that the evaluation of Sites 40 or 70A have no bearing on the design of the Letsibogo dam.

B2.2.2 Yields from Letsibogo Dam

The general layout of Letsibogo dam and reservoir are given in Figure B2.1. The reservoir characteristics have been established from the 1:10 000 orthophoto mapping undertaken as part of this study. The stage/area/volume curves are given in Table B2.4 and presented graphically in Figure B2.2.

Table B2.4
Level/Area/Volume for Letsibogo Reservoir

Level (m)	Area (km^2)	Volume ($m^3 10^6$)
828	0.0	0.0
830	0.1	0.1
832	0.2	0.4
834	0.6	1.2
836	1.2	3.0
838	2.3	6.5
840	3.7	12.5
842	5.9	22.1
844	8.6	36.6
846	11.8	57.0
848	15.8	84.6
850	21.0	121.4
852	26.3	168.7

Figure B2.2
Level/Area/Volume Characteristics for Letsibogo Reservoir

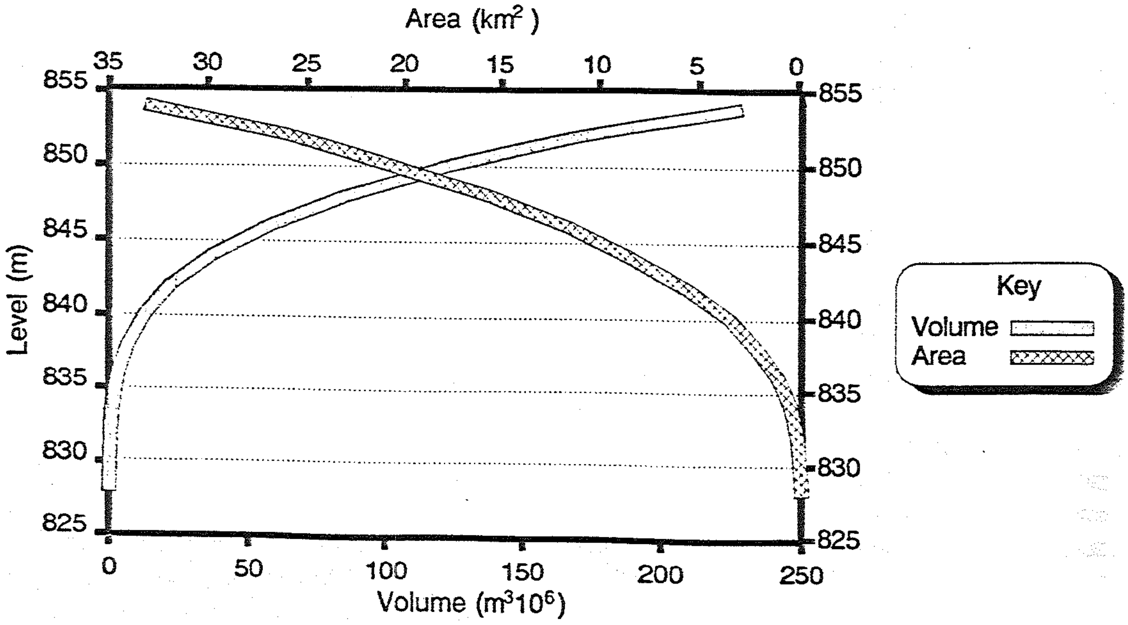
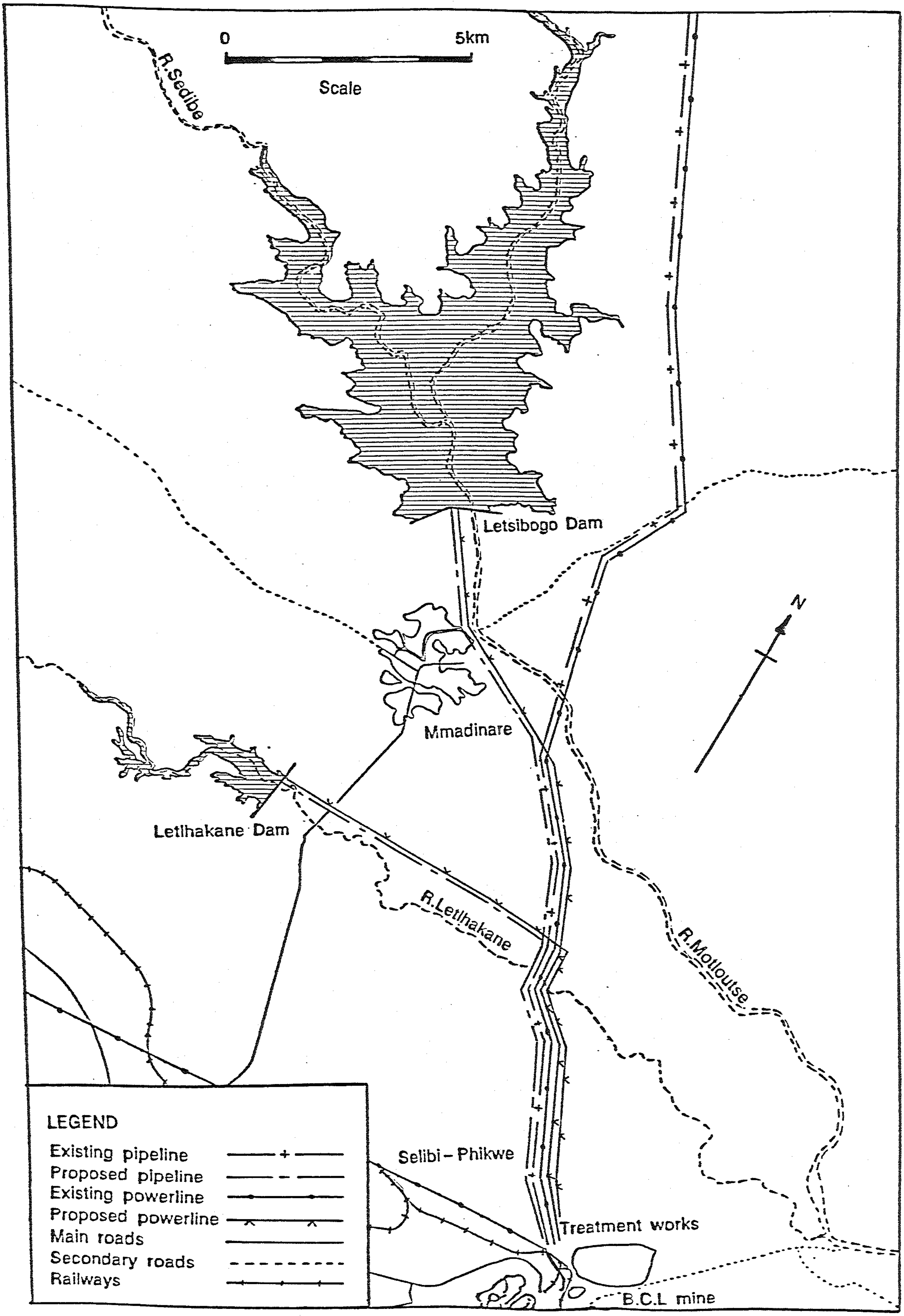


Figure B2.1

Letsibogo and Letlhakane Reservoirs



The long term 95/99% yields for a range of reservoir capacities have been established for the site, both initially and after 45 years of operation with the resulting siltation. The dead storage has been maintained at 1.0 $m^3 10^6$ throughout. The results are given in Table B2.5 and presented graphically in Figure B2.3.

Table B2.5

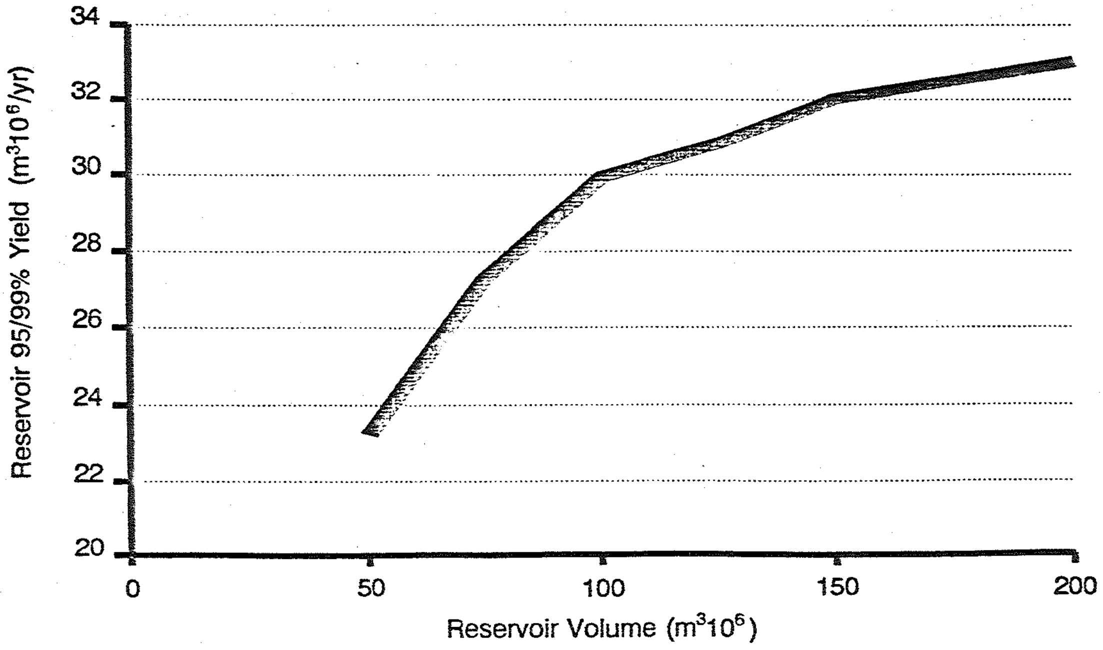
Annual 95/99% Yields for Letsibogo Dam

Reservoir capacity	Initial conditions	After 45 yrs operation	Reduction due to siltation
50	23.2	21.1	2.1
75	27.2	26.1	1.1
100	29.9	29.3	0.6
125	30.8	30.5	0.3
150	32.0	31.7	0.3
175	32.5	32.2	0.3
200	33.0	32.9	0.1

Note: All figures in $m^3 10^6$

Figure B2.3

Annual 95/99% Yields for Letsibogo Dam



The yield of Letsibogo dam has also been assessed under a range of different reliability criteria, with the results presented in Table B2.6.

Table B2.6

Letsibogo Dam Yields for Different Reliability Criteria

Reservoir capacity	Annual yield with no siltation 95% of months	95% of years	95% of volume	80% of months
50	28.4	20.9	30.6	42.9
75	33.4	22.6	35.4	48.6
100	35.5	28.8	37.7	51.2
125	36.6	31.6	38.6	52.1
150	36.8	32.0	39.2	53.0
175	37.6	32.5	39.7	53.7
200	38.2	33.0	40.3	53.9

Note: All figures in $m^3 10^6$

B2.2.3 Sensitivity Tests for Letsibogo Yields

The yields quoted in the previous section are based on a number of assumptions. In order to ascertain the importance of these assumptions the sensitivity to variations of a number of key parameters has been quantified. As the economic analysis has identified the optimum reservoir capacity to lie in the range of 100 to 125 $m^3 10^6$ the sensitivity tests are limited to these sizes. The main factor in establishing reservoir yields is the inflow sequence. In spite of rigorous analysis it must still be recognized that inflows could be less, or greater, than envisaged. The reservoir yield analysis has, therefore, been repeated for variations in inflow of ±20%.

The influence of evaporation estimates has also been investigated, again a variation of ±20% has been used.

The final component to be considered is the rate of siltation. As the reduction in yield due to siltation over 45 years is small (see Table B2.5) there is little point in considering lower siltation rates, consequently only an increased siltation rate has been considered. As the magnitude of variation could be much greater than for the other components the sensitivity to a siltation rate double that assumed has been established, this represents an annual influx of 0.66% MAR or 19.3 $m^3 10^6$ over the 45 year standard period.

The results of the sensitivity tests are given in Table B2.7.

Table B2.7
Sensitivity of 95/99% Yields

Reservoir capacity ($m^3 10^6$)		Base case	Variation in inflow		Variation in evaporation		Variation in siltation
			−20%	+20%	−20%	+20%	+100%
(a) Initial conditions							
100	Yield ($m^3 10^6$)	29.9	25.0	34.7	33.2	27.0	–
	Variation		−16%	+16%	+11%	−10%	
125	Yield ($m^3 10^6$)	30.8	25.9	36.7	34.4	27.7	–
	Variation		−16%	+19%	+12%	−10%	
(b) After 45 years							
100	Yield ($m^3 10^6$)	29.3	24.8	33.2	32.2	26.4	28.0
	Variation		−15%	+13%	+10%	−10%	−4%
125	Yield ($m^3 10^6$)	30.5	25.6	36.1	34.0	27.6	30.0
	Variation		−16%	+18%	+11%	−10%	−2%

From Table B2.7 it can be seen that yield estimates are most susceptible to variation in inflow. Two points are worth noting in this context:

- The Pitman modelling produced a reasonable good fit to the recorded data. There was, however, a tendency to underestimate flows in some of the dry years – see Annex A, Section A4.4. If this is a feature of the synthesised flows then flows in the critical dry years may have been higher than modelled.

- Findings from the sand river model, see Section B5.8, indicate that a significantly greater discharge may have entered the river in dry years than is measured at Tobane gauge. The difference is accounted for by evaporation losses from the bed of the river.

Both these factors tend to suggest that flows in dry years may be higher than are being used in the simulation. Dry years are particularly important in defining the yield of the dam. Set against these two points is the possibility that the unit discharge from the Letlhakane tributary may be higher, to the detriment of Letsibogo reservoir yields. No further consideration can be given to this aspect until some flow records are obtained from the two recently installed water level gauges.

Taking all these issues into account it is considered that using the yields resulting from a variation in inflow of ±20% will provide an adequate range to assess the economic sensitivity to variations in the hydrological parameters.

B2.2.4 Fluctuations in Letsibogo Level and Area

The pattern of fluctuations in level and area of the Letsibogo reservoir influence the possible uses of the water body, considered in the Environmental Impact Assessment, (see Annex K). A plot of these fluctuations helps provide a visualization of the reservoir operation. The 66 years of record is presented in Figures B2.4 and B2.5 for level and area, respectively. In particular the role of the trigger level can be appreciated. The trigger level for reducing release to 60% of long term yield has been optimised as 10.2% for the 125 m^{3}10^6 reservoir capacity. This represents a volume of 12.8 m^{3}10^6 and a level of 840 m.

A further influence of level fluctuations is on the pumping requirements from the reservoir. Pumps have to be designed such that the specified duty point is close to the peak efficiency for the pump set, and the pump can deliver the required discharge over the full range of pumping head. In order to establish the most appropriate reservoir level for pump design, and provide the basis for estimating power requirements, the median level has been established for the range of Letsibogo reservoir sizes. These are presented in Table B2.8.

Table B2.8
Median Reservoir Levels Over 66 Year Simulation

Reservoir capacity (m^{3}10^6)	Median level (m)
50	843.5
75	845.0
100	846.0
125	846.8
150	847.2
175	847.8
200	848.2

The minimum operational level of the reservoir is defined by the dead storage. With an allowance of 1.0 m^{3}10^6 this represents a level of 833.5 m. A typical plot of reservoir level exceedence probability is given in Figure B2.6.

B2.2.5 Bunded Reservoir Option

The recent study of open water evaporation in Botswana, made a preliminary assessment of putting a bund around Gaborone dam, to improve the area volume relationship (Appendix G, SMEC, 1987). To evaluate the possibility of a perimeter levee with regard to the Letsibogo reservoir the area/volume relationship was adjusted to simulate a 6 m bund round the reservoir. The first finding was that the dam height had to be increased by 2 m to maintain the reservoir volume of 125 m^{3}10^6. This does not completely reproduce the proposals outlined by SMEC, but it was considered sufficient to provide a preliminary evaluation.

With a bund following the 846 m contour, and a maximum retention level of 852 m, a 6 m high bund some 27 km long would be required. The maximum extent of the reservoir would be approximately halved, at 12 km^2. Should the proposal be considered further a more detailed assessment of bund alignment would be necessary.

As a result of the bund the annual yield from a 125 m^{3}10^6 Letsibogo reservoir was increased to 33.2 m^{3}10^6, representing an 8% increase. Such a small increase could not justify the expenditure required to construct such a bund. The small improvement as a result of improving the area/volume relationship would suggest that the natural shape of the reservoir constitutes a reasonably efficient storage.

Figure B2.4

Letsibogo Fluctuations in Level

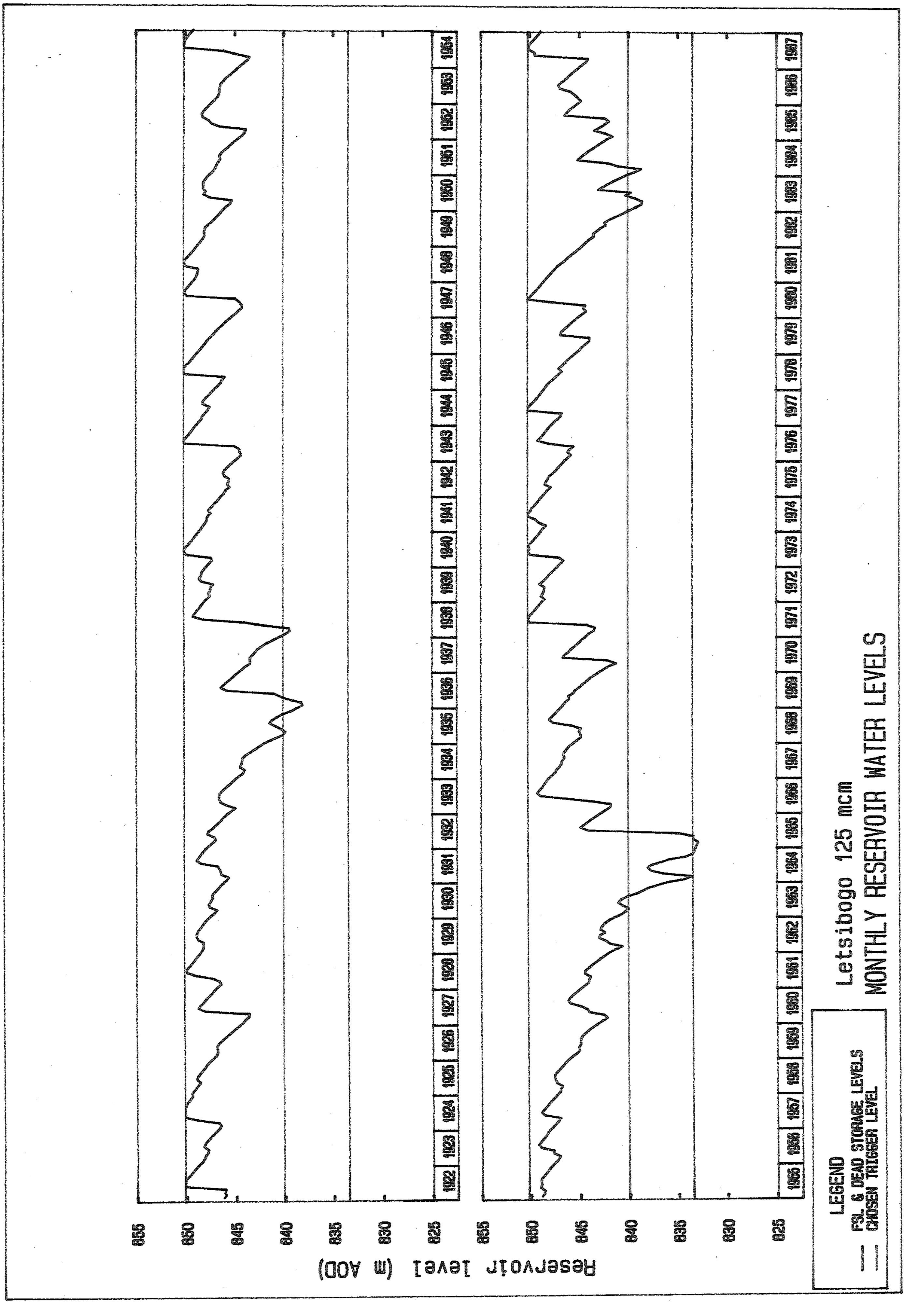


Figure B2.5

Letsibogo Fluctuations in Area

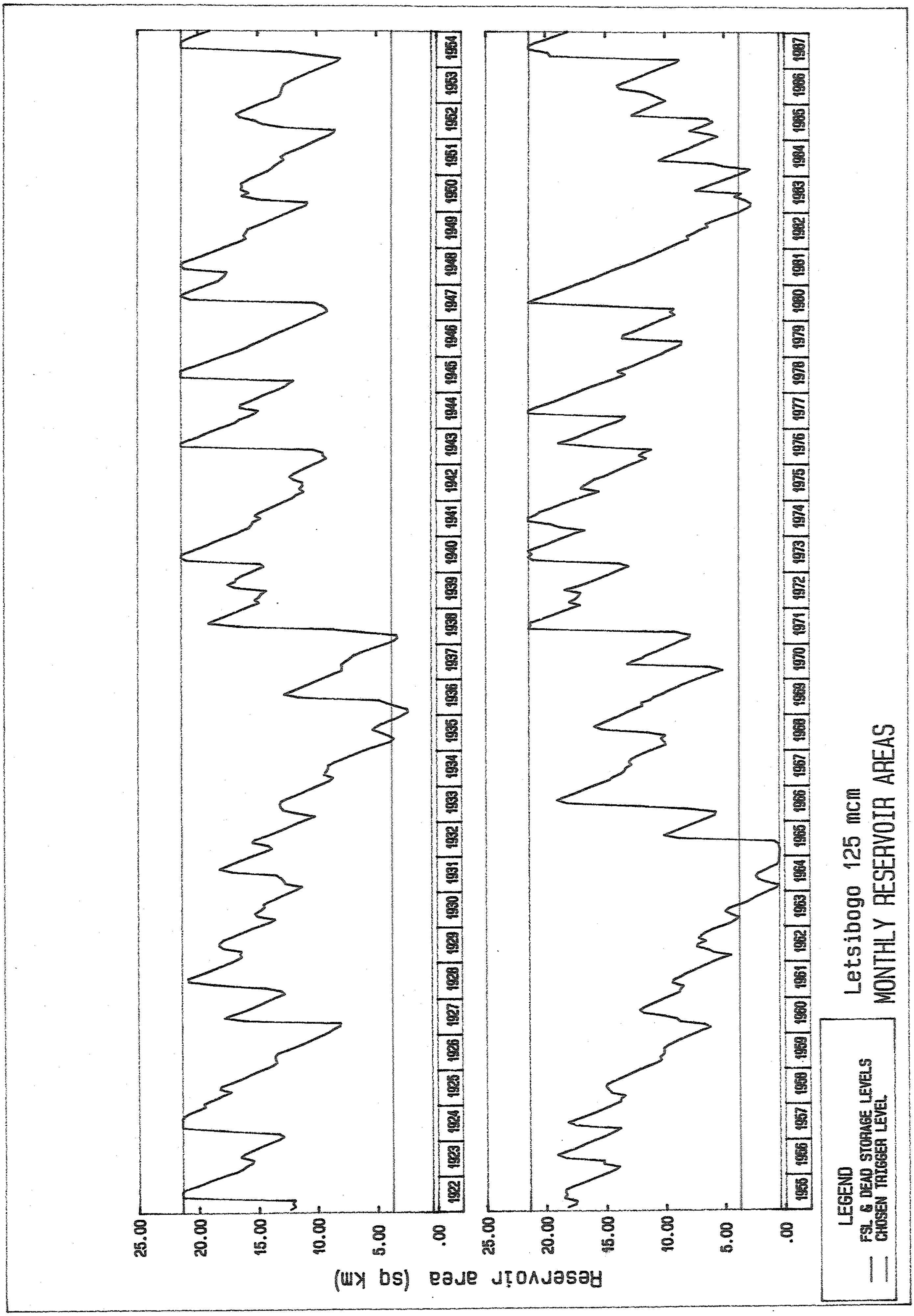
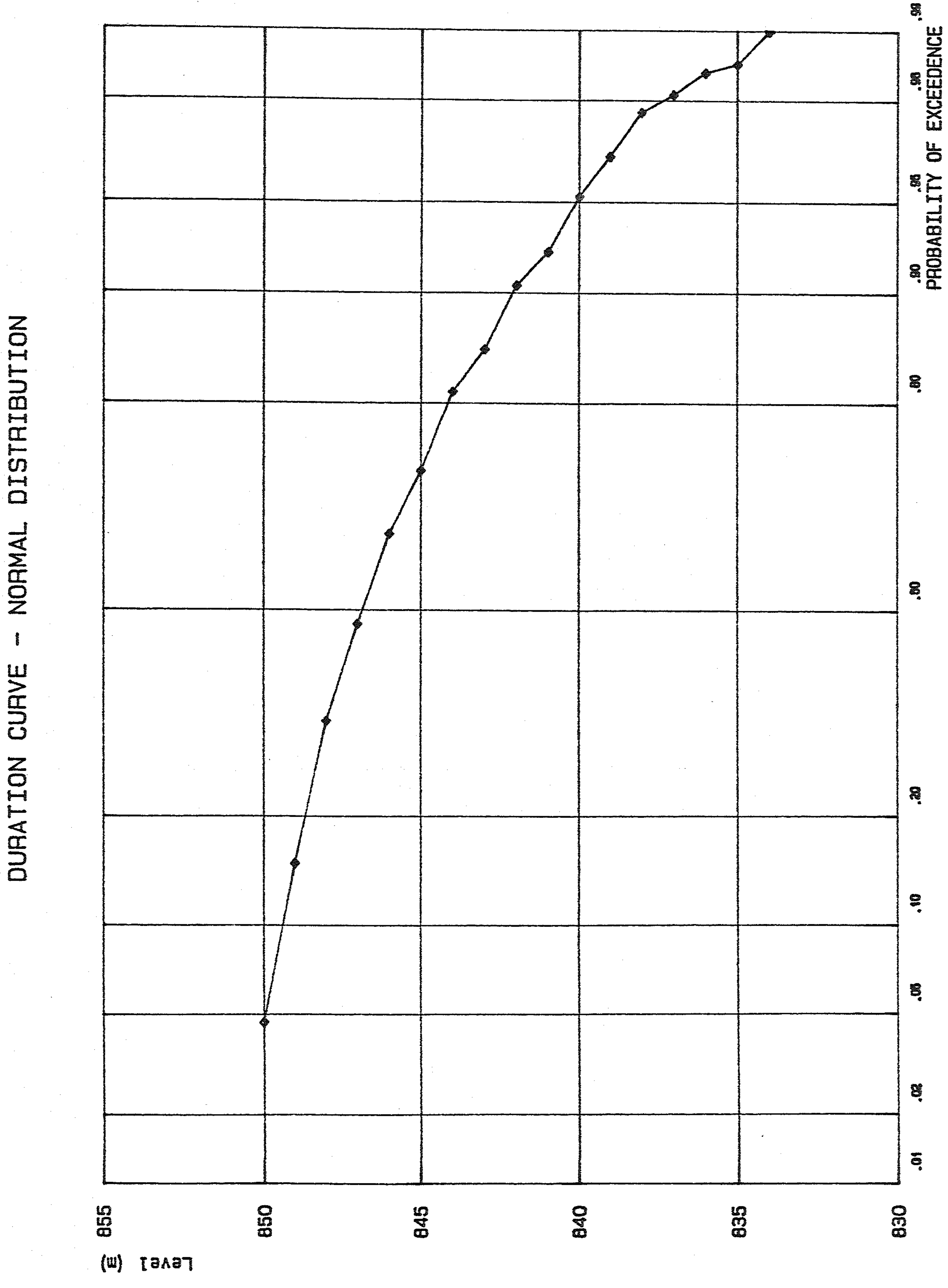


Figure B2.6

Letsibogo Level Frequency Plot



CHAPTER B3

LETLHAKANE RESERVOIR

B3.1 Introduction

The possibility of a dam site on the Letlhakane tributary has been considered to a pre-feasibility level. The level of study is primarily dictated by the lack of flow gauging for the river. The site has the attraction of being close to the Letsibogo site, allowing for the use of common lengths of raw water rising main, see Figure B2.1. The proximity to Letsibogo also leads to the consideration of joint operation. The Letlhakane site was originally considered in the phase 1 studies as a possibility in the event of comparatively high unit runoff from its catchment. The subsequent general increase in estimates of runoff has meant that the site has become more attractive in the case of equal unit runoff from the catchment areas of both the reservoirs. Even so the existence of the site does still offer some safeguard for the main Letsibogo development, inasmuchas the Letlhakane dam could still be sized to give adequate exploitation of the surface water resources should inflows to the main dam be lower than predicted.

With regard to matching the investment in resources to meet the growth in demand, the Letlhakane dam could fit in as the first of the 'northern' dams. However, the considerable uncertainty as to the inflow sequence (see Annex A, Section A4.6) means that dam, pump station and pipeline details could not be finalized in time to meet a commissioning date of 1995. The possibility of a Letlhakane dam fitting into the programme just before the Shashe dam has been considered, primarily to establish if there would be any influence on the optimum size of Letsibogo.

B3.2 Reservoir Yield Estimates

B3.2.1 Single Reservoir

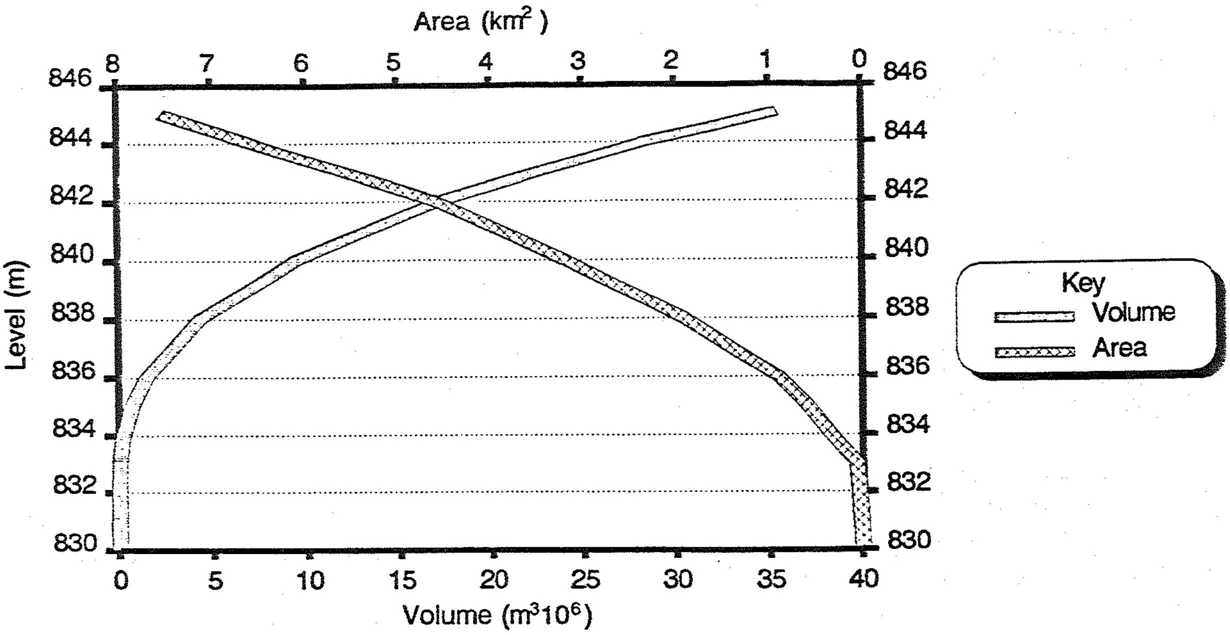
As discussed in Section B2.1.2 the inflow sequence to the Letlhakane site is based on the extended Tobane gauge flow record with an adjustment factor of 0.166. By this method the MAR of the site is estimated as 15.6 $m^3 10^6$. The reservoir characteristics have been derived from the 1:10 000 orthophoto mapping prepared for this study, the basic data is given in Table B3.1 and depicted in Figure B3.1.

Table B3.1
Level/Area/Volume for Letlhakane Reservoir

Level (m)	Area (km^2)	Volume ($m^3 10^6$)
830	0.0	0.0
833	0.1	0.0
834	0.3	0.2
835	0.6	0.7
836	0.9	1.5
838	1.9	4.3
840	3.2	9.4
842	4.6	17.2
844	6.6	28.4
845	7.5	35.4

Figure B3.1

Level/Area/Volume Characteristics for Letlhakane Reservoir



The long term 95/99% yields for a range of reservoir capacities have been established for the site, both initially and after 45 years of operation with the resulting siltation. The dead storage has been maintained at 0.25 $m^3 10^6$ throughout. The results are given in Table B3.2. This initial analysis takes no account of any benefit of conjunctive use with Letsibogo dam. The maximum reservoir capacity of 35 $m^3 10^6$ is set by topographic limitations of the site. Should a larger storage be required then a different site, slightly further down the valley, could be utilized, see Annex D, Chapter D9.

Table B3.2

Annual 95/99% Yields for Letlhakane Dam

Reservoir Capacity	Initial conditions	After 45 yrs operation	Reduction due to siltation
5	2.6	1.7	0.9
10	4.1	3.6	0.5
20	5.4	5.2	0.2
35	6.1	6.0	0.1

Note: All figures in $m^3 10^6$

B3.2.2 Yield of Letlhakane Combined with Letsibogo

The trend of all reservoirs is that greater yield can be taken if the reliability can be allowed to fall. The essence of conjunctive use between the two dams is to release water from the Letlhakane dam, to get high yield, albeit at reduced reliability, and to use the larger storage capacity of Letsibogo to maintain supplies. The configuration being considered is for the Letlhakane raw water pipeline to join with the rising main from Letsibogo to Selebi – Phikwe, see Figure B2.1. The proposed operation is such that full pumping capacity would be provided at Letsibogo dam, as the Letlhakane dam will often be empty, with the quantity pumped in any month reduced to take account of the supply from the Letlhakane dam. A range of dam sizes has been taken for both dams. Pumping capacity from the Letlhakane represents a third independent variable. Consideration has been given to pumping capacities of 10 and 20 $m^3 10^6$/yr. The 95/99% yields are given in Table B3.3.

Table B3.3

95/99% Yields for Letsibogo and Letlhakane Dams

Letsibogo capacity ($m^3 10^6$)	Letlhakane capacity ($m^3 10^6$) 5	10	20	35
(a) Transfer capacity 20 $m^3 10^6$/yr				
50	26.7 (3.5)	27.6 (4.4)	28.9 (5.7)	29.2 (6.0)
75	32.1 (4.9)	32.8 (5.6)	33.6 (6.4)	33.4 (6.2)
100	35.8 (5.9)	36.1 (6.2)	36.5 (6.6)	36.8 (6.9)
125	37.3 (6.5)	37.8 (7.0)	38.1 (7.3)	38.3 (7.5)
150	38.4 (6.4)	38.8 (6.8)	39.2 (7.2)	39.2 (7.2)
175	39.2 (6.7)	39.4 (6.9)	39.9 (7.5)	40.3 (7.8)
200	39.6 (6.6)	40.1 (7.1)	40.7 (7.7)	40.9 (7.9)
(b) Transfer capacity 10 $m^3 10^6$/yr				
50	26.7 (3.5)	27.4 (4.2)	29.1 (5.9)	29.6 (6.4)
75	32.0 (4.8)	32.6 (5.4)	33.1 (5.9)	33.7 (6.5)
100	35.2 (5.3)	35.7 (5.8)	36.1 (6.2)	36.6 (6.7)
125	36.5 (5.7)	37.5 (6.7)	37.6 (6.8)	37.8 (7.0)
150	37.6 (5.6)	38.2 (6.2)	38.6 (6.6)	38.9 (6.9)
175	38.3 (5.8)	38.9 (6.4)	39.4 (6.9)	39.6 (7.1)
200	39.1 (6.1)	39.7 (6.7)	39.8 (6.8)	40.0 (7.0)

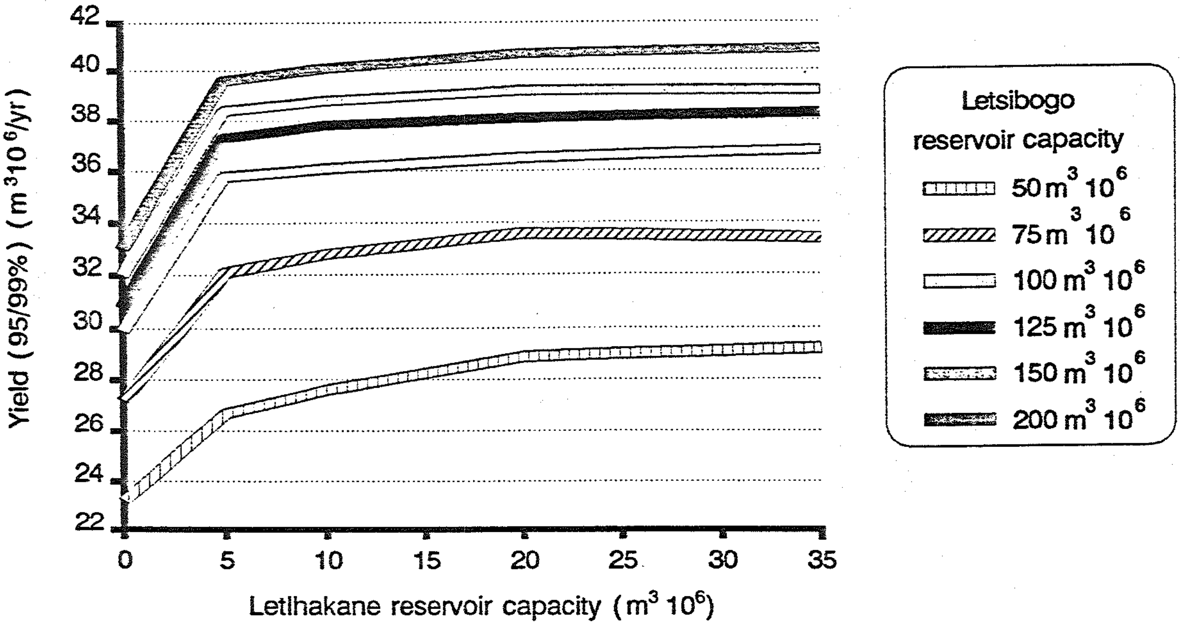
Note: Figures in brackets give incremental yields for Letlhakane dam

A sample output from the twin reservoir simulation is included in Appendix B – B. The most striking comparison between the alternative methods of operation of Letlhakane dam (cf Table B3.2 and Table B3.3) is the dramatic improvement in incremental yield as a result of conjunctive use, particularly for the smaller sizes of Letlhakane dam.

The joint yields resulting from the transfer capacity of 20 $m^3 10^6$/yr are presented in Figure B3.2.

Figure B3.2

95/99% Yields for Letsibogo and Letlhakane Dams



This figure highlights the increase in yield resulting from the introduction of the smallest Letlhakane dam considered, 5 $m^3 10^6$, and the diminishing returns from the larger dams. This is due to the method of reservoir operation, where the comparatively high pumping capacity means that the water is removed from the reservoir quickly, minimising the dependence on storage capability. Further consideration of the possible operational rules for conjunctive use of the two reservoirs is given in Section B3.3. The yields presented in Table B3.2 result from the recommended operational rule that is based on pumping from Letlhakane whenever water is available.

It may be seen that the reduction in yield due to employing a transfer capacity of 10 $m^3 10^6$/yr rather than 20 $m^3 10^6$/yr is small. The adopted operational rule means that the releases from Letlhakane dam are independent of the size of Letsibogo dam, being solely dependent on pumping capacity at the Letlhakane site. The quantity released from Letlhakane is greater than the incremental yield, with the releases from Letsibogo reduced and corresponding increases in evaporation and spillage. The economic analysis must take account of actual pumping costs. The average releases from Letlhakane dam, over the 66 year period of simulation, are given in Table B3.4.

Table B3.4

Average Releases from Letlhakane Dam ($m^3 10^6$/yr)

Pumping capacity ($m^3 10^6$/yr)	Reservoir capacity ($m^3 10^6$) 5	10	20	35
10	6.5	7.8	8.7	8.9
20	8.2	9.8	11.1	11.9

In general terms the cost of a dam forms a high proportion of the total cost of developing a surface water resource. Hence the option of increasing pumping capacity to reduce the size of the dam is attractive. Setting the pumping capacity at Letlhakane site to below about 10 mcm/yr (317 l/s) would limit the effectiveness of the conjunctive use approach and require a larger reservoir capacity to achieve a particular yield. It is, therefore, considered that the two pumping capacities assessed constitute the realistic range of options. At this pre-feasibility stage, further work on this aspect is not justified.

B3.2.3 Reduction in Yield due to Siltation

The reduction in yield from the jointly operated reservoirs, due to siltation, has been assessed. Applying the assumed rate of siltation (0.33% of MAR) to the Letlhakane results in a silt inflow of 2.3 $m^3 10^6$ over a 45 year period. The dead storage for Letlhakane dam has been taken as 0.25 $m^3 10^6$ in all cases. The results of the economic analysis, in Annex M, point towards the 5 $m^3 10^6$ Letlhakane as being the most attractive. However, the estimated sediment inflow over the period is approaching half the storage. Should the actual silt load be significantly higher then the operational life of the Letlhakane could be seriously reduced. In view of the potential of this site it is recommended that a programme of sediment inflow monitoring be instigated at the recently installed Letlhakane water level gauging station.

The yield reductions due to siltation of both reservoirs are given in Table B3.5.

Table B3.5

Reduction in 95/99% Yields due to Siltation over 45 years

Letsibogo capacity ($m^3 10^6$)	Letlhakane capacity ($m^3 10^6$) 0	5	10	20	35
(a) Transfer capacity 20 $m^3 10^6$/yr					
50	2.1	2.5	2.4	2.6	2.2
75	1.1	2.2	2.2	1.9	1.7
100	0.6	1.8	1.4	1.0	1.0
125	0.3	0.8	0.7	0.7	0.5
150	0.3	0.7	0.5	0.4	0.4
175	0.3	0.7	0.4	0.3	0.4
200	0.1	0.7	0.4	0.4	0.3
(b) Transfer capacity of 10 $m^3 10^6$/yr					
50		2.6	2.0	3.3	2.4
75		2.7	2.2	1.1	1.2
100		1.6	1.5	0.9	0.7
125		0.8	0.7	0.7	0.3
150		0.9	0.4	0.6	0.3
175		1.2	0.4	0.3	0.3
200		1.2	0.4	0.3	0.3

It may be seen from Table B3.5 that the reduction in yield is very small, particularly for the larger sized reservoirs.

B3.2.4 Pattern of Drawdown

The pattern of drawdown for the Letlhakane reservoir, operated conjunctively with Letsibogo, is given in Figures B3.3 and B3.4, in terms of levels and areas, respectively. The contrast with the operation of the Letsibogo reservoir is clear from the comparison with Figures B2.4 and B2.5.

The probability of exceedence for Letlhakane levels has been considered, with a typical plot given in Figure B3.5. The median levels for each of the Letlhakane reservoir capacities has been extracted from the level exceedence series. The results are presented in Table B3.6.

Table B3.6

Median Letlhakane Reservoir Levels Over 66 Year Simulation

Reservoir capacity ($m^3 10^6$)	Median level (m)
5	834.2
10	834.3
20	834.4
35	834.4

The minimum operational level of the reservoir is defined by the dead storage. With an allowance of 0.25 $m^3 10^6$ this represents a level of 834 m. It can be seen that the median level is close to the lowest operational level, reflecting the high proportion of the time that the reservoir is effectively empty.

An assessment was also made of the effect of Letlhakane dam operation on the general pattern of drawdown of Letsibogo reservoir. This was found to be negligible, with the median levels hardly effected. Consequently estimates of pumping head from either of the two sites were not dependent on the size of the other.

B3.3 Rules for Joint Operation of Reservoirs

In establishing the yields from the two dams operated jointly some consideration was given to the operating rules by which the decision to pump from Letlhakane was made on a month by month basis. Initially the decision was made on the basis of minimizing the amount of spillage and the combined reservoir area at the end of each month. However, this lead to the anomalous finding that, in some instances, the combined yield was reduced by increasing the size of Letlhakane. This was found to be a consequence of the reservoir area/volume relationships, which are presented in Figure B3.6. In this figure a flatter slope to the area/volume relationship indicates an efficient storage shape. For example a vertical sided container would show as a horizontal line on the area/volume curve. As the figure shows the characteristics of the Letlhakane reservoir are marginally superior over much of its volume. The net result was to conclude for many of the months that withdrawal from Letsibogo was the right decision to minimize the combined evaporation loss from both reservoirs. However, this operating rule could not 'recognize' that the more significant role of the Letsibogo is to store water in preparation for an extended drought period. It was

Figure B3.3

Letlhakane Fluctuations in Level

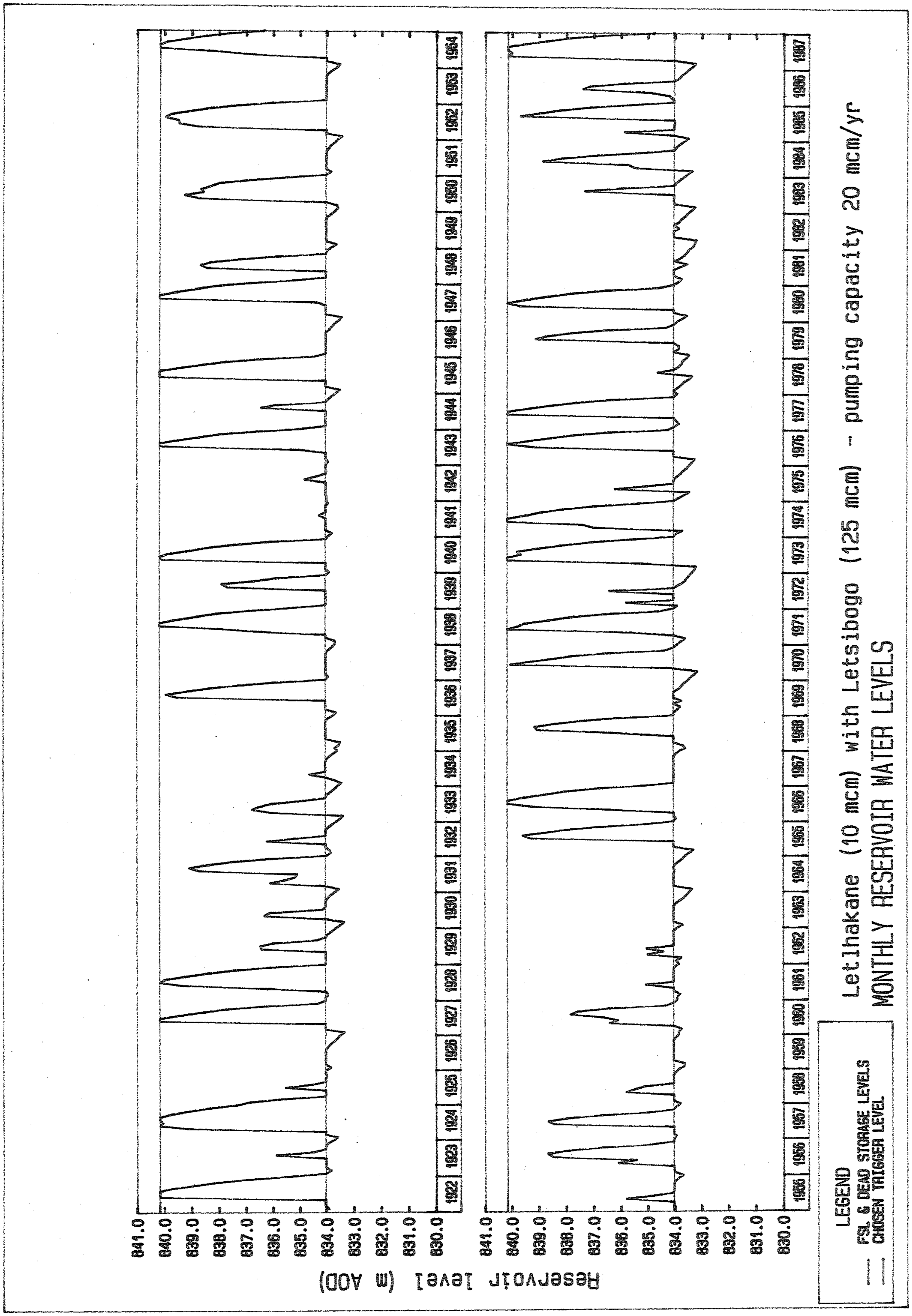


Figure B3.4

Letlhakane Fluctuations in Area

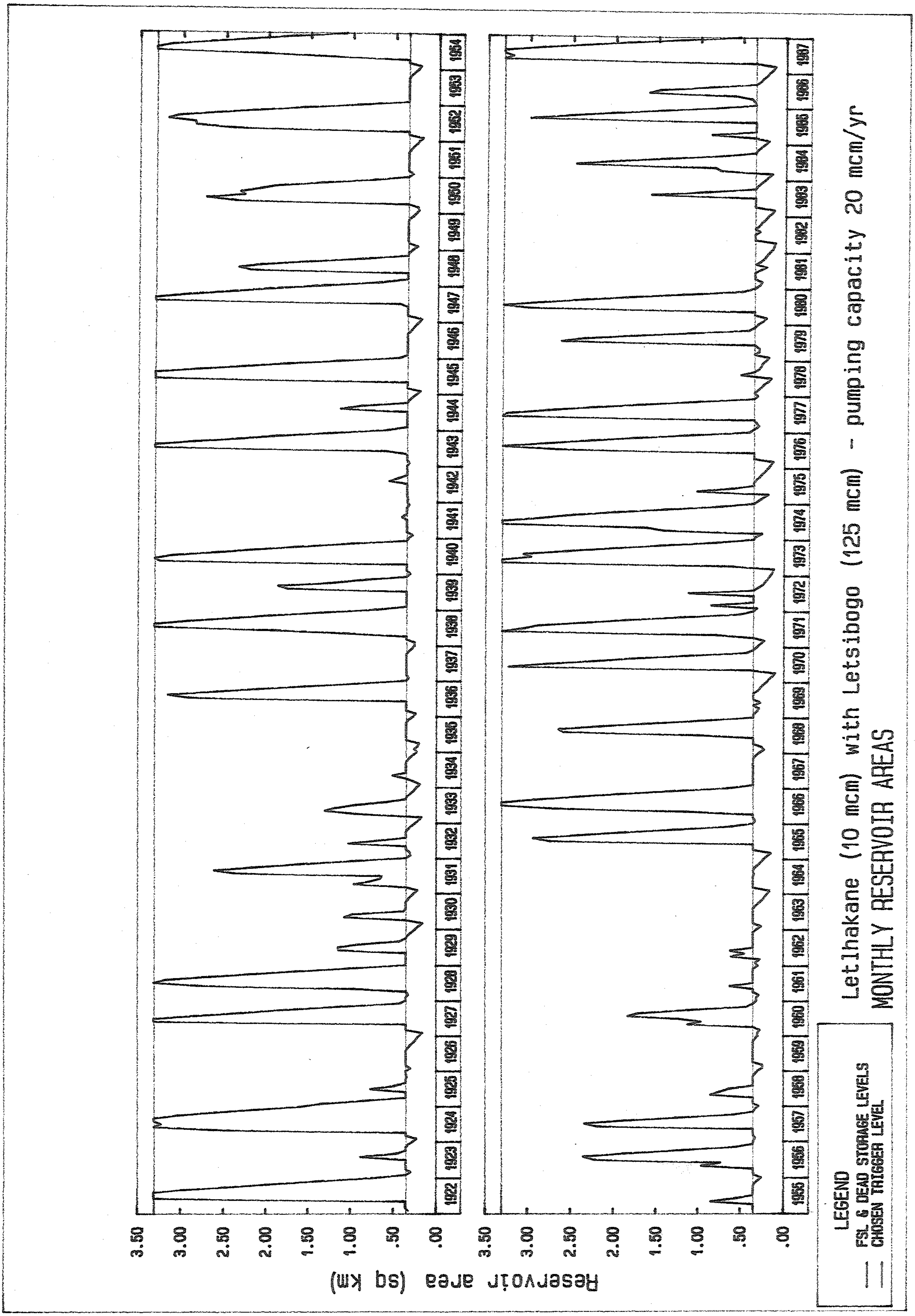


Figure B3.5

Letlhakane Level Frequency Plot

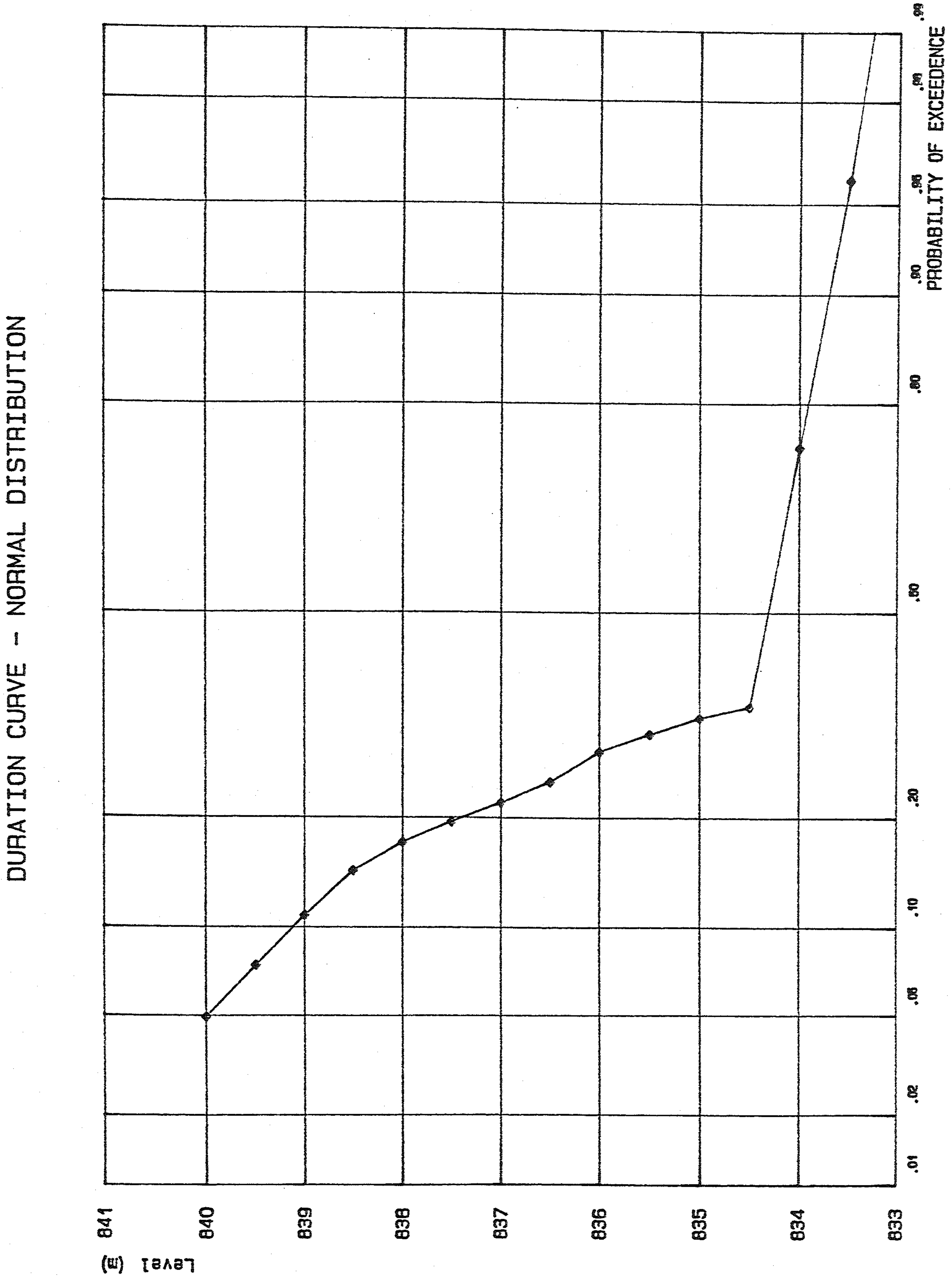
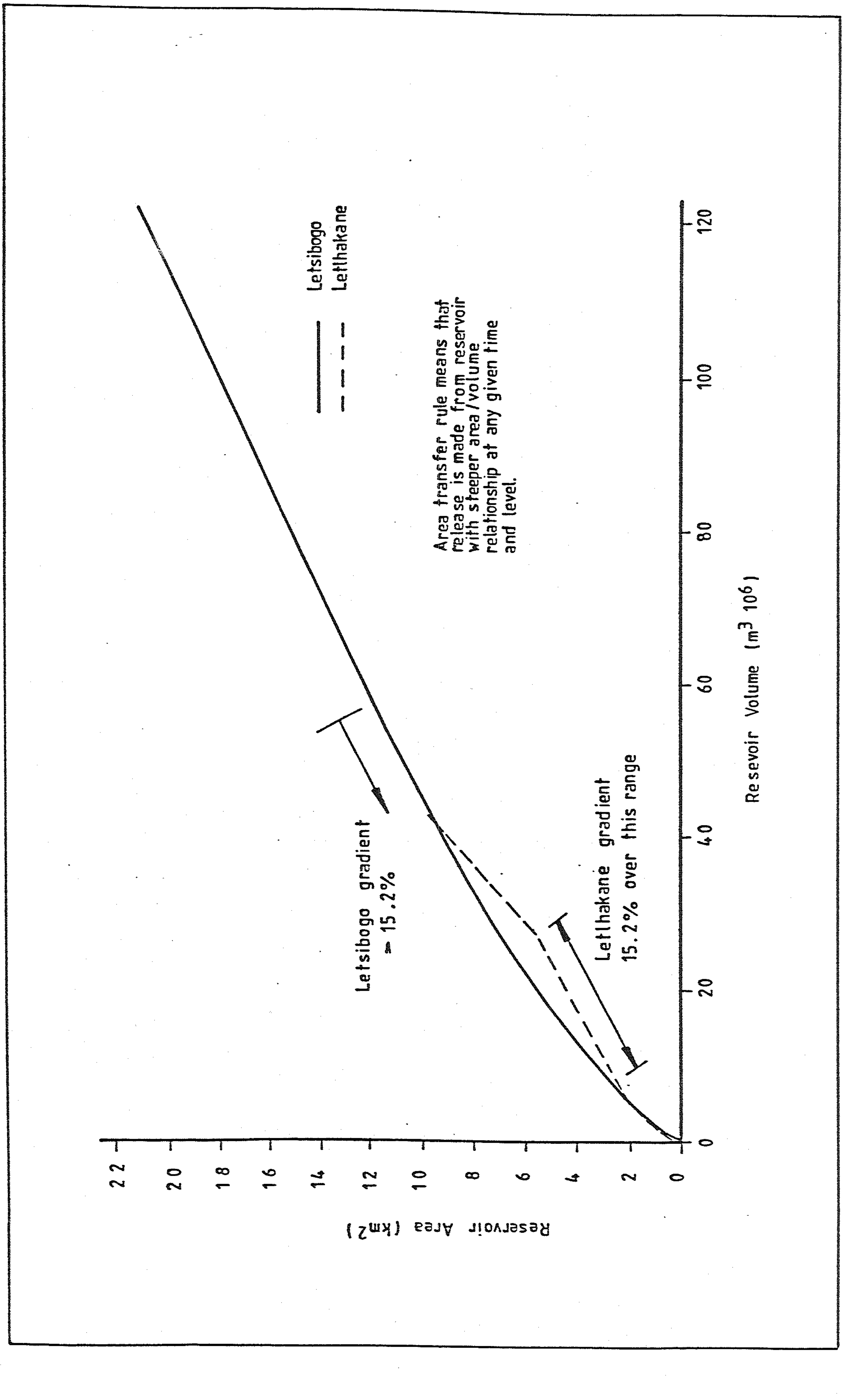


Figure B3.6

Letsibogo/Letlhakane Comparative Area/Volume Characteristics



therefore concluded that the reservoirs should be operated on the rule that water is pumped from Letlhakane whenever it is available.

During any detailed design of Letlhakane dam the issue of operation rules should be considered further. Without any reduction in ultimate yield it may be possible to reduce the quantity pumped from the Letlhakane dam with a consequent reduction in pumping costs.

CHAPTER B4

LETLHAKANE FAULT ZONE

B4.1 Introduction

Within the middle Motloutse valley the most significant potential groundwater resource is the Letlhakane Fault Zone. A groundwater resource offers a second possibility for conjunctive use with Letsibogo dam. Unfortunately there is a lack of reliable information with regard to the hydrogeological parameters of the Fault Zone. It has, therefore, been necessary to adopt a range of possible values for various parameters in order to gain some idea of the potential significance of this resource. As with the Letlhakane dam the lack of basic data has limited this aspect of the study to a pre-feasibility level.

A prerequisite for the detailed design of any development to exploit this resource is the collection of basic data on aquifer properties. An outline of the scope of the field work and data collection requirements is given in Appendix B-C.

The Fault Zone lies some 8 km north of Selebi-Phikwe township. It has been geologically mapped at a scale of 1:120 000 and can be seen on satellite imagery extending at least 20 km both east and west along the Letlhakane and Motloutse rivers, see Figure B4.1. The fault represents, at least in part, a linear groundwater reservoir which has been exploited as a water supply source. The abstraction rate has been as high as 25 l/s (0.8 $m^3 10^6$/yr if sustained).

In physical terms groundwater from the Fault Zone could be integrated into the surface water resources, with the raw water rising mains from the Letsibogo and Letlhakane dams able to pass through a wellfield located on the fault, acting as a collector.

Groundwater could be exploited in a number of ways, namely:

- as a continuous supply, with recharge as the critical factor
- as a backup supply in years of low surface runoff, with storage as the critical factor
- a combination of these approaches

B4.2 Hydrogeological Setting

The Letlhakane Fault Zone comprises a major structural discontinuity with a substantial shatter zone on its southern (downthrow) side. The Fault Zone underlies the Letlhakane River and sections of the Motloutse. In the Fault Zone there occur recent deposits, remnants of Karoo sediments and sheared Pre-Cambrian bedrock. The Fault Zone was first identified as a potential aquifer in 1971 and partially investigated in 1973-74 as a groundwater source for BCL by Australian Groundwater Consultants (AGC, 1974). Geophysical surveys and very limited drilling indicated a three layer semi-confined or leaky aquiferous zone with all units in hydraulic continuity with each other. These units can be described as follows:

a) Recent deposits, comprising alluvium, river sands and other unconsolidated overburden. This unit generally possesses low transmissivity but high storage, is unconfined and in direct contact with sand river recharge and recharge from rainfall over the aquifer zone. This upper unit also provides a recharge source via slow leakage to the underlying Karoo or fractured Basement.

b) Karoo sediments, comprising clayey siltstones, carbonaceous mudstones and minor sandstones. Storage may be high but transmissivity is generally low. Recharged by leakage from overlying deposits and by rainfall over the outcrop.

c) Sheared/weathered Basement rocks, comprising gneiss, amphibolite, anorthosite and schists. Storage is generally low but transmissivity may be very high, especially in zones of brittle, open fracturing. This unit appears to provide the main water yielding zone to abstraction boreholes, with the overlying units providing the storage and recharge.

The extent of the aquiferous units adjacent to the fault has been assessed by geophysics (seismic and resistivity). The thickness of the three layer sequence is assumed to be of the order of 200 m, its width varying from 500 to 1 200 m in the Motloutse area. The Fault Zone is at least 20 km long in the vicinity of the Letlhakane and Motloutse rivers and may extend a considerable distance further towards Serule and the central Karoo basin proper.

A conceptual model of the Letlhakane Fault Zone aquifer is illustrated in Figure B4.2.

Figure B4.2

Conceptual Model of Letlhakane Fault Zone Aquifer

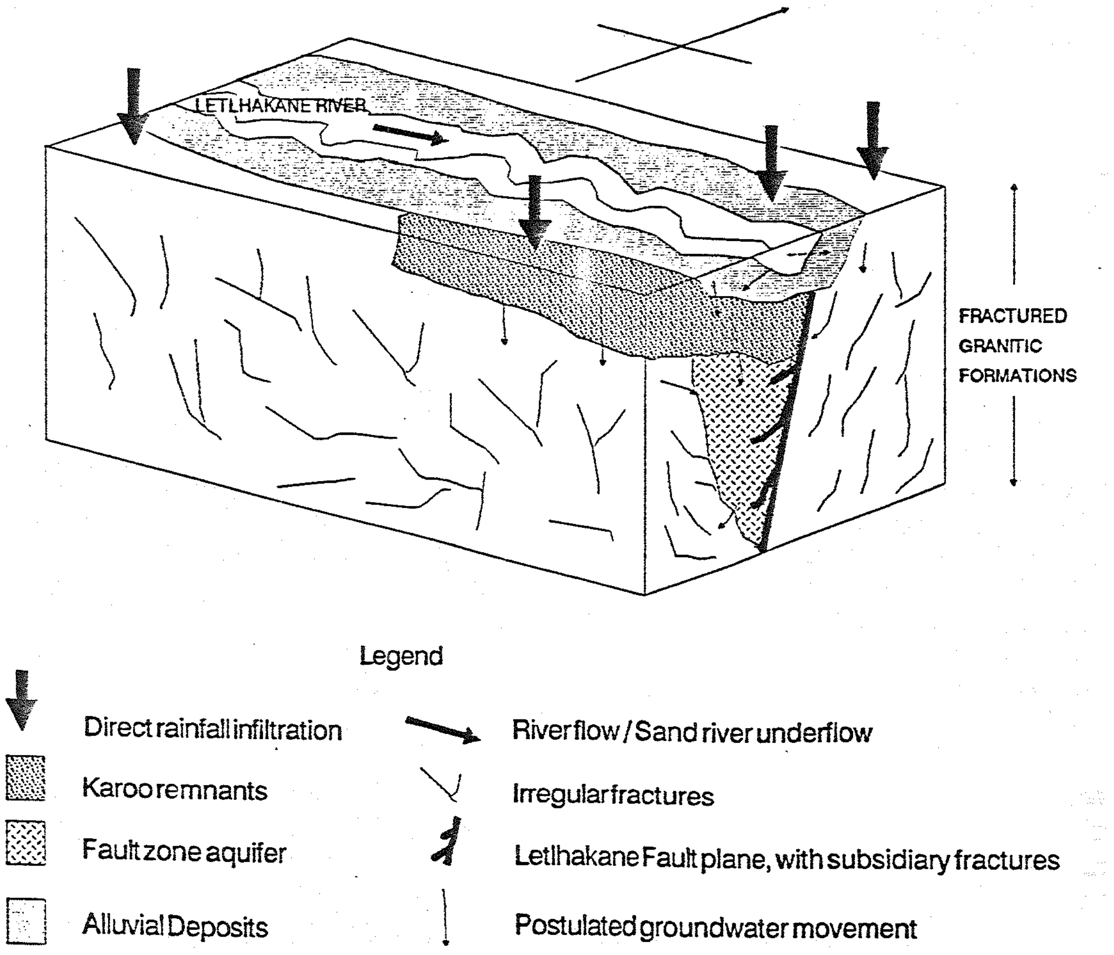
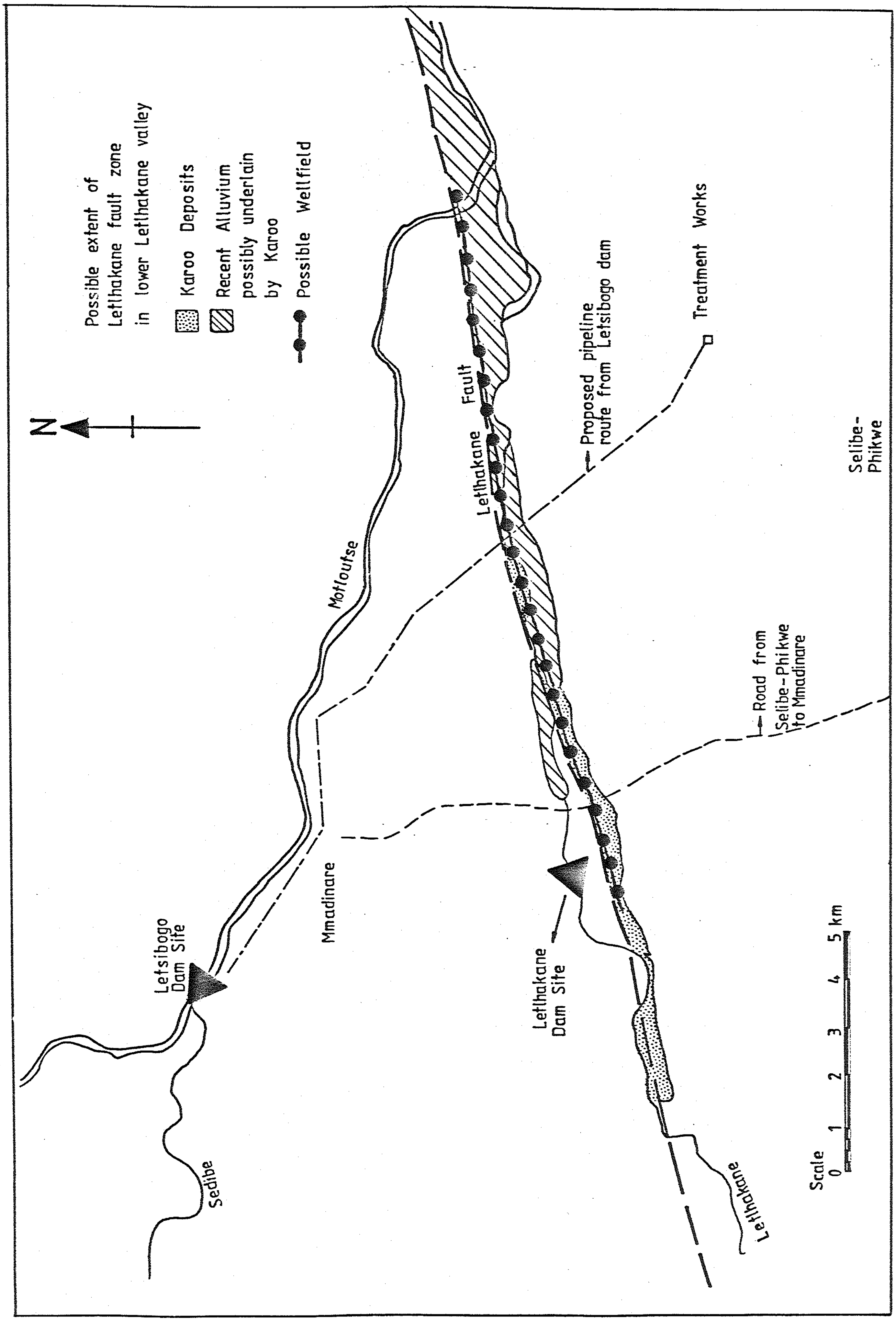


Figure B4.1

Location of Letlhakane Fault Zone



B4.3 Aquifer Parameters

AGC did not successfully conclude an investigation programme and, significantly, did not complete any adequate aquifer testing. Their estimates of resource potential was based on a storage parameter of 20%, which is almost certainly too high. Without more detailed study the best that can be done is to estimate the aquifer characteristics from experience elsewhere. Unfortunately, by its nature a fracture zone is extremely variable and storage coefficients of between 0.01 and 0.2 could be anticipated.

Estimates of aquifer thickness (assumed by AGC to be around 200 m) also appear to be somewhat excessive since no boreholes were drilled to more than 120 m. In the absence of any more recent field investigations it has been considered prudent to be more conservative in current estimates of resources. For the current study the drainable thickness has been taken as between 50 and 100 m.

Whilst the Fault Zone is up to 1 200 m wide in places the average width assumed for this study has been set at 600 m. The effective length of the 'reservoir' is assumed to be in the range 12 to 20 km.

Combining all these parameters results in estimates of water stored in the aquifer of between 3.6 and 240 $m^3 10^6$, with storage coefficient as by far the most significant parameter. The range of 'exploitable volume' derived in this way is too wide to allow any meaningful attempt to test the sensitivity of yields over the full range. Attempting to make 'best estimates' in such circumstances is, of course, difficult. The basic need that has been identified is for a detailed study of the groundwater potential of the Fault Zone, see Appendix B – C. In the absence of further information a stored volume of 36 $m^3 10^6$ has been assumed, of which 50% may be recoverable. The sensitivity of combined yield from Letsibogo and the Fault Zone has been assessed using a range of exploitable volume of between 9 and 36 $m^3 10^6$.

The other parameter of importance is the annual recharge, this is considered in the following section.

B4.4 Recharge to the Fault Zone

Groundwater hydrochemical studies, undertaken during 1973 indicate generally good potable quality characterised by a 20% component of 'recent' bicarbonate water. This latter tends to indicate fairly good recharge potential, although earlier studies did not attempt to quantify such recharge or the magnitude of the renewable resource.

Assessment of recharge of any aquifer system is usually a long term process and is best achieved by monitoring of groundwater levels, abstractions, surface flows and rainfall. From this data a water balance may be established and the groundwater recharge component evaluated. In the case of the Letlhakane Fault Zone such long term data is not available and would take some years to acquire once suitable monitoring points had been established; quantitative evaluation of recharge is thus not immediately possible. However, certain comments may be made concerning the recharge potential of the Fault Zone which may influence its possible exploitation as a groundwater resource. In the context of regional hydrogeology the Letlhakane Fault Zone constitutes a relatively broad, linear feature possessing good porosity and permeability in relation to other geological units in the area and which for much of its length (some 60 km) underlies the course of the Letlhakane River. Clearly the course of the river has been partially controlled by the fault structure and river flow constitutes one of the sources of recharge to the Fault Zone. In 'hard rock' fractured formations it may also be reasonably assumed that groundwater piezometry will approximate to the surface topography and hence subsurface drainage via minor fractures within the Letlhakane basin will be towards the Fault Zone and will contribute to its recharge.

In addition to recharge from surface flow and diffuse areal contributions from rainfall, additional recharge may occur by longitudinal throughflow along the Fault Zone from its western extremity where the fault transects areas of primary (Karoo) aquifers. Such aquifers potentially provide significant intergranular storage and may create a source of recharge by flow from the less transmissive Karoo aquifer to the more highly transmissive Fault Zone.

The three recharge mechanisms postulated above will clearly contribute in different degrees to the overall recharge of the Fault Zone. Very limited verbal evidence from the owner of an operating borehole which is actually located in the Letlhakane Fault Zone indicates that the borehole responds very significantly to wet season flow in the river. This would tend to indicate that recharge from this source is the dominant component. However, it is clear that after saturation of the sand river, continued river flow will not contribute to recharge until part of the sand river storage has infiltrated to the aquifer or has been removed by base flow within the sand itself. Annual recharge will thus depend primarily on the frequency, duration and magnitude of river flows. Evidence from the Francistown area where the Tati River is underlain by a lithologically controlled linear aquifer, indicates that the most rapid recharge occurs when there are a series of high daily rainfall amounts accompanied by high daily flow rates in the Tati River. The larger the flow volume the lower the percentage loss to recharge. Groundwater hydrographs also indicate that aquifer recharge still occurs when local rainfall is not accompanied by river flow, the recharge is reduced and occurs over a much longer period.

By comparison with work in the Francistown area (Gibb, 1987), Ramotswa (WLPU, 1985) and Lobatse (Gibb, 1986) the following recharge components can be tentatively quantified.

a) Recharge from direct rainfall over the Fault Zone and alluvial aquifer. If it is assumed that the effective recharge area is approximately 36 km^2 (60 km x 600 m) and the influent rainfall is approximately 4.5% MAP (430 mm) then the annual recharge component is 0.67 $m^3 10^6$.

b) Recharge from rainfall over the whole catchment by rapid runoff and/or shallow weathered zone underflow to the aquifer. The area of the Letlhakane catchment is approximately 1 320 km^2 and approximately 40% of this area is underlain by granitic strata which promotes this mode of recharge. If it is assumed that only 2% MAP is effective in contributing to groundwater recharge, then the annual recharge component from this source is 4.54 $m^3 10^6$.

c) Recharge from the Letlhakane river flows via the sand river and bank (alluvial) storage. Records indicate that the MAR in the Letlhakane is 15.6 $m^3 10^6$ of which, by comparison with the Tati at Francistown, only about 2% may be expected to recharge to groundwater. The annual recharge component from this source is thus 0.31 $m^3 10^6$.

d) Throughflow (recharge) in the Fault Zone from Karoo aquifers to the west. This component is the most difficult to assess since no longitudinal piezometric gradients along the Fault Zone have been measured. However, it may be assumed that such gradients will be relatively low since there are no apparent major discharges from the Fault Zone. It is therefore assumed that recharge contributions from this source would be small and possibly of the order of 0.05 $m^3 10^6$ per annum.

From the above estimates, based on a number of important assumptions extrapolated from studies elsewhere, it appears that the annual recharge to the Letlhakane Fault Zone over its entire length from the Motloutse confluence to the vicinity of Serule will be of the order of 5 $m^3 10^6$. If we assume that any wellfield will only be able to extract from a length of 20 km, approximately one third of the total, then the annual recharge should be about 1.5 $m^3 10^6$. As this excludes any significant induced throughflow from the western section of the Fault Zone this value is considered to be conservative.

B4.5 Fault Zone Yield

An assessment has been made of the increase in system yield that could be expected from exploitation of the Letlhakane Fault Zone aquifer. The system envisaged is that the operation of the groundwater resource would be governed by the level of the Letsibogo such that pumping from groundwater commences when the reservoir level drops below a predefined trigger. This is similar to the 'demand trigger' used to reduce reservoir releases from full yield to 60%, in establishing the 95/99% yield.

A modified version of the Consultant's reservoir simulation program has been developed to establish the twin trigger levels for operating this system. The 'groundwater trigger' has been optimised on the basis of nearly drawing down the groundwater aquifer to the maximum extractable volume at least once in the 66 year simulation. The intention is that the groundwater pumping should be such that the water is available in the most critical months. Hence, too high a trigger level would result in the groundwater resource being depleted when the reservoir supply cannot be maintained, too low a trigger level would mean that full use has not been made of the groundwater resource.

The level fluctuations over the period of simulation for joint operation of the Letsibogo reservoir and groundwater resource are depicted in Figures B4.3 and B4.4, respectively.

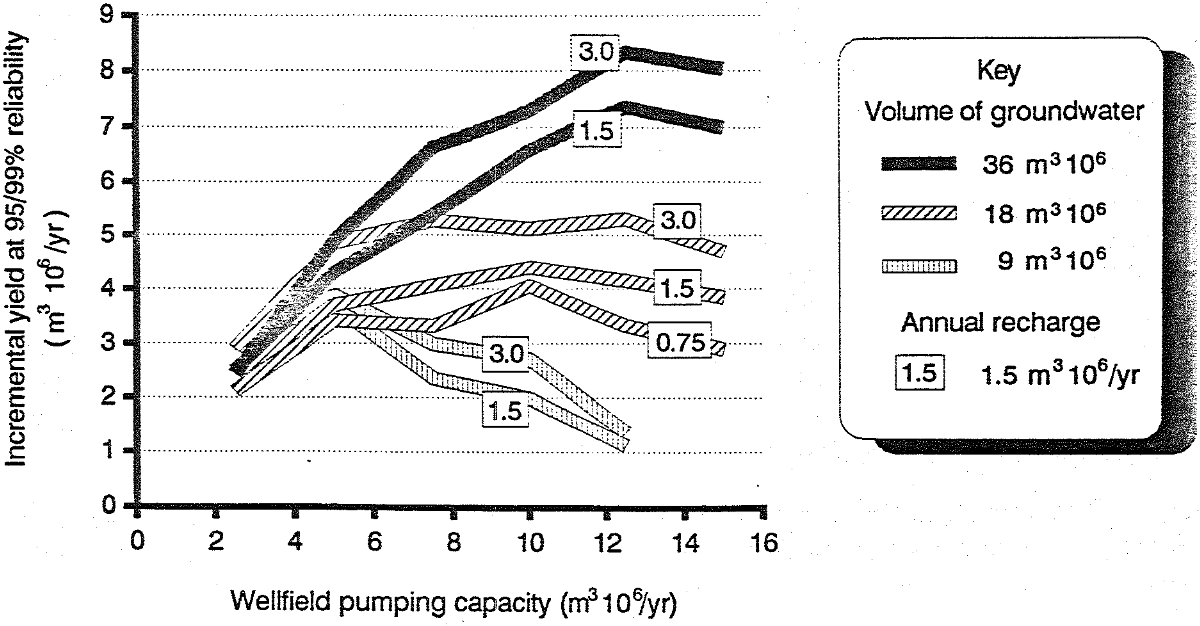
Figure B4.4 has been prepared on the basis of the aquifer being simply modeled as a box 100 m deep with the extractable volume in the top 50 m. From a water resource viewpoint the precise dimensions of the aquifer are not important, but the figure helps to visualise the operation of the groundwater resource.

Three parameters have been considered in this exercise. The key factors defining the aquifer are maximum extractable volume and annual recharge, with the groundwater development expressed as total installed pumping capacity. The previous sections established the best estimate of extractable volume as 18 $m^3 10^6$, with annual recharge estimated as 1.5 $m^3 10^6$/yr, although considerable variation is possible. A range of extractable volume from 9 to 36 $m^3 10^6$ has been considered, in conjunction with annual recharge varying between 0.75 and 3.0 $m^3 10^6$/yr. As no more detailed information is available it has been assumed that inflow to groundwater is constant throughout the year.

The results are presented in Figure B4.5 as incremental increase in the 95/99% yield over the base case of Letsibogo reservoir of 125 $m^3 10^6$ with a yield of 30.8 $m^3 10^6$ at the required reliability.

Figure B4.5

Incremental Yield with Varying Aquifer Characteristics



The main feature of Figure B4.5 is the dominating effect of the extractable volume of groundwater. For low levels of installed pumping capacity the effect of changes to aquifer parameters is not very pronounced, with incremental yields close too, or sometimes slightly greater than the delivery capacity of the wellfield. This clearly shows the benefit of conjunctive use. The average value of various components of the simulation are given in Table B4.1 for a typical case.

Table B4.1

Components of the Reservoir Simulation

Component	Average values ($m^3 10^6$/yr)	
	Base case (Letsibogo 125 $m^3 10^6$)	With groundwater (Aquifer 18 $m^3 10^6$)
Wellfield capacity	–	5.0
95/99% Yield	30.8	34.5
Incremental yield	–	3.7
Delivery from reservoir	30.1	33.8
Evaporation	26.0	24.4
Direct rainfall	5.8	5.4
Spill from reservoir	14.0	12.5
Delivery from wellfield	–	1.1
Aquifer recharge	–	1.5
Spill from groundwater	–	0.5

Table B4.1 reveals that the main factor in increased yield from conjunctive use is increase in releases from the reservoir as a result of lower evaporation loss and spillage, which are

Figure B4.3

Letsibogo Level Fluctuations in Conjunctive Use with Groundwater

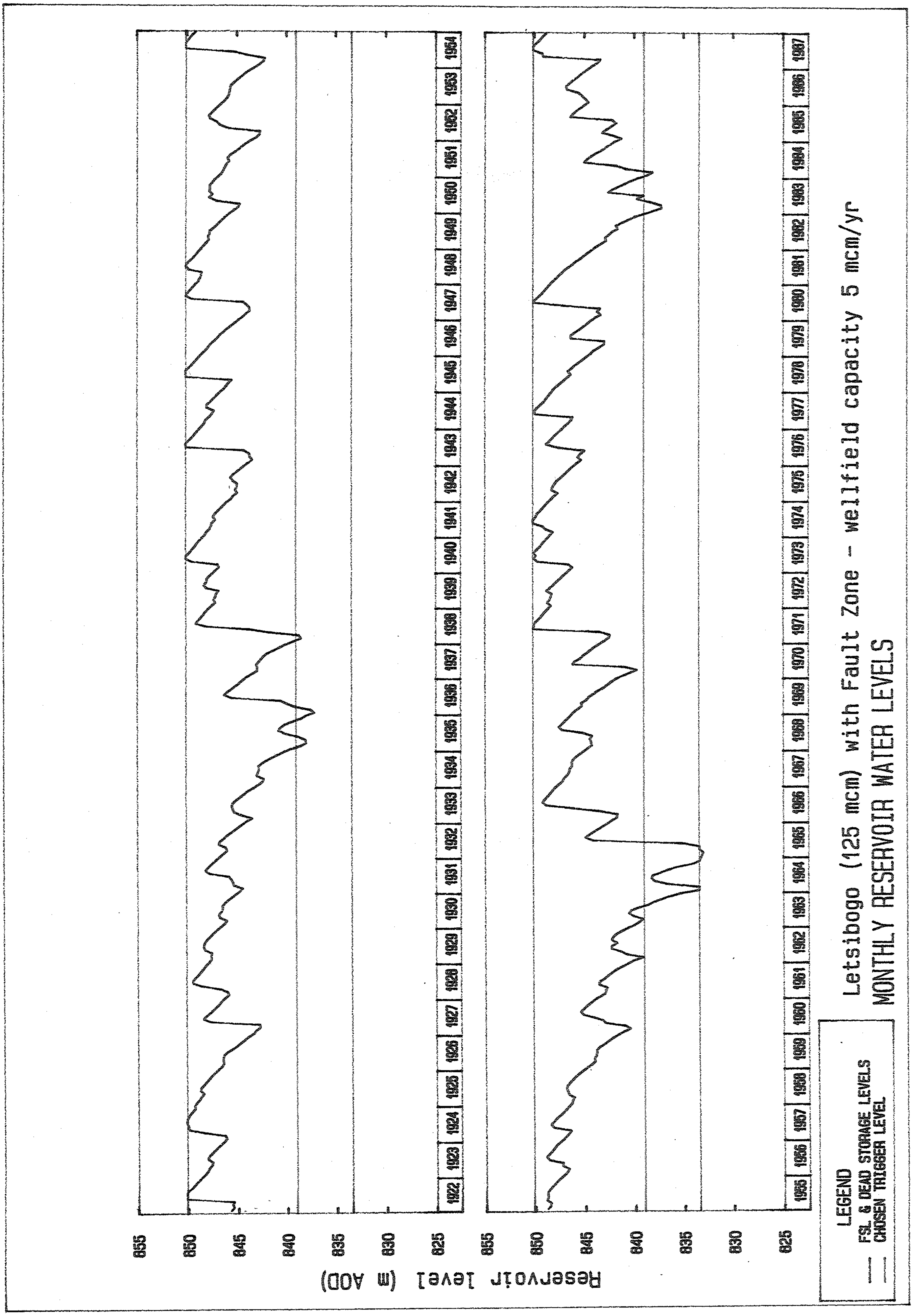
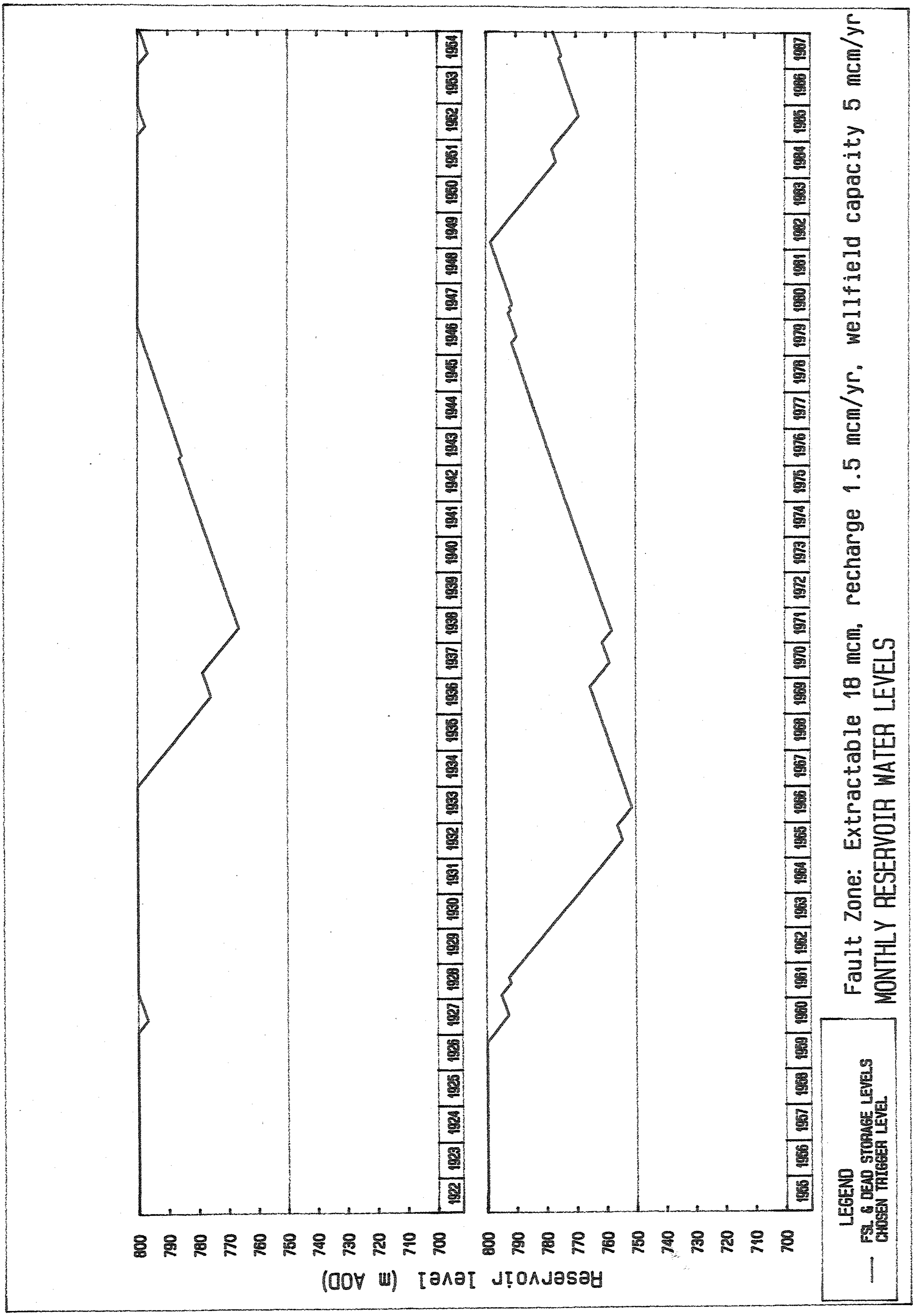


Figure B4.4

Fault Zone Fluctuations in Level



in releases from the reservoir as a result of lower evaporation loss and spillage, which are only slightly counteracted by a reduction in the contribution from direct rainfall. This is a direct consequence of being able to run the reservoir to a generally lower level because of the 'backup' function of groundwater. This is reflected in the demand trigger which is reduced from 10.2% to 7.8% of reservoir volume by the introduction of groundwater. The trigger level for operating the wellfield was optimised as 26.5%.

Further refinement of operating rules for a wellfield on the Fault Zone cannot be justified with the present state of knowledge of the resource. However, it has been noted that slightly higher yields may be available in certain circumstances if the groundwater optimisation allowed the resource to be completely depleted on occasions, rather than attempting to ensure that full wellfield yield is always available. This raises the question of what happens during the 1% of months when yield would be below the 60% target set by the 95/99% yield analysis. When considering conjunctive use it may be more advisable to adopt a 95/100% yield analysis.

A further observation relates to the trigger rules derived for higher capacity wellfields. For example a wellfield capable of delivering 12.5 $m^3 10^6$/yr with an exploitable volume of 18 $m^3 10^6$ and a recharge of 3.0 $m^3 10^6$/yr results in reservoir volumes of 3.5% and 5.3% for the demand trigger and groundwater trigger, respectively. It may be that such operational guidelines are impractical in view of the amount of reservoir depletion allowed before any action is taken. Such an analysis also runs the risk of tailoring operation rules to meet the characteristics and peculiarities of one particular drought sequence. It would probably be preferable to operate a comparatively large wellfield with reduced pumping at one trigger level and full extraction only when a lower trigger level is met.

Whilst this analysis is severely limited by the lack of reliable data on aquifer characteristics it does indicate the potential benefits of the conjunctive use of Letsibogo reservoir with a wellfield on the Letlhakane Fault Zone.

B4.6 Cost of Groundwater Development

Establishing costs for such a development is also a problem because of the lack of information on aquifer parameters, which control the yield and spacing of tubewells. Nonetheless, adopting the same 'best guess' approach has enabled some idea of the basic cost of such a development. Whilst development of such an aquifer would not be necessary until the demand on the Letsibogo reservoir is nearing safe yield (about 2003 without irrigation) the conjunctive use approach does require that sufficient pumping and delivery capacity can be installed at Letsibogo dam.

The layout of a wellfield capable of delivering 5 $m^3 10^6$/yr (158 l/s for 24 hrs/day) is presented in Figure B4.1.

The layout is based on an assumed average borehole yield of 7 l/s, at a spacing of 500 m. To the basic requirement for 23 wells an additional 10% has been included for standby and a further 20% allowance for dry wells. This results in a total requirement for 31 boreholes, 26 of which would be equipped with electric submersible pumps. The general details for an individual borehole are given in Table B4.2.

Table B4.2

Borehole Details

Average yield	7 l/s
Initial depth to watertable	15 m
Local drawdown at pump	30 m
Regional drawdown induced by wellfield dewatering	50 m
Friction losses in borehole	5 m
Friction loss along collector	0 – 45 m
Required head at rising main	40 m
Total pumping requirement	140 – 185 m
Total borehole depth	200 m
Drilling diameter : 0 – 30 m	15 inch
: 30 – 200 m	12 inch
Casing diameter : 0 – 200 m	8 inch
Casing length	150 m
Screen length	50 m

The friction loss along the collector line has been established using the Colbrooke – White method, with a friction factor of 0.3. Pipe diameters were selected to give velocity at peak discharge of about 1 m/s. Friction losses along the collector varied from zero at the raw water rising main to 45 m and 17 m at the extremities of the western and eastern branches, respectively, with an average of all wells of 13 m. The difference between the two branches results from the ground level slopes down the valley. At detailed design stage further consideration would have to be given to optimum wellfield layout.

Pump costs have been based on two types of electric submersible pumps, Grundfoss type SP27 – 23, capable of delivering 7 l/s at 150 m head, and type SP27 – 28 which can deliver 7 l/s at 185 m head. Pump costs are based on UK prices, with an allowance for delivery, but no allowance for taxes and duties. A summary of the cost of development is given in Table B4.3.

Running costs have been assessed on the basis of local power generation. The alternative would be to provide a link to the national grid, which would then charges for electricity would be based on BPC's Business III tariff. This comprises a standing charge of P 26/kW and P 0.1015/kWh. The option of local generation capability is that majority of the running costs are limited to the cost of diesel when the unit is in operation, once the capital outlay has been made. The structure of the power tariff is such that the operation of the pumps for a short period only would mean that the standing charge must be paid for the following year. This aspect would require careful consideration during any latter stages of study of this resource.

The efficiency of the selected pumps is about 70%, with a motor efficiency of 90% the overall efficiency is 63%. The average pumping head is about 155 m (see Table B4.2) and the average annual delivery is about 1.1 $m^3 10^6$ (see Table B4.1), hence the average annual power requirement is 737.5 MWh. To generate one kilowatt of power requires 0.3 litres of diesel, giving an annual fuel consumption of 221 m^3, costing P 170 400.

Table B4.3

Cost of Wellfield with Delivery Capacity of 5 $m^3 10^6$/yr

Item	Unit	Quantity	Rate (P)	Amount (P)
Mobilisation	Sum			46 000
Drilling exploratory boreholes	Nr	9	40 650	365 850
Drilling and testing production boreholes	Nr	31	50 800	1 574 800
Supervision of construction	Nr	40	7 000	280 000
Surface geophysics	Sum			374 000
Borehole geophysics	Sum			94 500
Total : Boreholes				2 735 150
Pumps*: Grundfoss type SP27–23	Nr	13	27 500	357 500
Grundfoss type SP27–28	Nr	13	33 000	429 000
Total : Pumps				786 500
Collector pipework : dia 100 mm	m	500	23	11 500
dia 150 mm	m	3 500	28	98 000
dia 200 mm	m	3 000	39	117 000
dia 250 mm	m	4 000	55	220 000
dia 300 mm	m	3 500	73	255 500
Sub–total pipework				702 000
Additional 5% for excavation in rock				35 100
Additional 20% for pipework fittings				140 400
Total : Pipework				877 500
500 kVA diesel generators (2 duty, 1 standby)		3	135 000	405 000
Installation and Cabling	Sum			200 000
Power house, bulk fuel store etc	Sum			200 000
11 kV transmission lines	km	15	20 000	300 000
Total : Power Supply				1 105 000
Contingencies (15%)				825 600
Total				6 329 750

* Pump costs include motor, transformer, 3 inch riser, ect

The other recurrent cost relates to maintenance of the pumping and generating equipment. Allowing an annual sum of 5% of equipment costs results in an annual expenditure of P 60 000.

It must be stressed that all the costs outlined above can only be considered as indicative. Project details, particularly the number and spacing of boreholes, can only be established after an investigation programme to establish aquifer parameters.

B4.7 Interaction Between Letlhakane Dam and Fault Zone

Consideration would have to be given to the possibility of interaction between a dam and groundwater extraction from the Letlhakane valley. However, there are a number of factors which suggest this may not be a significant problem:

- the Letlhakane dam site is located north of the Fault Zone
- there is only a shallow depth of water in the reservoir, even at FSL
- the reservoir will be emptied comparatively quickly, with no over-year storage
- the top of the highly permeable shatter zone is well below the ground surface and overlying layers are only slowly permeable

With regard to the last point, evidence from test boreholes, as reported by Robins (1971), showed the general piezometric level to be over 14 m below the ground. This would indicate that there is no direct connection between the river and the shatter zone and so all water has to pass through the relatively impermeable surface layers. Should this prove to be the position then lowering the piezometric level within the shatter zone should not have a pronounced effect on direct seepage from the river.

Whilst the preliminary assessment, outlined above, would suggest that there will be no problems with interaction between the two resources, detailed field investigations will be required for the dam and the aquifer to quantify any effects.

B4.8 Water quality

Some reservations should be noted with regard to water quality. No regular programme of water quality data collection is currently undertaken. During the course of this study a number of samples have been taken from wells within the aquifer. Two wells were sampled in August 1988, along with a sample from the BCL mine 'clear water' dam. EC from the mine sample was 6.4 mmhos/cm, whilst the two samples from the Fault Zone showed ECs of 6.0 and 1.2 mmhos/cm (cf European Community guide level 0.4 mmhos/cm, although maximum permissable is about 2.3 mmhos/cm). It is not clear whether these levels are the result of localised pollution or representative of a significant portion of the aquifer.

From the limited information available it is clear that an assessment of water quality is an important requirement of any further study.

B4.9 Combined Yield of Letsibogo Dam, Letlhakane Dam and Fault Zone

Should the position with regard to mutual interference between a dam on the Letlhakane and a wellfield drawing from the Fault Zone prove to be not detrimental to either resource, then there is a possibility of developing both, to operate conjunctively with the main Letsibogo dam. Obviously lack of information is a serious constraint but an attempt has been made to quantify the ultimate potential of the Middle Motloutse valley water resources. With Letsibogo dam at 125 $m^3 10^6$, Letlhakane dam at 10 $m^3 10^6$ with a pumping capacity of 20 $m^3 10^6$/yr, the long term 95/99% yield from all three resources would be 41.6 $m^3 10^6$/yr. This has been based on a wellfield capacity of 5 $m^3 10^6$/yr, extractable volume of 18 $m^3 10^6$ and an annual recharge of 1.5 $m^3 10^6$. Assuming an aquifer of twice the size, and double the annual recharge produces a yield of 45.4 $m^3 10^6$/yr with a 12 $m^3 10^6$/yr capacity wellfield.

CHAPTER B5

SAND RIVER RESOURCE

B5.1 Introduction

The Motloutse sand river is classified as a major sand river by the magnitude of its potential theoretical yield per kilometer length of sand bed aquifer. The most comprehensive studies undertaken on the nature and characteristics of the Motloutse sand river have been under the auspices of the DWA Sand River Project, which has been undertaken in three phases from 1980 onwards. Reports have been issued by Wikner (DWA,1980) and Nord (DWA,1985). Prior to these, preliminary work was completed as part of any earlier study of water storage in sand river (Thomas and Hyde, 1972); it was also considered during the study of 'Shashe Complex – Phikwe Temporary Water Supply' (Gibb, 1969).

The general physical characteristics of all the major sand rivers of eastern Botswana are similar. All these rivers are ephemeral, have wide sandy beds and have flashy flood characteristics. The sand bed deposits usually comprise medium to coarse sand with equal, or occasionally lesser, amounts of fine grained sand/silt and gravel. These deposits are usually shallow, varying between 3 and 9 m in depth in the section of the Motloutse covered by the study. The continuity of the sand aquifer along the river bed is broken by the occurrence of numerous rock bars or barriers of more resistant strata which effectively divide the sand aquifer into basins of widely varying size. A number of previous studies have assumed that such rock bars create totally impermeable barriers. This is now considered to be only partially correct since many of the rock bars are highly fractured and jointed and would almost certainly allow some downriver groundwater underflow.

The sand river has been assessed during this study mainly in the context of downstream impacts of dam construction on the sand river resource. As highlighted in the Environmental Impact Assessment (see Annex K), the sand river constitutes an important local resource for both human and livestock populations. The river also has a possible role in maintaining the riverine vegetation. The task of understanding the functioning of the sand river is to define and then quantify the components of the water balance. The basic elements are as follows:

- surface runoff
- evaporation (surface and subsurface)
- flow through the sand aquifer
- surface flow
- irrigation use
- other consumptive use
- rainfall
- evapotranspiration of the riverine strip
- seepage out from the river bed
- flow into and out of bank storage
- BCL mine operations and Selebi-Phikwe sewage work discharge

In order to establish the relative importance of the various components and attempt to make quantitative assessments a sand river model has been developed. This is discussed in section B5.7.

Comments from the local population suggest that the sand river is a perennial source. Even after the recent drought of a number of consecutive years with below average runoff there was still water available in the sand river, exploited by shallow wells. It is interesting to note that this observation has been born out by the sand river model.

B5.2 Aquifer Properties

The coarse sand and fine gravel fractions of the sand river form a highly transmissive aquifer with excellent storage properties. A number of aquifer testing exercises and analyses of abstraction system performance (Wikner, 1980, Nord, 1985), have indicated transmissivity values in the range 400 to 1 500 m^2/d with an average horizontal permeability of some 0.003 m/s. Nord (1985) states that a transmissivity of 1 300 m^3/d is typical for a normal sand river. Clearly, the sand river aquifer is unconfined and an average specific yield (storage coefficient) of 17.5% has been calculated.

Attention has been concentrated on the section of river from just upstream of the Letsibogo dam site to about 20 km downstream of Tobane, a total distance of about 58 km, see Figure B5.1. The groundwater gradient along the line of the river is very gentle, with an average slope of 1.5 m/km, varying between 0.8 and 2.6 m/km. The velocity of flow of the groundwater body is of the order of 0.3 to 0.5 m/day, with flows in the range of 1 to 4 l/s (80 to 350 m^3/d).

B5.3 Sand River Water Resource

From depth probes of the thickness at regular intervals of the sand body (Wikner 1980) and using a storage coefficient of 17.5% the storage volume per kilometer of river length has been calculated. Details of the storage in each reach are given in Appendix B – D, which gives the basic data input for the sand river model. The section of river from Letsibogo to Tobane is estimated to contain a total of 2.60 $m^3 10^6$, although estimates of the proportion that may be practically extractable vary from 50% to as much as 80% (Nord, 1985).

It should be noted that all the information on aquifer storage is derived from basic survey work undertaken in 1979 and 1980. Since that time the BCL mining operation has lead to the extraction of considerable volumes of sand over a 3 – 4km stretch. The assumed effect of any surface flow is to bring the aquifer to a fully saturated condition. The main mechanism for depleting the quantity of water thereafter is evaporation. Initial depletion to a depth of 0.6 m is fairly rapid, perhaps after one month. Hence, in terms of year round storage the capacity of the top metre or so should be discounted, unless there is any programme of artificial recharge. Consequently the impact of the sand extraction is to deplete the sand river as a water resource. However, as no more recent sand river bed survey is available it is not possible to quantify this effect.

B5.4 Return Flow from Selebi – Phikwe

A significant factor with regard to the water resource function of the sand river is return flows from Selebi – Phikwe. These come from two main sources, the sewage works and the BCL mine. Of these the flow from the mine is dominant, comprising largely discharge of cooling water, although this is combined with occasional discharges of highly polluted releases (or escapes) from the tailings dam. The pollution aspects and possible changes in the operation of the mine to reduce these discharges are covered by Annex L.

The net result of these discharges is an average inflow of some 10 000 m^3/day (120 l/s), although there is considerable daily variation (see Table B5.1). From the water resource point of view this has the effect of creating a virtual 'aquifer full' situation downstream of the discharge point and minor surface flow for a considerable distance downstream. A series of measurements of this flow have been undertaken as part of this study, the results are discussed in Section B5.5.

The presence of this resource has allowed the development of a number of small scale irrigation plots, both down the Matatane stream, which is the conveyance route to the Letlhakane river, and also along the Motloutse from the Letlhakane confluence. There are however, reservations about the quality and future reliability of this water for both human consumption or agricultural use.

B5.5 Flow Measurements in the Sand River

Many of the components of the water balance (identified in Section B5.1) are very difficult to measure directly. However, the rate at which a flow in the river is depleted provides a measure of the combined effects of evaporation, evapotranspiration from the riverine strip and consumptive use. Under the conditions of surface flow induced by rainfall in the catchment the position with regard to losses in any given reach is confused by contributions from local catchments, direct rainfall and flow into and out of bank storage.

The flow from the mine and sewage works (see previous section), when monitored through a period with little or no rainfall, offers the possibility of observing the combined effect of all the losses to the system. Accordingly a programme of flow measurement was initiated.

Flow in the river was of the order of 100 l/s. It was not possible to directly measure a flow of this magnitude in a channel as large as the Motloutse. Hence a series of wooden flumes were placed in the natural low flow channel of the river; their locations are given on Figure B5.1. A photograph of the flume is shown in the Main Report. The cross-section of the flume was 0.6 m wide by 0.5 m high. Rudimentary 'training works' were installed upstream, sufficient to ensure that the flow passed through the flume. The results of these flow measurements are given in Table B5.1, and presented in Figure B5.2.

Table B5.1

River flow measurements

Flume reference	Chainage (km)	Discharge measurements (l/s)			
		15/9/88	1/11/88	4/11/88	8/11/88
LET	0.00	127	197	186	188
MOT1	2.35	116	Washed out or stolen since		
MOT2	4.55	90	time of previous measurements		
MOT3	9.80	47	99	108	125
MOT4	15.25	13	92	81	81
MOT5	17.30	0	73	60	65

As shown in Figure B5.2 the overall loss rate was remarkably consistent over the range of flows and period of time covered. It is also clear that the actual quantity of water from the mine and sewage works does vary, although the frequency and the magnitude of the variations is not known. The significance of these conclusions are discussed in Section B5.6.

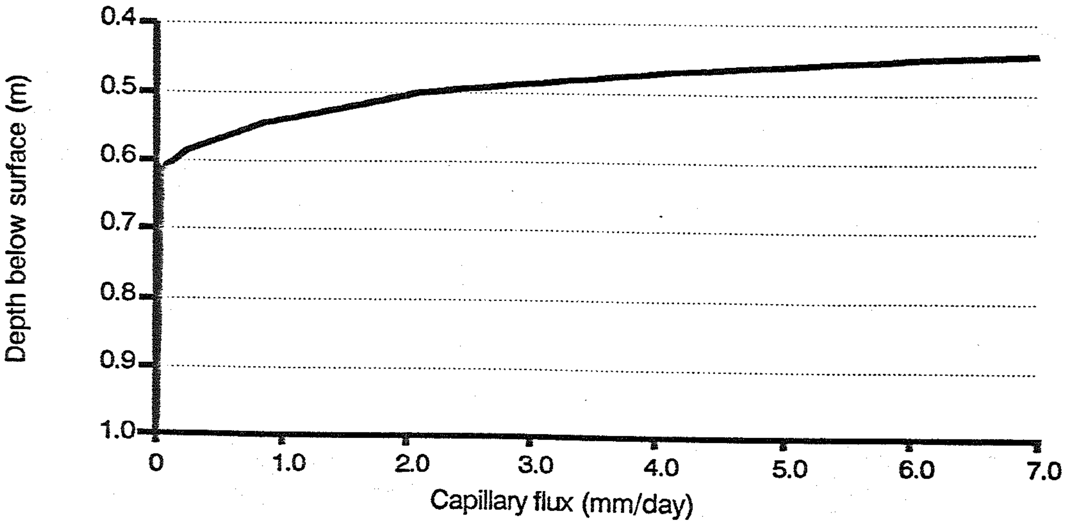
B5.6 Evaporative Losses from the Sand River

The estimated open water evaporation (Eo) for November is 7 mm/day (see Annex A, Section A2.4). The observed width of the surface flow in the river immediately downstream of the uppermost flume, on the 8th November 1988, was 7.5 m. At the prevailing rate of evaporation, this computes to a surface evaporation of less than 1.0 l/s/km. The observed rate of loss was about 7.5 l/s/km. It is clear, therefore that the remaining 6.5 l/s/km must be lost as subsurface evaporation, evapotranspiration from the riverine forest, seepage to underlying aquifers and consumptive use. Of these, it has been established that subsurface evaporation is by far the most important.

The paper 'Soil Moisture Forecasting' (Ritjema 1969) investigates the soil moisture characteristics of a number of standard bare soil types, and attempts to relate evaporative rate to depth to the saturated layer. The paper relates the ability of a given soil type to transmit water from a subsurface layer (the capillary flux) to depth below the surface and moisture content in the unsaturated layer. Evaporative loss is thus the minimum of the rate of capillary flux (which is set by combination of depth, soil type and moisture content) and the potential evaporation (which is set by the climatic conditions). For the purpose of this study it has been assumed that the sand river bed acts as a coarse sand and that drainage is so rapid that the moisture content of the unsaturated sand is close to zero. The nature of the relationship between depth to watertable and capillary flux under this set of assumptions is given in Figure B5.3.

Figure B5.3

Capillary Flux Potential



The simple relationship depicted in Figure B5.3 is considerably complicated by the nature of the cross-section of the river channel. For a given water level in the sand (assumed to be horizontal) there will be range of unsaturated sand depths. The actual loss from a particular stretch of river requires that the losses be integrated for each cross section. To accomplish this task a steady-state computer model of the sand river was developed.

Figure B5.1

Extent of Sand River Model

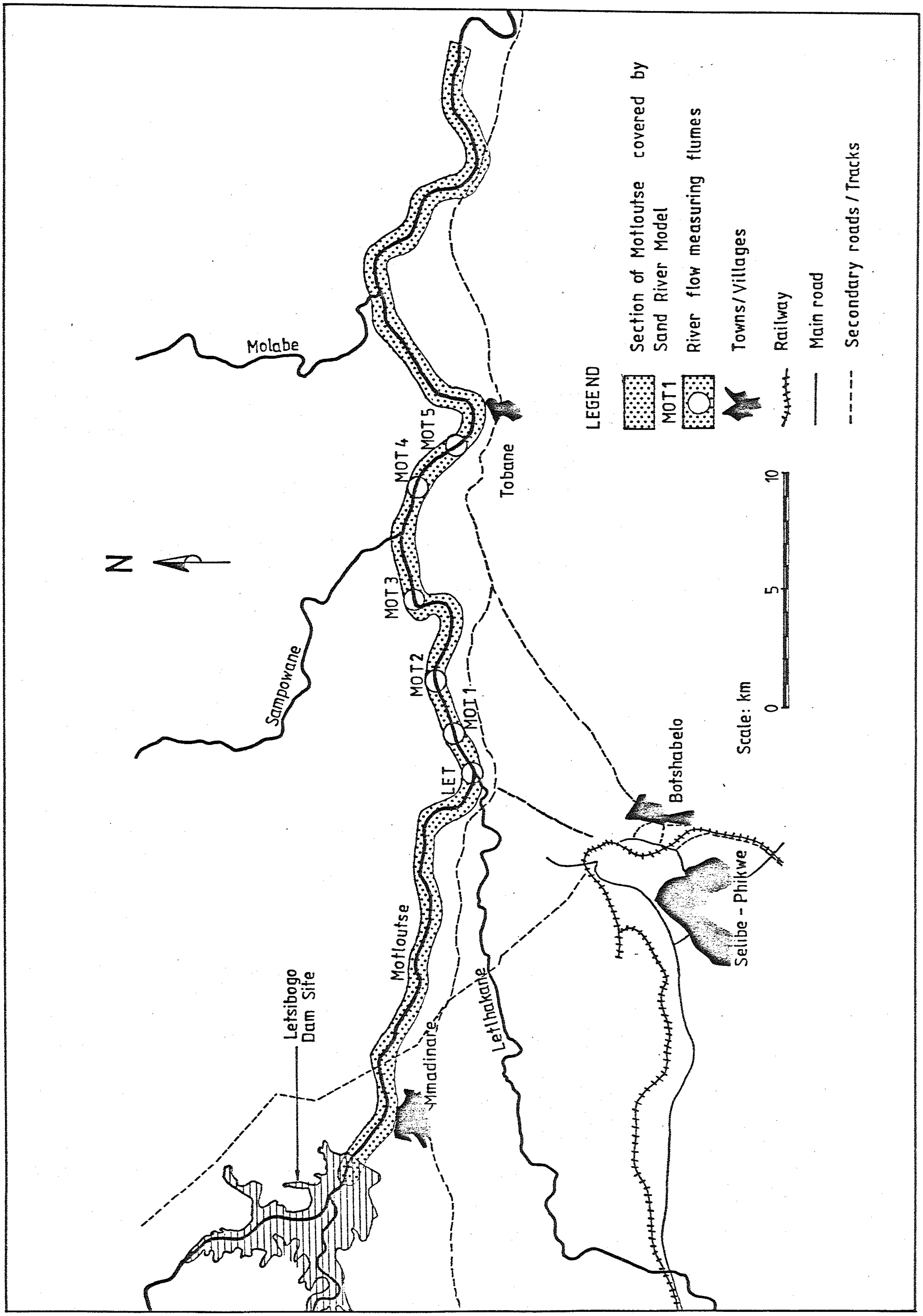
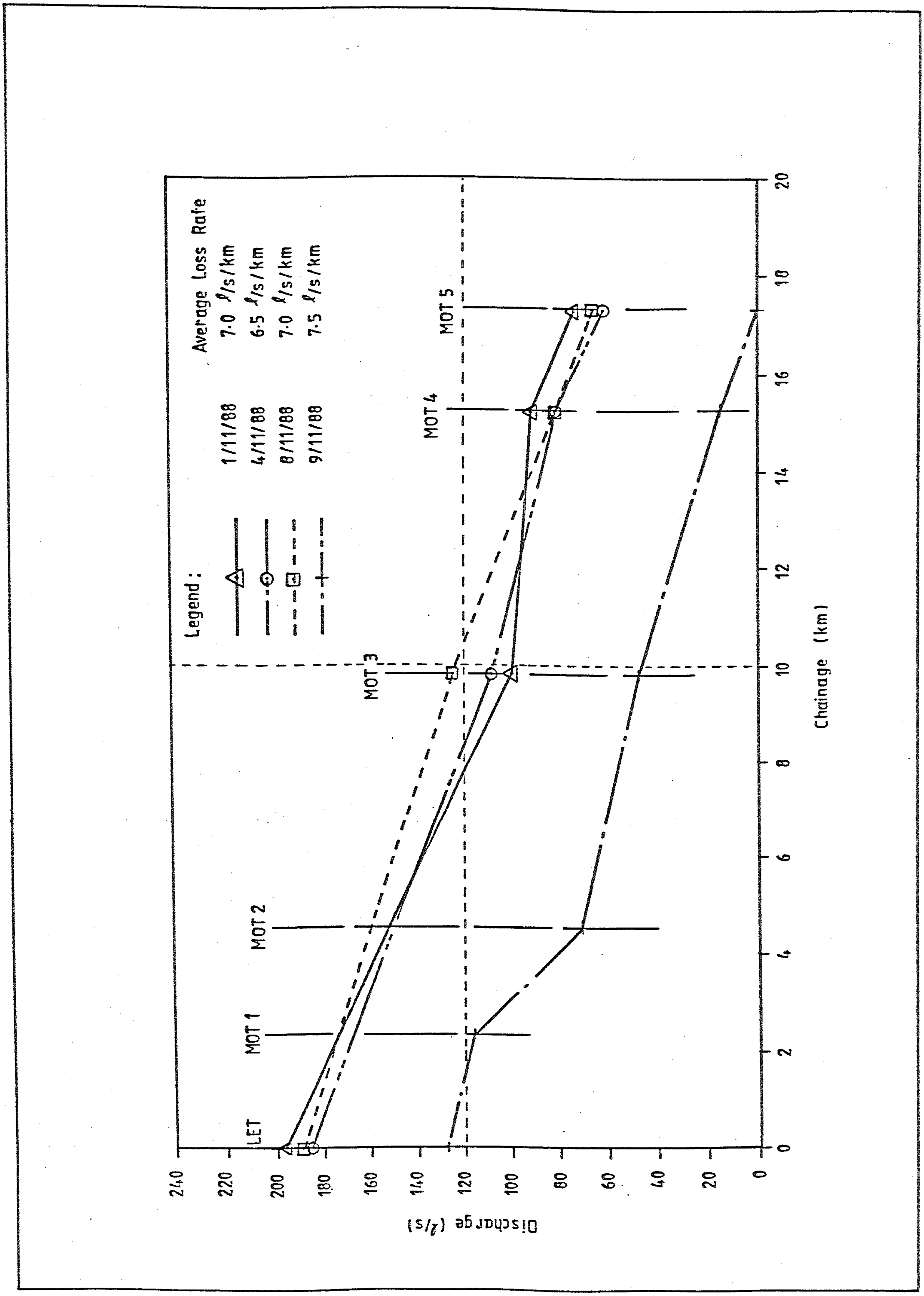


Figure B5.2

Observed Channel Losses



This model establishes the depth of water at each section using a standard backwater type analysis. The river is modeled as a series of cells, with cross-sections of sand and rock profiles defining the end of each cell. Working from the downstream end of the model the flow conditions across successive boundaries are established using a standard backwater energy balance approach for surface flow and Darcy's law to estimate longitudinal flow through the sand aquifer. As the calculation proceeds the loss to evaporation is established for each cell.

The scope for this steady-state model was limited to those reaches were full cross section details were available, which in practice means those reaches surveyed by Wikner (DWA, 1980) as the earlier Gibb work did not publish any of the cross section data. The model was run for the 7 km reach downstream of the Letsibogo dam site, simulating a range of releases.

The results are presented in Figure B5.4, expressed as losses per kilometer. It may be seen that the losses are remarkably constant over the range of flows considered. The overall value of 6 l/s/km (with Eo of 7 mm/day) is very close to the measured loss rates of 6.5 to 7.5 l/s/km. A further point to note is that the average width of the river over the 7 km covered by the model is 90 m, whereas the 17 km covered by the flow measurements has an average width of 106 m. Taking these differences into account it may be concluded that virtually all of the losses from the sand river may be explained in terms of surface and subsurface evaporation loss.

This finding has a number of important implications. On the assumption that all sections behave in the same way, it is adequate to base calculations of losses on evaporation from surface and subsurface only. The assumption of homogeneity that underscores this conclusion is major extrapolation of the known facts, but with the present state of knowledge there is little alternative. A second sand river model has been developed for this study, to perform a daily water balance, see Section B5.7. This model has been based on this crucial assumption, allowing no losses to evapotranspiration of the riverine strip, nor any loss to deep seepage.

The conclusion that no significant amounts of water are taken from the sand aquifer by riverside vegetation is also important in terms of conservation of this local resource. The dependence of the riverine strip on the sand river resource is discussed further in Annex K.

B5.7 Sand River Water Balance Model

B5.7.1 General

Whilst the steady-state sand river model gave considerable insight into the functioning of the sand river it was clear that an assessment of the full impact of the dam would require a simulation that could monitor the position over an extended period, taking account of variable inputs and outputs. As there appears to be no great dependence by the riverine vegetation the main aspect to consider with regard to downstream impacts is the use by the local population. In this regard it has been assumed that water levels at the end of the dry season represent the crucial parameter. During the dry season water is extracted by the means of shallow wells in the sand river bed. The depths of these wells is assumed to be more important than any effect that leads to these low levels being reached earlier in the season.

The model was initially calibrated against measured water levels during the 1981/82 hydrological year. After calibration a number of model runs were performed to assess the change in water levels once Letsibogo Dam is in operation during median and dry years.

B5.7.2 Model Details

The mathematical model is based on a daily water balance. The river has been divided into 70 cells with lengths varying from 0.15 km to 2.0 km covering a total length of 58 km from Letsibogo Dam, see Figure B5.1. Cell divisions were selected on the basis of surface water catchments and sand river reaches as defined by rock bars.

Each cell is characterised by the following parameters:

- length
- surface width
- sand and rock levels at each end of the cell
- stage/storage relationship

Two sources of data were used to define the river channel, Gibb (1969/70) and Wikner (1980). The latter work covers the first 12 km downstream of the dam and 18 km downstream of Tobane, with the Gibb study covering most of the intervening 28 km.

Unfortunately, the Gibb report does not give details of any cross-section surveys, in contrast to the Wikner report. Therefore it was not possible to use actual surveyed sections. As a result, a 'characteristic section' was developed from Wikner studies and applied throughout the length of river covered by the model. This section was developed by taking individual cross sections as surveyed by Wikner and redistributing sand levels so that the lowest point was at one bank with the level rising to the opposite bank, the area of flow being maintained between actual and developed cross sections at any water level. The characteristic section was then established as the mean of the individual sections. This simplification was far from desirable but, given the lack of basic data, there was little option. Should this model be taken any further then a programme of cross-section surveys should be instigated, with the model converted to use the actual data.

The basic data inputs to define the cells of the model are given in Appendix B-D.

To obtain an estimate of surface runoff all the subcatchments downstream of the dam site were delineated and planimetered from 1:50 000 scale maps. The unit runoff was based on the record of flows at Tobane, although it was found necessary to apply a correction factor, as discussed in Section B5.8. The evaporation from each cell is obtained using the relationship defined in Section B5.6, and the monthly evaporation estimates established for the catchment modelling, see Annex A, section A2.4.

The flow through the sand aquifer is based on the Darcy equation:

$$Q = Aki = TBi$$

where i = hydraulic gradient of flow defined by the water levels between the cell where the water balance is being carried out and the cell immediately downstream

k = hydraulic conductivity, taken as 0.003 m/s

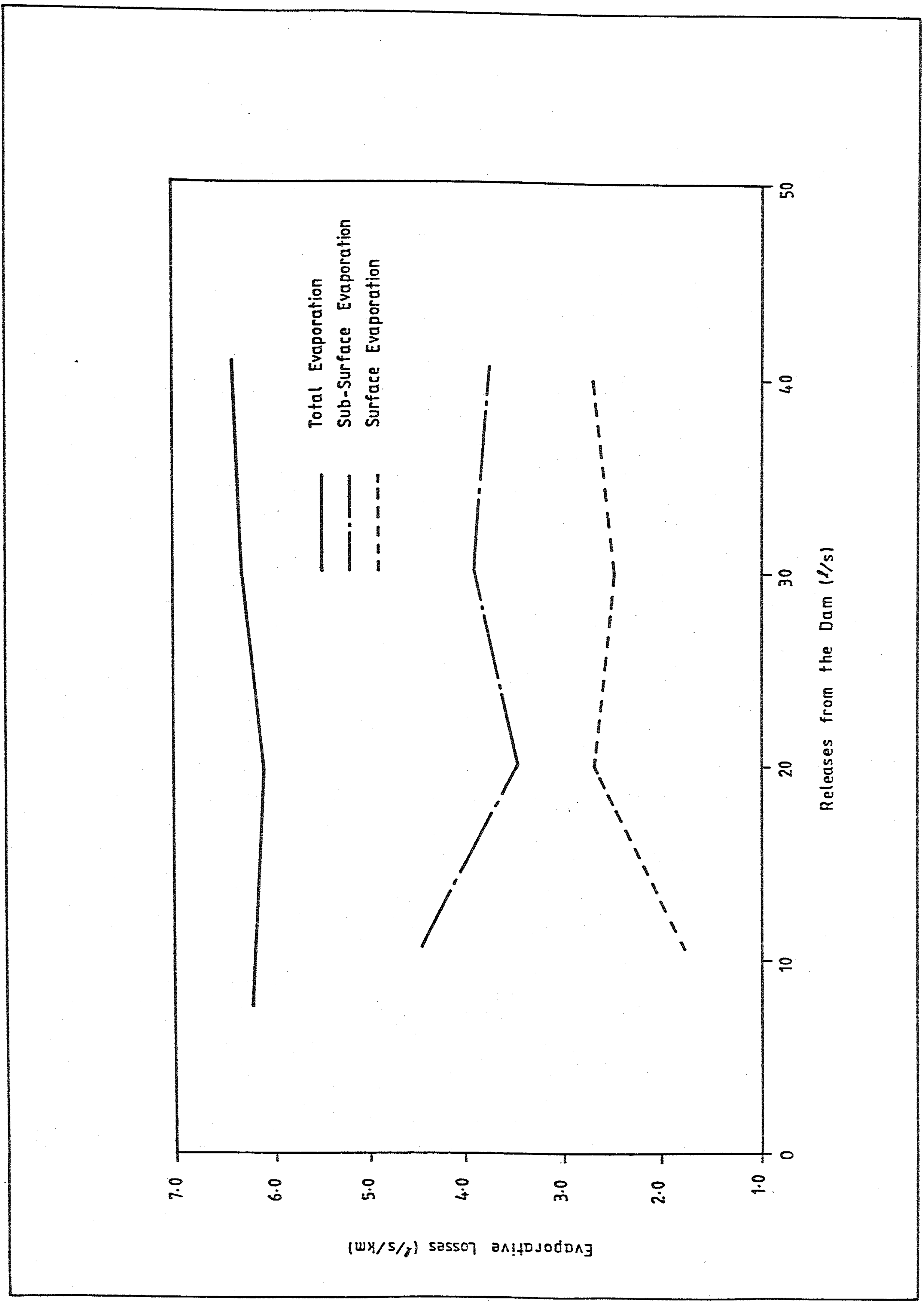
A = area of flow = $B \times D$, where D is the transmissivity depth which is evaluated from the depth to rock level between the two cells.

B = cross-section width

T = transmissivity

Figure B5.4

Computed Channel Losses



Surface water flow is calculated from Manning's equation, using the characteristic cross-section, with Manning's coefficient taken as 0.025 and a longitudinal slope of 1.5 m/km, the mean slope along the sand river.

Monthly rainfall figures are based on catchment rainfall at Tobane. The rainfall is applied on the first day of every month in the model.

B5.7.3 Consumptive Use

There are three main components of consumptive use of the sand aquifer, in order of magnitude these are:

- small scale irrigation (556 500 m^3/yr)
- cattle and livestock (280 000 m^3/yr)
- local population, in villages and dispersed (135 000 m^3/yr)

The estimate of irrigation consumption is based on the areas identified during field surveys. In all 26 ha is presently under irrigation between Letsibogo Dam and Tobane, as listed in Table B5.2.

Table B5.2

Small-scale Irrigation Between Letsibogo and Tobane

Distance from Letsibogo dam (km)	Area (ha)
2.0	2.9
13.7	0.3
15.7	2.5
18.0	11.0
23.8	3.5
38.3	5.8

The water demand associated with these areas was derived by the SPRDP (Minster, 1989). Assuming surface irrigated vegetable crops throughout, a 120 % cropping intensity and an irrigation efficiency of 50 % the water demand for irrigation is as shown in Table B5.3.

Table B5.3

Gross Water Requirements for Small-scale Irrigation from the Sand River

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Requirement (l/s/ha)	0.65	0.46	0.49	0.25	0.05	0.16	0.38	0.46	0.42	0.48	0.68	0.71

The demands placed on the sand river by the human population are somewhat complicated by the pattern of population movement. The two major concentrated extraction points within the reach under consideration serve the villages of Mmadinare and Tobane. A significant proportion of these village communities are involved in cultivation of the land in the rainy season (taken as November to March for the purpose of the model) and many move to alternative residences during those months. To account for this two demand patterns have been applied, representing the seasonal distribution of population. Population estimates applicable to 1989 have been used (derived from projections made from the 1981 census) with per capita consumption taken from 'A Profile of Environment and Development in Botswana' (University of Botswana, 1986), as given in Table B5.4.

Table B5.4

Estimates of Water Demand for Local Populations Between Letsibogo and Tobane

Locality	Number	Demand (l/day)	Consumptive Use (m^3/day)
(a) Dry season (April to October)			
Rural	411	20	8.2
Mmadinare	14 863	20	297.3
Tobane	3 266	20	65.3
(b) Wet season (November to March)			
Rural	13 400	20	268.0
Mmadinare	4 540	20	90.8
Tobane	600	20	12.0
Total			370.8

Estimates of the current cattle and other livestock population within the catchment area have been made as part of the Environmental Impact Assessment (see Annex K). Current levels are, however, still depressed by the recent drought. By estimating the extent of the stock losses incurred in the last few years it has been possible to establish the pre-drought stock levels. These figures are expected to be the maximum possible as the livestock population is normally limited by the grazing area rather than the water resource. The water consumption attributable to livestock is given in Table B5.5.

Table B5.5

Estimates of Water Demand for Cattle and Livestock

	Number	Demand (l/day)	Consumptive Use (m^3/day)
Cattle	9 550	45	429.8
Goats	10 250	10	102.5
Donkeys	2 140	15	32.1
Total (general river use)			564.4

The consumptive use quantified above has been applied to the sand river water balance model in two forms. The irrigation and village demands are point extractions and are attributable to specific cells of the model. Livestock and rural population demands have been assumed to be spread uniformly down the river. Over the 58 km covered by the model the livestock demand represents 0.113 l/s/km and the local population represents 0.053 l/s/km during the wet season. It may be seen that consumptive use is small compared to the peak rates of evaporation loss of 7 l/s/km.

Finally, at the Letlhakane/Motloutse confluence an additional input of 400 m^3/hr discharged by the BCL mine and 80 m^3/hr discharged from the sewerage works has been added to the water balance, see Section B5.4. Some of the implications of curtailing this discharge have been briefly considered, see Section B5.8.

B5.8 Calibration of Model

A major drawback in attempting to calibrate the sand river water balance model is the fact that no systematic data collection has ever been undertaken with a sufficient density to provide an adequate record to calibrate against. The analysis covered by this study is considered to demonstrate the potential for gaining a greater understanding of the functioning of the sand river. Such information is vital if there is any intention to exploit this resource to its maximum potential. A certain amount of fieldwork would be essential if this approach were to be taken further, in particular water levels should be monitored on a continuous basis at a number of points down the river. Currently, the only data available to check the accuracy of the mathematical model is sand aquifer water levels measured at Tobane and Mmadinare, along with the flow records from the Tobane gauging station and the limited fieldwork undertaken by this study.

Water levels are measured during the dry season by initially leveling a point on the river, digging down to the watertable at that point and levelling the water surface. Although the same position on the river is measured during each survey this is not necessarily the lowest point on the river, this is particularly important when comparing results from the model. Measurements, which are taken monthly on average, are reproduced in Appendix B–D. The recorded data obviously contains a number of errors, many are obvious but it is not possible to detect small errors. Consequently the unreliability of the data must be borne in mind when assessing the performance of the model.

The sand and watertable positions are recorded as absolute levels, to the national datum. The function of evaporation relates to the depth to watertable, hence relative depths are more important than absolute levels in this context. According to the recorded levels there were fluctuations in sand levels through the dry season. This may be explained by local disturbance, possible as a result of excavation to reveal the watertable. To overcome this problem with the data an average sand level was derived for each dry season. Watertable depths were then established as the difference between recorded water levels and the average sand level.

The 1981/82 season was used as to calibrate the model; as the driest year in the 66 years of record this could be expected to show the greatest degree of depletion of sand river water levels. The year was also comparatively well covered by the records.

In order to reproduce the conditions prevailing in 1981/82 various alterations were made to the standard data inputs given in Section B5.7.3. The revised position is given below:

- there was no irrigation in 1981/82
- the population figures were revised in line with the 1981 census
- livestock populations estimated as midway between the maximum levels and the low at the end of the drought

The recorded runoff for 1981/82 was 5.30 $m^3 10^6$, which represents a runoff 0.67 mm/km. The first finding from the water balance model was that applying this unit runoff to each of the subcatchments resulted in a total runoff at Tobane that was considerably less than the record. It was apparent that the volume entering the river channel was being depleted by evaporation before reaching the Tobane gauge point. After a number of trials it was established that a factor of 1.24 was required to reproduce the total flow that was recorded. This has important implications with regard to assumed inflow at the Letsibogo dam site in low flow years. If the runoff from the entire catchment is uniform then the inflow to the dam site would be 24% greater in 1981/82. The Letsibogo site represents 69% of the Tobane catchment, see Section B2.1, hence the inflow for 1981/82 is taken as 3.66 $m^3 10^6$. Applying the correction factor for losses would bring the inflow to the dam site up to 4.53 $m^3 10^6$. Whilst this effect was not applicable to the higher flow years, see Section B5.9, the years of low flow are particularly significant in establishing the reliable yields from the reservoir. It would appear, therefore, that more confidence can be placed the inflow figures in dry years as being underestimates rather than overestimates.

The model was run with a daily time step for the period October 1981 to September 1982. The results are shown in Figure B5.5 as a comparison between modelled and recorded water levels for Mmadinare and Tobane.

The record at Mmadinare shows a remarkably good correlation with the levels predicted by the model. The initial water level assumed for the model run was 0.6 m below the sand surface. The actual measured level was 0.71 m. However, the setting of the initial water level does not have any persistent effect on the overall results. All the other points are within 0.1 m of the recorded levels.

By contrast the Tobane water level record does not show such a good correlation. During the wet season the actual water levels are within 0.3 m of those predicted by the model, while during the dry season differences of up to 0.8 m were found. As there were no direct records of releases from the BCL mine it was considered that reduced outflow from this source could be a possible explanation for the lower recorded levels. To test this hypothesis the contribution from the mine and Selebi-Phikwe sewage works was eliminated. The results are also presented in Figure B5.5. It can be seen that the effect at Tobane during the dry season is minimal.

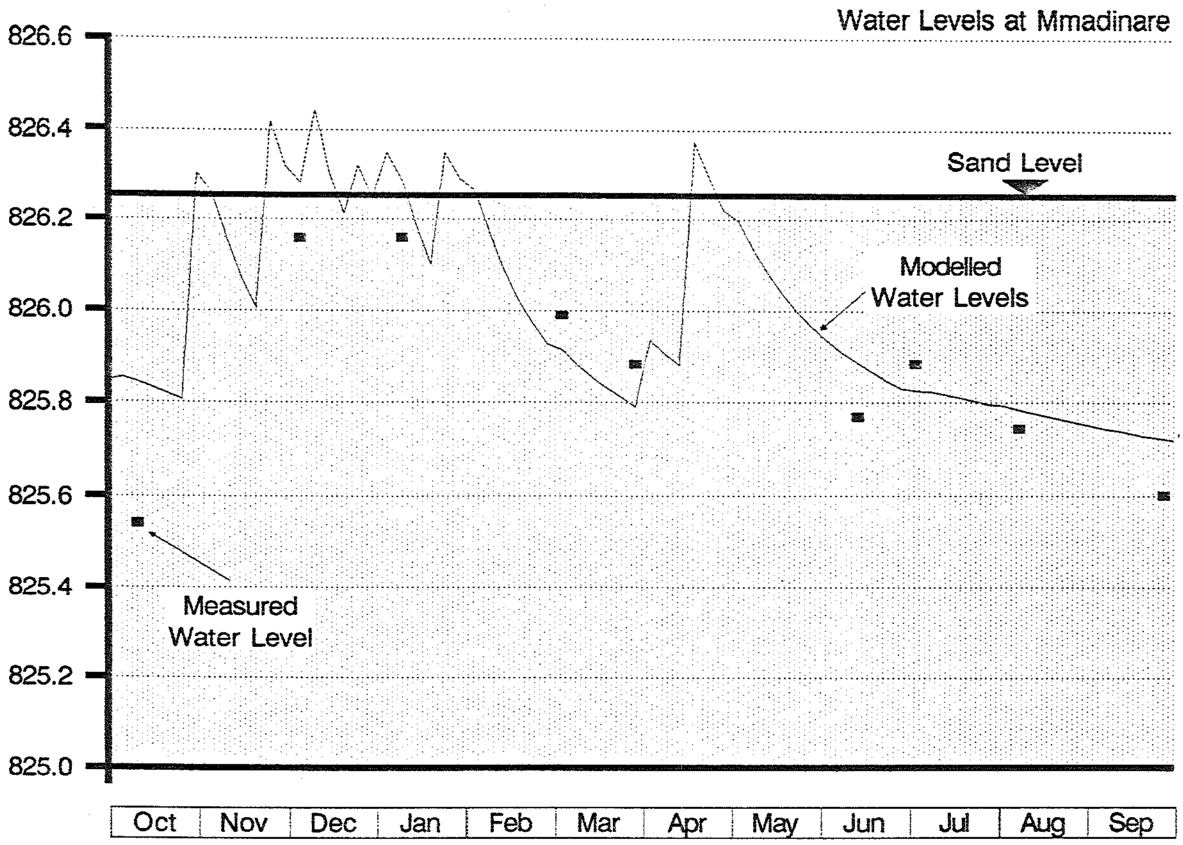
The most likely explanation for this difference is in the quality of the level records. It is not known whether the water level monitoring point is at the lowest point in the section. If the point were, say, 0.5 m above the lowest point then the depth to the watertable would appear to be 0.5 m greater. It should be noted that the general gradient of water level decline is well reproduced. This helps support the argument that significant quantities of water are not being taken from the river by the riverine strip, as this would result in a steeper decline in water levels through the dry season.

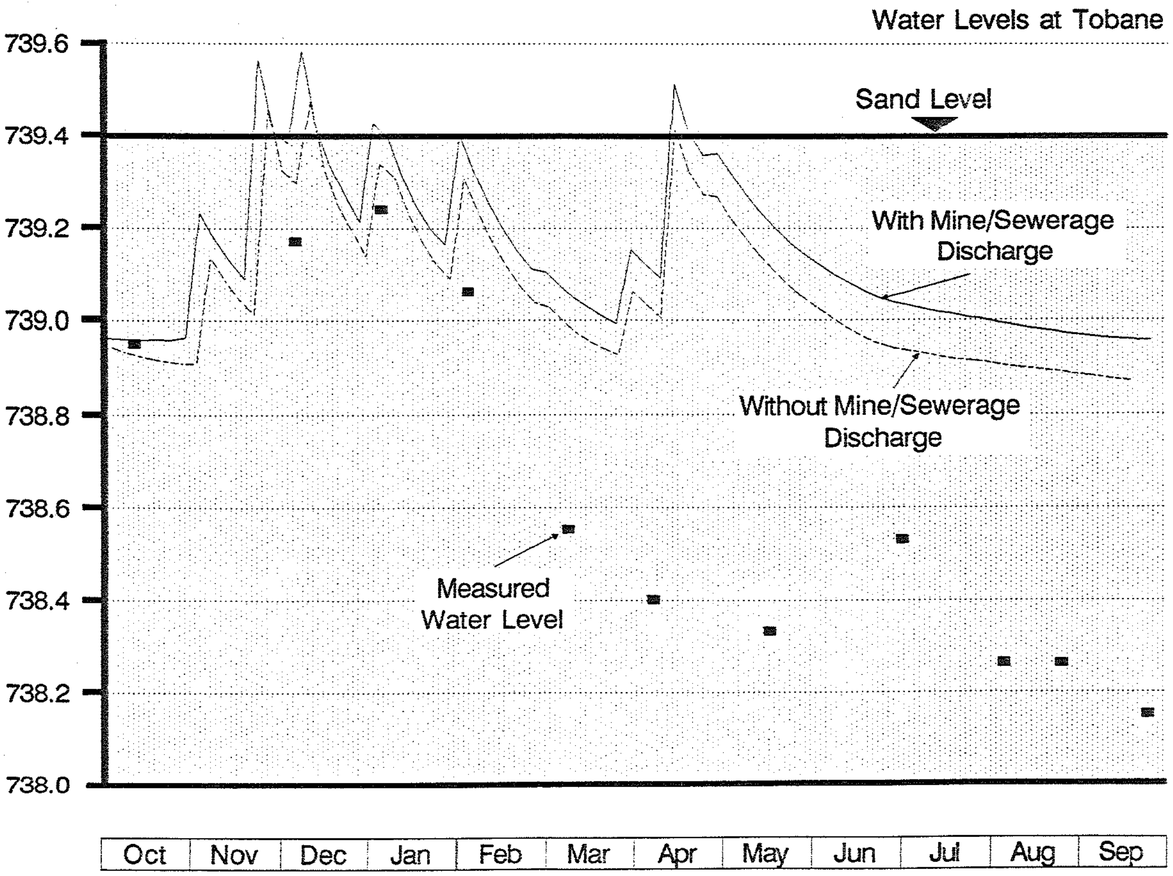
As the main point of the model is to assess the effects of the Letsibogo dam on downstream water levels the picture at Mmadinare is much more significant than that at Tobane. It is, therefore, considered that the comparison between modelled and recorded data for the driest year on record is sufficiently close to confirm that the main processes of the sand river are being adequately reproduced by the sand river model.

As a final comparison the model was run for the 17 km downstream of the Letlhakane confluence, for the month of November. The purpose of this run was to see how closely the observed flows were reproduced, see Section B5.5. Starting with a flow of 197 l/s the flow had diminished to 99 l/s over the reach, equivalent to a loss of 5.2 l/s/km. This may be compared to the recorded flows were the average loss rate over the same reach varied from 6.5 to 7.5 l/s/km. It is difficult to ascribe a reason to this difference. It may be the

Figure B5.5

Sand River Model Calibration





result of the averaging process used to define the characteristic cross-section, or it may be the result of a small amount of evapotranspiration from riverine vegetation. An associated factor could be the presence of a number of pools in the bed of the river, which are not possible to reproduce using the model based on the characteristic cross-section.

B5.9 Median Year

Following the calibration exercise it was considered that the model was sufficiently accurate to enable some indication to be gained of the likely impact of Letsibogo dam. The position with regard to the median year was considered first.

From the 66 year record of flows at Tobane gauging station the median year corresponds to that of 1979/80: total flow was 65.0 $m^3 10^6$, which is equivalent to a runoff of 8.20 mm/km. The recalibration exercise, found necessary to achieve measured runoff in the case of the dry year, was repeated for the median year. However the resulting correction factor was found to be 0.965. The fact that this factor is slightly below 1.0 is thought to be due to the BCL mine discharge upstream, and also the contribution of direct rainfall onto the sand river bed, both of which are additional inputs, whereas the total gauged flow had been attributed to catchment runoff.

To establish the effect of the dam the model was run with and without the contribution of the Letsibogo catchment. For the 'with dam' case the subsurface flow in the sand river at the dam site was also curtailed. The results are presented in Figure B5.6 as a long section down the river showing water levels at the end of the dry season. In order to exaggerate the differences the results are also presented in Figure B5.7 as the relative difference between the two sets of levels. From Figure B5.7 it can be seen that there is up to 1.4 m extra drawdown immediately downstream of the dam, reducing to 0.1 m at a distance of 4 km from the dam site. Further downstream there is additional drawdown varying from 0.05 m to 0.20 m until the Letlhakane/Motloutse confluence. At this point the combined contributions from the Letlhakane catchment (1 939 km^2) and the BCL mine are sufficient to swamp any minimal residual effect.

These initial findings confirmed that there would be a significant effect at Mmadinare, which is only 2 km downstream of the dam. This effect is exaggerated by the extraction for the village water supplies and two small irrigation holdings. To alleviate these problems the supply for Mmadinare and the irrigation area were cut off, simulating the case of supply directly from the dam. The results are also presented in Figures B5.6 and B5.7. It can be seen that the effect is quite pronounced with additional drawdown as a result of the dam virtually eliminated, except for the first kilometer downstream of the dam. With regard to this first kilometre, it is extremely unlikely that seepage from the dam can be fully eliminated. Consequently, it may be concluded that, in the median flow year, the only compensation required to maintain the sand river to meet consumptive use downstream is that the supply to Mmadinare should be taken directly from the reservoir. The position with regard to the 2.9 ha of irrigation should be reviewed at detailed design stage.

The change in water levels throughout the year is presented in Figure B5.8. The figure shows the effect of the dam in curtailing surface flow. Once inflow contributions have ceased the recession curve has two distinct gradients, a comparatively sharp decline over the first month, under the influence of evaporation, followed by a much more gradual decay, as result of longitudinal subsurface flow and the uniformly distributed livestock demands. It may be seen that the precise timing of the first, sharp, decline is not critical in establishing the final water level at the end of the dry season.

The role of direct rainfall onto the sand surface has been brought out by this work. With

The role of direct rainfall onto the sand surface has been brought out by this work. With a storage capacity of 17.5% the top metre of sand only requires 175 mm of rainfall to achieve full saturation. The 80% exceedence rainfall for Selebi-Phikwe is 138 mm. This means that with no surface flow at all there is still a good chance that the sand river will be significantly recharged each year. Once full saturation is reached the rate of decline is virtually the same whether as a result of a large flood or an isolated storm that produces minimal runoff.

B5.10 Dry Year

Having established that the dam would produce no significant effect on downstream water levels at the end the dry season in the median year the model was then used to assess the impact in a dry year. The 1981/82 year, as was used to calibrate the model, was chosen for this purpose, being the driest year in the 66 years of extended record.

Using the same runoff factor as during calibration (1.24) the model was run twice : once without the dam, simulating present conditions; and once with the dam but assuming the demands for Mmadinare and the small local irrigation areas will be supplied directly from the dam. The results are shown of Figures B5.9 and B5.10. The results have also been added to Figure B5.7, to give a comparison of the relative changes.

The pattern found was similar to that of the median year, although slightly more severe. Water levels are higher in the immediate vicinity of Mmadinare. There is a slight lowering of water levels over the first 17 km (to 8km upstream of the Letlhakane confluence). However, as this difference rarely exceeds 0.3 m in this, the driest year on record, it is considered that the construction of the dam does not have a detrimental effect on downstream users.

It is also apparent that overall there is very little difference in the dry season water levels in the sand between median and dry years. This lends support to the hypothesis that even during the severest of droughts the sand river still provides a reliable source of water.

B5.11 Long-term Impacts

To finalise the assessment of the impact of Letsibogo Dam on the sand river water levels, the program was set to run over three years. The dry year, 1981/82, was again used for this purpose. This was considered to be an extreme 'worse case': three drought years without the dam spillway being overtopped.

The main area of interest was in the 10 km of the river immediately downstream of the Letsibogo dam site, where the surface run-off was very low, upstream of where the substantial catchments of Letlhakane and Sempowane rivers replenish the sand river. Table B5.6 details the results over this critical reach. At the end of the dry season the water levels are lowered very slightly, a maximum of 0.15 m over the three year period.

As observed previously the major mechanism in maintaining water levels is replenishment of the sand river by rainfall. The rainfall during the dry year was 236 mm, which if applied in one storm would raise water levels by 1.35 m. This was found to be adequate to prevent any long term progressive drawdown over the three year period.

Figure B5.6

Dry Season Water Levels (Median Year)

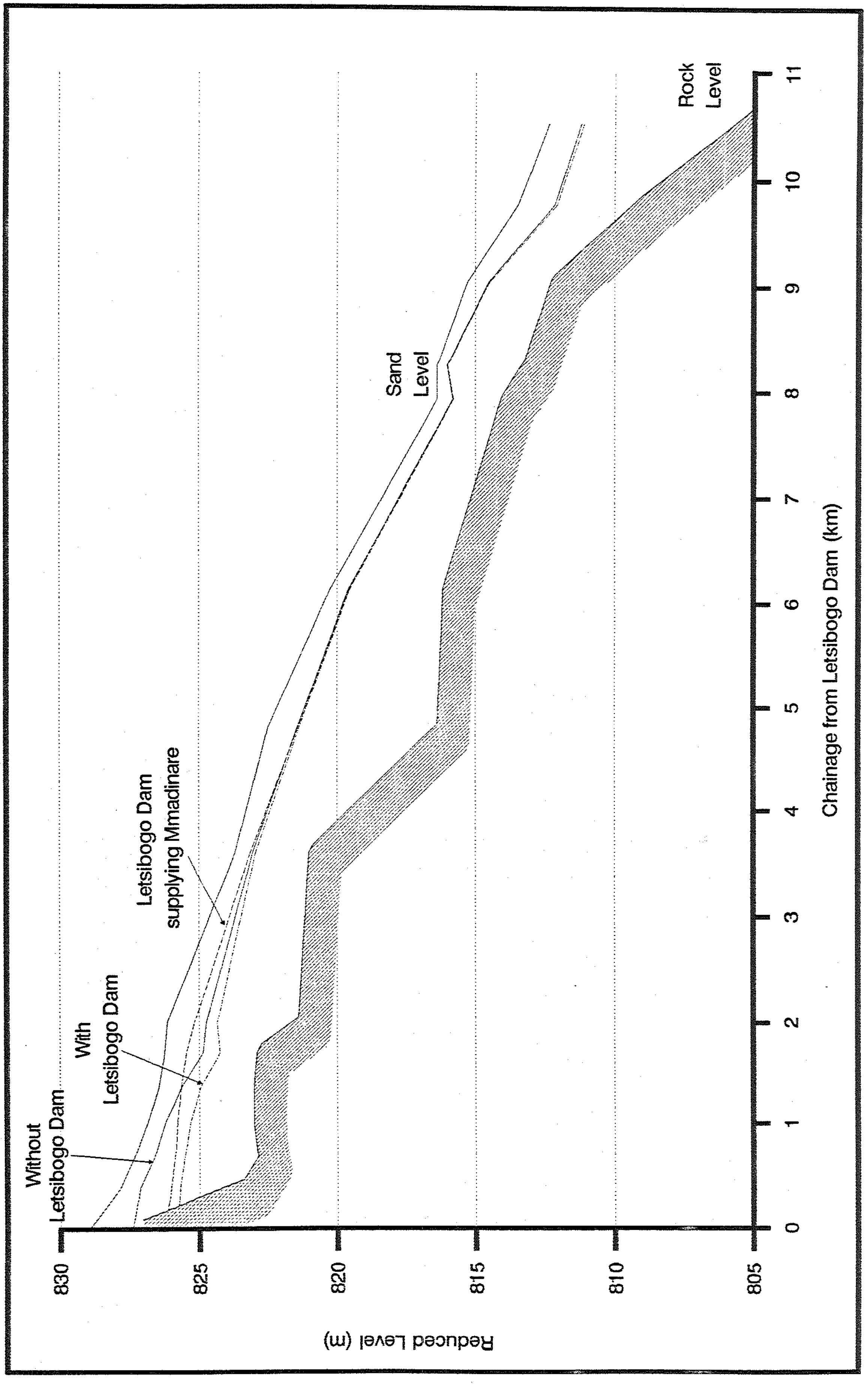
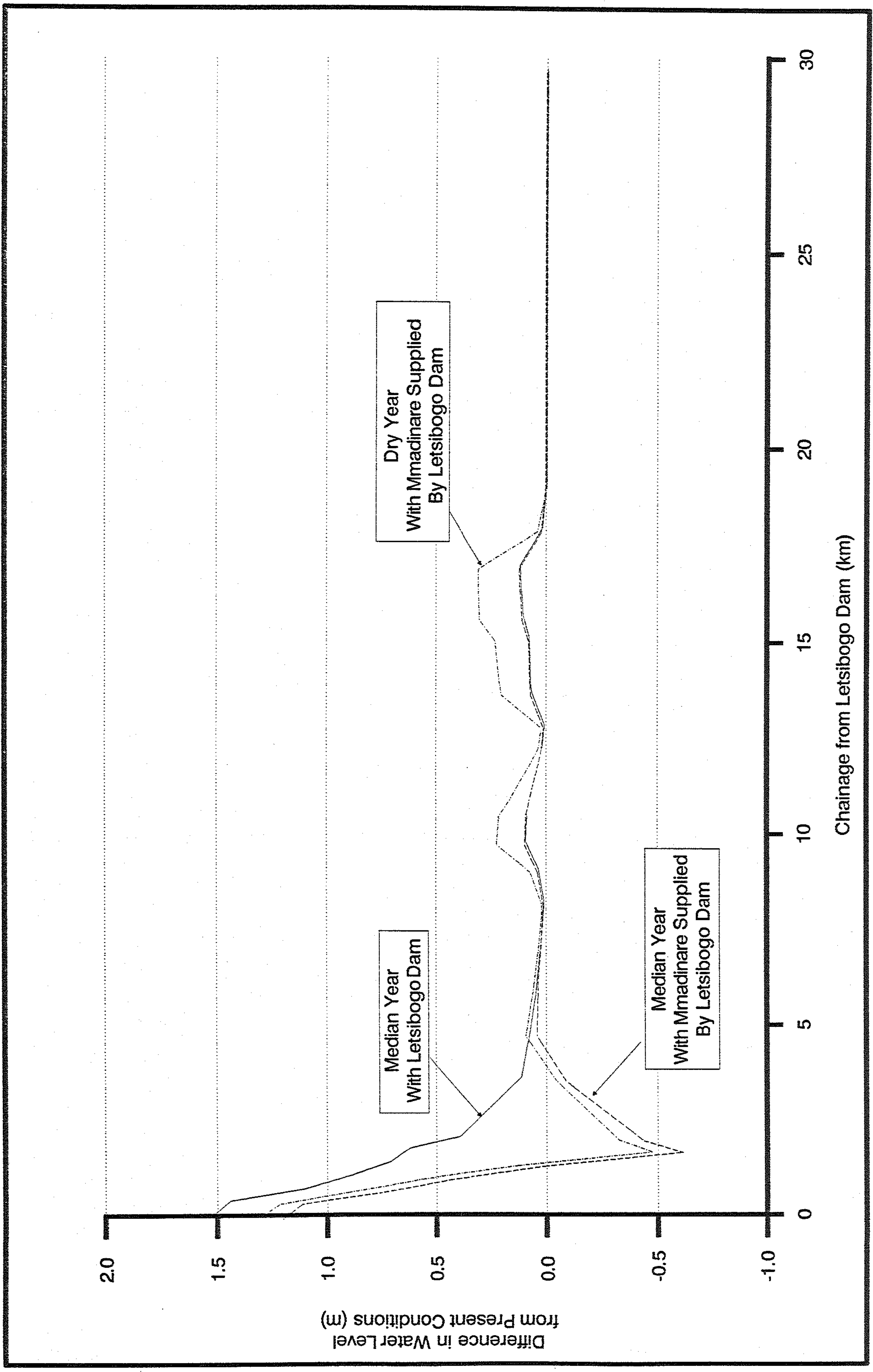


Figure B5.7

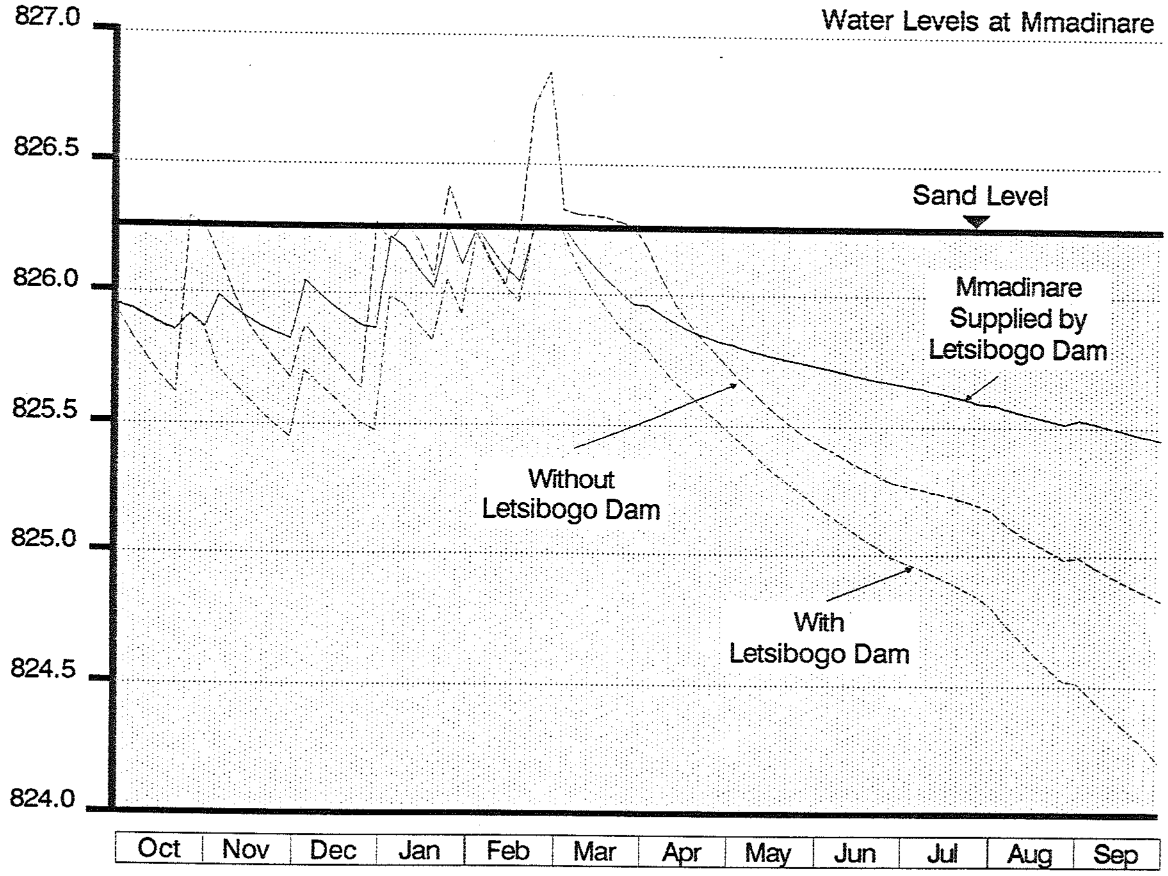
Comparison of Water Levels in Sand River



Fiigure B5-8

Annual Water Level in the Median Year

Water Levels at Mmadinare



Water Levels at Chainage 4.5 km

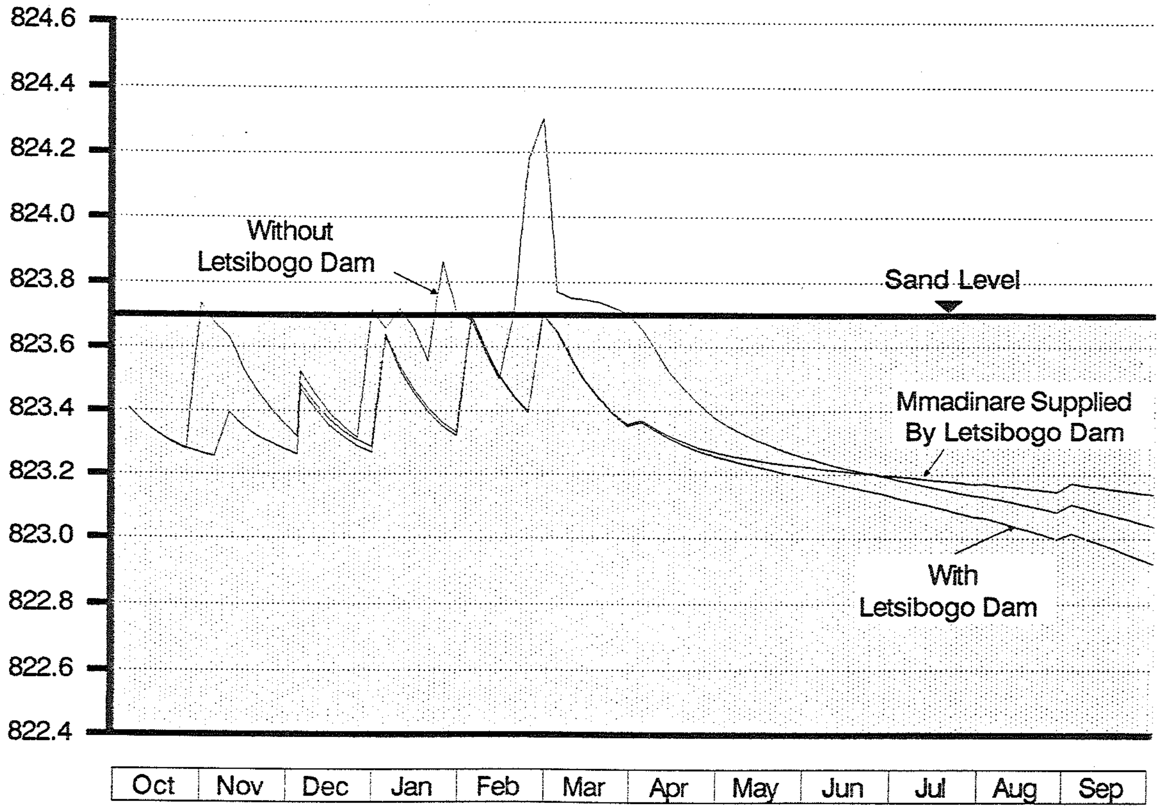


Figure B5.9

Dry Season Water Levels (Dry Year)

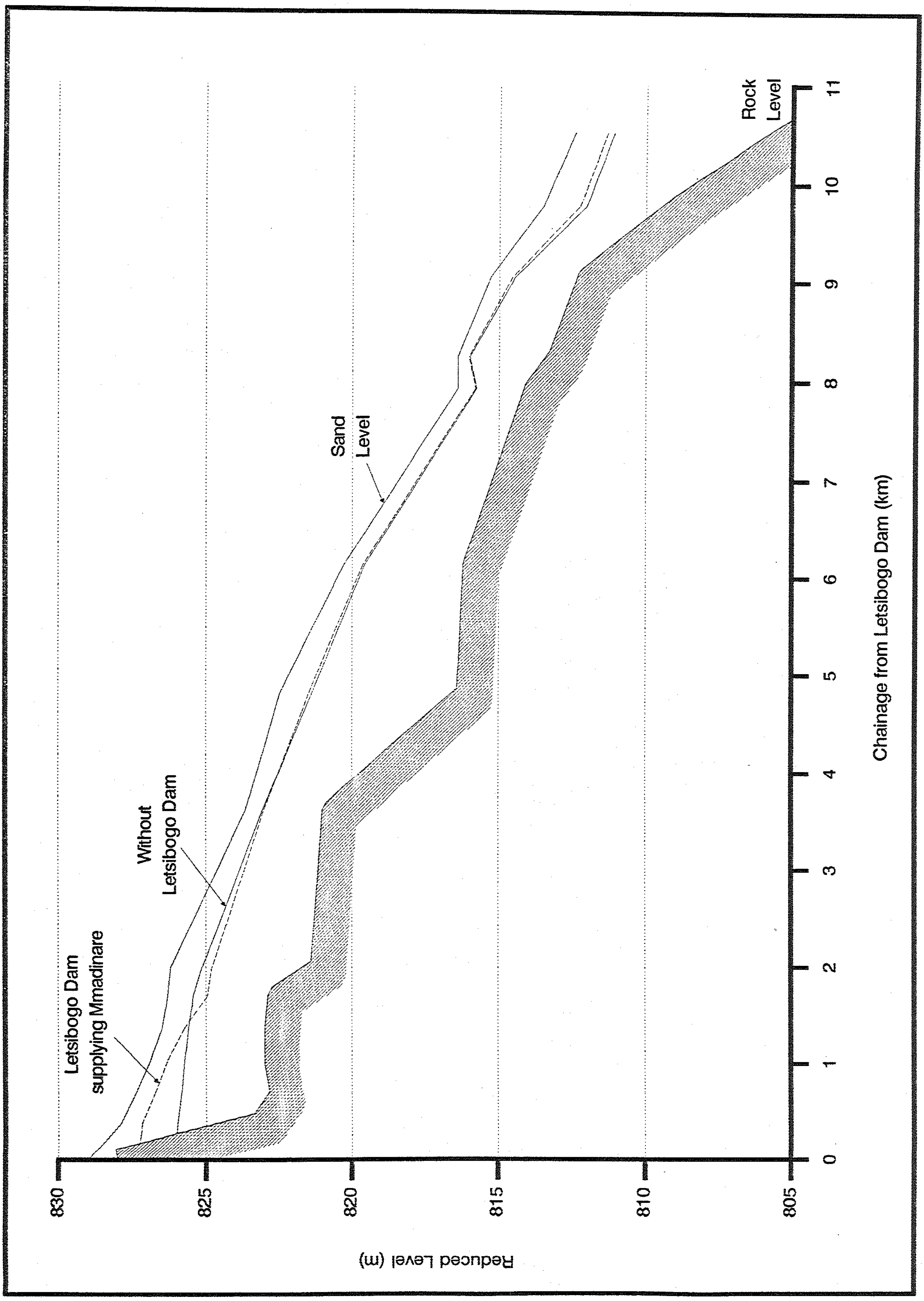


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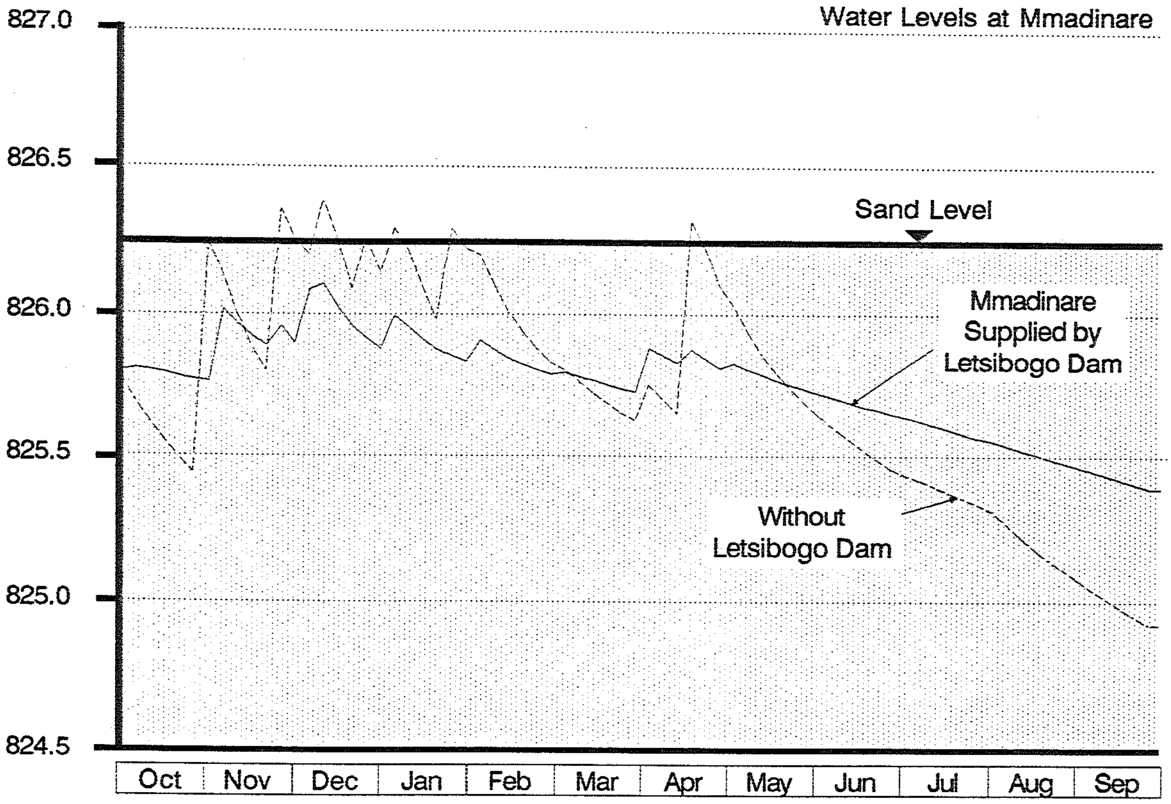
Figure B5.10

Annual Water Levels in the Dry Year



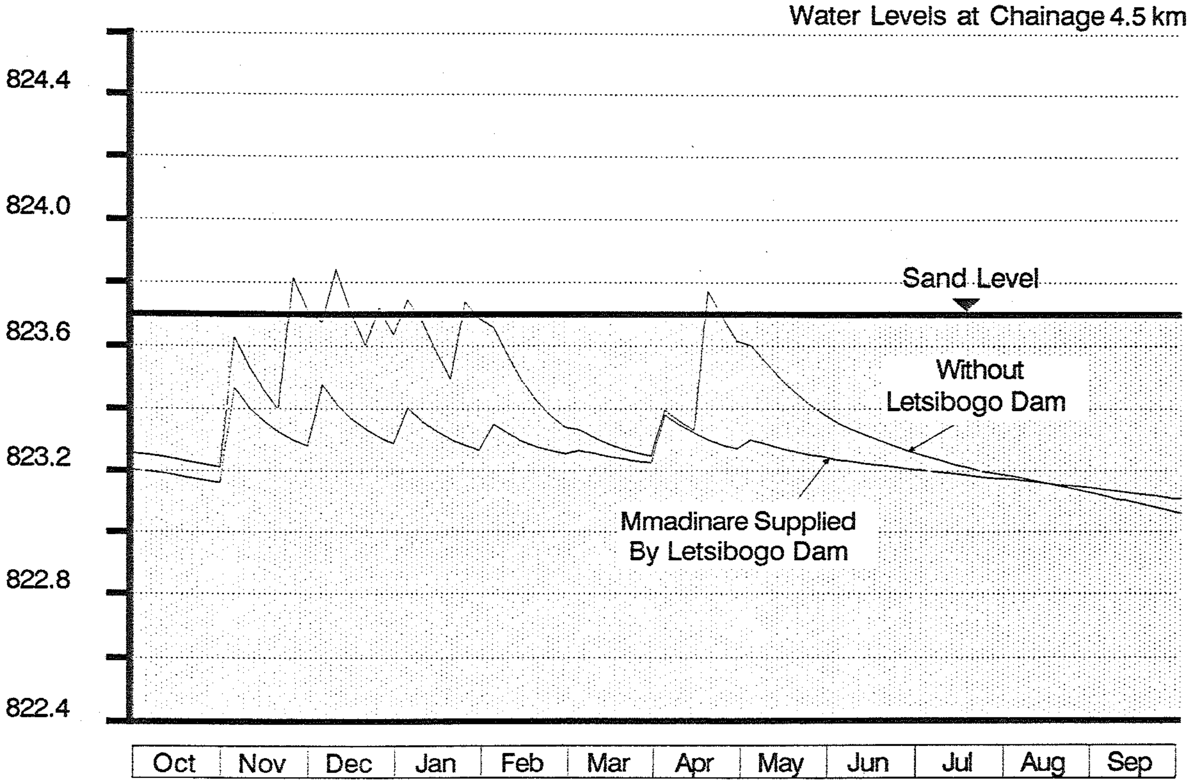


Table B5.6

Water Levels in the Sand River
During a Three Year Drought

Chainage (km)	Sand level (m)	Water levels at the end of the dry season Year 1	Year 2	Year 3
0.00	828.00	826.05	825.92	825.90
0.38	827.90	825.96	825.86	825.84
0.68	827.40	825.83	825.75	825.73
1.02	826.90	825.73	825.65	825.63
1.36	826.50	825.60	825.53	825.52
1.70	826.30	825.43	825.38	825.36
2.00	826.20	825.12	825.08	825.07
3.60	823.70	823.11	823.10	823.10
4.80	822.50	821.40	821.40	821.39
6.13	820.30	819.59	819.58	819.58
7.93	816.40	815.78	815.78	815.78
8.25	816.40	816.00	816.00	816.00

B5.12 Conclusions

With the existing level of basic data it has not been possible to produce a model of the sand river that leaves no room for doubt. Nonetheless, it is considered that the calibration was sufficiently successful to have some confidence in the general trends that have been established. To summarise these are:

- no additional compensation flows are required from the dam as the transfer of the source of supply for Mmadinare and local irrigation is adequate compensation for downstream users of the sand river

- the area of significant drawdown in water level is limited to the first kilometre below the dam and the inevitable seepage from the dam may even compensate in this area

The sand river model has also been used to evaluate the efficiency and timing of releases for large scale irrigation. The results are discussed in Annex I.

CHAPTER B6

RELEASES FOR IRRIGATION

B6.1 Introduction

Any releases for irrigation will reduce the amount of water available to meet primary demand, which is urban supply. As discussed in Section B2.1.7, the allocation in times of shortage has been simulated by trigger rules. The position being considered in this chapter is with regard to the long-term steady-state supply. The conditions prevailing in the crucial period between commissioning of the Letsibogo dam and the following resource is assessed in the following chapter.

B6.2 Reliability for Irrigation Supplies

Reservoir simulation has been used to establish the quantity available for primary demand for the case where there exists a commitment to irrigation. Irrigation releases would be required with a defined reliability and annual quantity. The approach was, initially, to establish the volume available for irrigation at an 80% reliability, given an urban demand less than the full 95/99% yield. However, the consequence of establishing a trigger rule for the irrigation supplies is that, for an average of one year in five, there would be no water. The conventional wisdom of an 80% reliability for irrigation (from a dam entirely devoted to irrigation, for example) is based on the implied assumption that in dry years, even though full irrigation would not be possible, there would still be some water available. With a multi-use dam this is not the case, as it is necessary to curtail all irrigation supplies to ensure that urban demand can be maintained. Hence, it is considered necessary to increase the reliability of irrigation supplies, to a suggested level of 90%. This will have the effect of reducing the amount reliably available.

An example of the annual results associated with an irrigation reliability of 80% is given in Appendix B-E. The example is based on a Letsibogo reservoir of 125 $m^3 10^6$, which provides a yield of 30.8 $m^3 10^6$/yr at a 95/99% reliability. If the urban demand were only 20 $m^3 10^6$/yr then the amount available for irrigation would be 20.3 $m^3 10^6$/yr at 80% reliability. Simulating this demand pattern on the 66 years of river inflow data, assuming two crops a year, resulted in the loss of one crop in each of the years, 1933, 1936, 1938, 1952, 1954, 1959, 1960, 1961, 1962, 1965, 1970, 1980, 1982, 1983, 1984 and 1985, with both crops lost in 1934, 1935, 1963 and 1964. The 'bunching' of the dry years is a pronounced feature. This pattern of crop failure is likely to deter a potential investor.

B6.3 Available Long Term Yield for a Multi-Use Dam

Adopting the 90% reliability criterion for irrigation does, of course, reduce the number of failure years. The second example given in Appendix B-E repeats the analysis carried out previously, with the revised reliability criterion. Maintaining the same primary yield, the annual quantity available for irrigation is reduced from 20.3 to 15.4 $m^3 10^6$. The resulting failure years are now 1935, 1936, 1938, 1962, 1963, 1964, 1965, 1970, 1983 and 1984, with both crops lost in 1935, 1963 and 1964. This pattern of crop failure is considered to be more acceptable.

The analysis has been repeated for a range of primary demands, with the results presented in Table B6.1 and Figure B6.1. As the range of possible Letsibogo reservoir sizes has been reduced as a result of the previous analysis (MacDonald, 1989), the performance of the dam as a multi-use resource has only been assessed for a reservoir size of 125 $m^3 10^6$. The position with regard to the supplementary Letlhakane dam and/or Letlhakane Fault Zone groundwater development would have to be assessed during the full feasibility study of each resource.

Table B6.1

Joint Yields from Letsibogo Dam

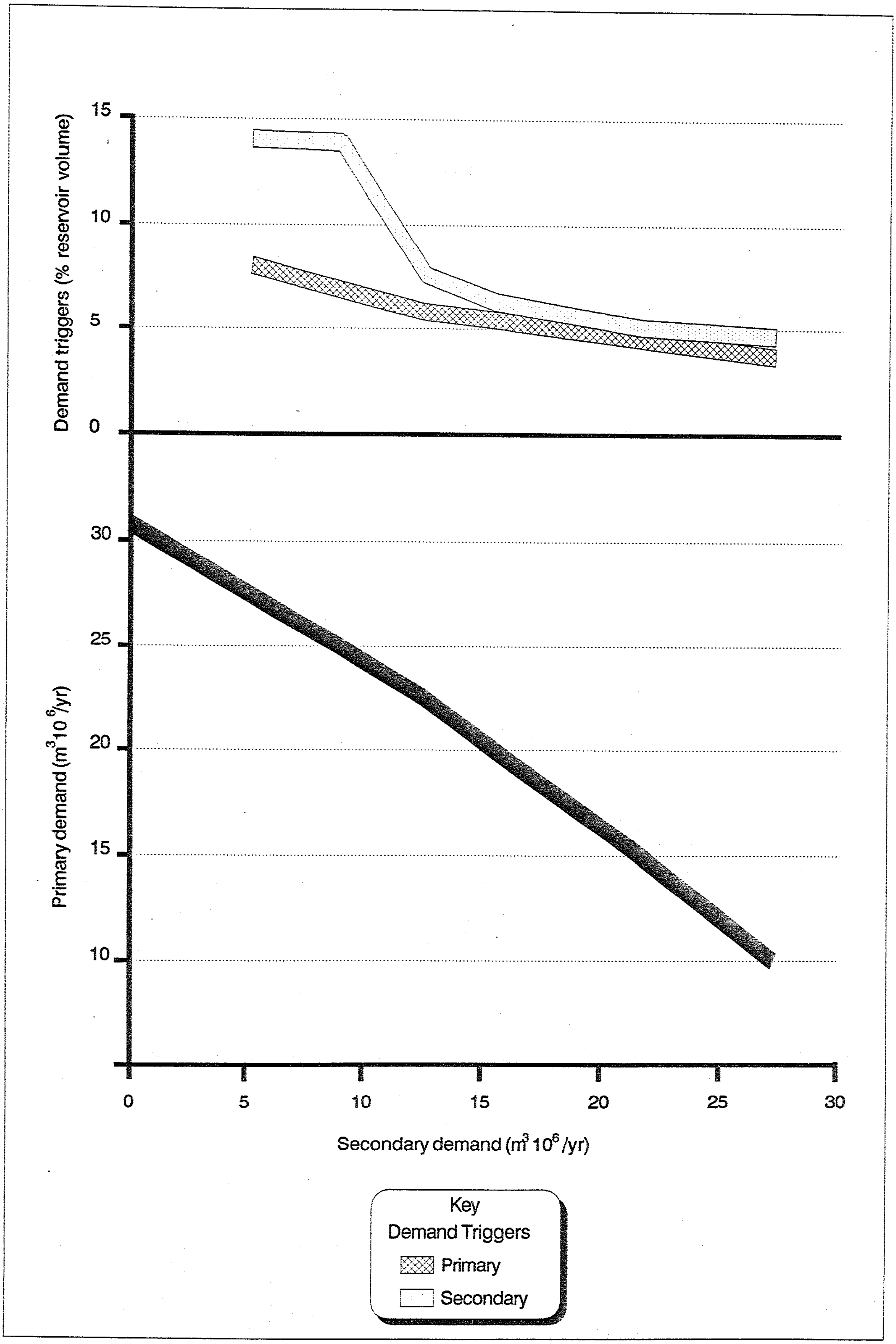
Primary yield reliability 95/99%	Secondary yield reliability 90%
10.0	27.1
15.0	21.6
20.0	15.4
22.5	12.4
25.0	8.9
27.5	5.1

Consideration of large scale irrigation has been limited to two main options, the first covering 1 019 ha, the second covering 559 ha, see Annex I. The crop water requirements have been assessed as 15 800 m^3/ha for a basic crop rotation of cotton-wheat-maize. For the purpose of this exercise it has been assumed that a pipeline is used to convey the irrigation water from the dam to the irrigable areas and that no additional efficiency factor is required over and above the field efficiency of 65%. Hence, the irrigation requirements associated with the two irrigation options are 16.1 and 8.8 $m^3 10^6$/yr. It may be seen from Figure B6.1 that the quantity available to meet primary demand whilst also satisfying irrigation demand is 19.4 and 25.1 $m^3 10^6$/yr for the larger and smaller irrigation options respectively.

The full primary yield from the size of dam used for this analysis is 30.8 $m^3 10^6$/yr. Hence the 'penalty' in terms of urban demand may be considered as 11.4 $m^3 10^6$/yr long term reduction in primary yield for the case of a 1 019 ha development and only 5.7 $m^3 10^6$/yr for the smaller 559 ha development.

Figure B6.1

Long Term Yield of Multi-use Dam



CHAPTER B7

SUPPLY AND DEMAND AFTER LETSIBOGO IS COMMISSIONED

B7.1 Introduction

The final aspect to receive attention during the water resource assessment of the study is the position with regard to supply and demand in the years immediately following commissioning, assumed to be 1995. Two aspects have been considered:

- will the Letsibogo dam fill with sufficient reliability to meet demand in the early years?

- does the comparative under use in the early years have any impact on timing of the next resource?

To answer these questions a further modification has been made to the basic simulation computer program. The methodology is outlined in Section B2.1.8. The position has been considered both with regard to primary demand and the effect of the introduction of irrigation.

B7.2 Demand

The essential feature of the previous steady-state analysis is that the capability of the resource to supply water is established without reference to actual demand. In effect the demand is assumed to be infinite and the analysis is used to establish what proportion of that infinite demand can be met by the resource. Within the context of the Letsibogo reservoir, meeting a primary role of urban supply, the overwhelming feature is the growth in demand, essentially to meet the requirements of Gaborone/Lobatse area. Estimates of demand have been taken from the recently published, 'Water Consumption and Demand Estimates for an Integrated Supply System in Eastern Botswana' (SMEC, 1988). The proportion of that demand to be met from the Letsibogo dam is taken as the theoretical shortfall which has been established as the difference between projected demand and the current long term system yield.

A further point taken into consideration at this stage is operation of the existing Shashe dam. From the water resource point of view the Shashe dam is able to supply to Selebi-Phikwe any spare water (after meeting local Francistown demand) up to the limit set by the delivery capacity of the transfer pipeline; this is currently being upgraded to 15 $m^3 10^6$/yr. When the running costs are taken into account, however, the Letsibogo supply represents the cheaper source, by virtue of lower pumping head. Hence, the operational decision may be taken to take water from Letsibogo in preference to the Shashe source. This gives a range of possible demands on the Letsibogo dam in the early years of operation; these are given in Table B7.1.

Table B7.1 has been prepared on the basis of the 125 $m^3 10^6$ Letsibogo reservoir. After the construction of Letsibogo dam, it has been assumed that the next resource to be developed is the Lower Shashe, which is the subject of a concurrent study (SMEC, 1989). As a starting point the timing of the Lower Shashe dam has been taken as 2004, as dictated by long-term 95/99% yields. However, the main reason for looking at the period from 1995 to 2007, is to ascertain whether there is any possibility of Lower Shashe dam being delayed.

Table B7.1

Theoretical Demands on Letsibogo Dam

	Net demand on new resource	Letsibogo (Shashe pumping continuously) Case 1	Letsibogo (Shashe pumping curtailed) Case 2
1995	7.1	7.1	22.1
1996	11.8	11.8	26.8
1997	14.0	14.0	29.0
1998	16.2	16.2	30.8[3]
1999	18.4	18.4	30.8
2000	21.0	21.0	30.8
2001	23.7	23.7	30.8
2002	26.7	26.7	30.8
2003	29.8	29.8	30.8
2004	33.2	30.8[2]	30.8[2]
2005	37.1	30.8	30.8
2006	41.3	30.8	30.8
2007	44.9	30.8	30.8

Notes: (1) All values in $m^3 10^6$
(2) Assumed date for commissioning Lower Shashe
(3) Shashe pumping recommenced but at lower amounts

The performance of the overall system is beyond the scope of this study, however it will be an important component of the forthcoming 'Botswana Water Master Plan'. A key feature of that study will have to be the operation of the 'North-South Carrier' (NSC). One alternative is to transfer the net demand in the south, where net demand is the difference between actual demand and the long-term 95/99% reliable yield of the southern water supply systems. However, net demands during the early years are less than the long term yield of Letsibogo and running costs of the NSC can be minimised by overdrawing Gaborone dam, transferring water from Letsibogo only when Gaborone dam levels are depleted below a 'trigger' level. This mode of operation may result in annual volumes transferred being less than or greater than net demands in the south, depending on inflows received by Gaborone dam, but the average volume transferred will be lower than net demands due to savings in evaporation and spill made by operating Gaborone dam at a lower level than would otherwise be the case.

Larger transfers would be made with increasing southern demand until net southern demands approach the reliable supply which can be obtained from Letsibogo, after making allowance for local demands not supplied from the existing Shashe dam. At this time, it may prove economically attractive to transfer all spare water from Letsibogo to Gaborone, up to the limit of the transfer capacity, thus maximising the water resource potential of the overall system and delaying as long as possible the time when an additional source is required.

The implications for operation of Letsibogo dam are profound. The 'demands' given in Table B7.1 correspond to the net demand in the south plus shortfalls in local demands not supplied from the existing Shashe dam. These demands are thus, on average, an overestimate of the actual demands to be met by Letsibogo if the NSC is operated as outlined above, at least in the period preceding full utilisation of the system. Nevertheless, they are the best estimates that can be made at the present time.

B7.3 Primary Demand Reliability in the Early Years

The two demand patterns given in Table B7.1 have been used as the two basic cases, with the exception that demand in year 2004 onwards is based on the net demand, representing the case where the Lower Shashe Dam has been delayed. An example of the program output for this growth option is given in Appendix B – F. The results are given in Table B7.2 and presented graphically in Figure B7.1. In Table B7.2 'full' represents the demand given in Table B7.1 for the particular year, with 'reduced' referring to 60% of the 'full' value.

Table B7.2

Primary Demand Reliability for 1995 to 2007

	Reliability as months (%)							
Year after commissioning	Low demand Case (1)		High demand Case (2)		Intermediate Case (3)		Intermediate Case (4)	
	Full	Reduced	Full	Reduced	Full	Reduced	Full	Reduced
1	99.2	99.4	91.5	92.9	91.5	92.9	91.5	92.9
2	99.5	100.0	93.7	97.5	93.7	97.5	93.7	97.5
3	99.4	100.0	92.6	98.1	92.6	98.1	92.6	98.1
4	98.9	100.0	93.7	98.3	97.3	99.2	93.7	98.3
5	99.5	100.0	92.6	98.9	98.3	100.0	96.1	99.7
6	99.1	100.0	92.6	98.6	98.0	100.0	96.7	100.0
7	98.9	100.0	93.1	98.9	98.1	100.0	97.2	99.8
8	98.7	100.0	94.0	98.9	98.0	99.8	97.5	99.7
9	98.1	100.0	94.3	98.7	97.5	99.4	97.0	99.4
10	97.2	99.4	92.9	98.7	96.7	99.2	95.8	99.2
11	95.0	99.1	91.5	98.4	94.7	99.1	94.0	99.1
12	91.0	98.3	88.7	97.6	91.0	98.3	91.0	98.0
13	85.8	97.0	84.3	96.4	85.7	97.0	85.7	96.9

The trigger rule for the 95/99% reliability criterion has been set at 10.2% of reservoir volume, the level established by the steady – state analysis. To prevent premature operation of the trigger rule it is not applied until the level has been exceeded in an October in the particular sequence under consideration.

Case 3 and Case 4 of Table B7.2 represent an intermediate situation in which transfers from Shashe are increased to the maximum available from year 4 and year 5, respectively.

A number of conclusions may be drawn from Figure B7.1. It has been assumed that the dam starts to impound in October 1994 but no demand is placed on the dam until January 1995. Without continuing transfers from Shashe (Case 2) the reliabilities for meeting urban demand are below the required 95/99%. However, if transfers from Shashe are maintained then the required reliabilities are satisfied up to year 11. Hence, it may be concluded that, from the point of view of meeting urban demand, it is not necessary to bring forward the construction programme for Letsibogo dam, as the existence of the Shashe pipeline can provide sufficient security in the early years.

The second point is that a further resource is not needed until year 12, for Case 1. Demand in year 11 is 37.1 $m^3 10^6$, which is considerably greater than the 95/99% long term yield of 30.8 $m^3 10^6$/yr. Hence, the benefit of under use in the early years can be seen to translate into higher reliable yields in latter years. Making predictions for 11 years hence is, of course, prone to errors, as demands and inflows could be very different from those assumed. Given a five year planning period for Shashe dam it should be possible to make more accurate projections about the likely position in 2004 from the current status of all resources in 1999. A decision can then be taken as to whether the detailed design of the dam should be initiated. The final decision relating to the commencement of the tender process, leading to construction, can then be made using further updating of the actual position. In this way the expenditure on water resources can be minimised, whilst maintaining the required reliability of urban supply.

From Figure B7.1 it is clear that the short term savings resulting from minimizing transfers from Shashe dam have potentially significant implications from the overall water resources point of view. Case 3 and 4 investigates the possibility of curtailing Shashe transfers in the early years (when potential savings in running costs are greatest) but reversing the operating rules in year 4 (1998) or year 5 (1999). It can be seen that the yield reliabilities have almost reached their Case 1 levels by year 11 (2005), although Case 3 is marginally preferable. The important finding of these exercise is that the investment programme can be significantly influenced by the operating policy.

The findings of this analysis are:

- the reliability of supply from Letsibogo dam is adequate in the early years, with Shashe pipeline fulfilling an important back-up role
- there is a potential benefit of an additional two years in delaying the next resource, provided timely decisions are made regarding the operational policy of Shashe pipeline

In reaching these conclusions it is important to realise that the analysis has been limited to the northern resources, no account has been taken of the operational policy for the NSC.

B7.4 Reliability of Supply in the Early Years with Irrigation Demands

Using the same approach the influence of irrigation supplies on reliabilities in the early years of Letsibogo dam operation has been assessed. The two basic irrigation options have again been used, with the 1 019 ha option requiring 16.1 $m^3 10^6$/yr and the 559 ha option requiring 8.8 $m^3 10^6$/yr. The results are presented in Table B7.3 and Figure B7.2.

In Table B7.3 'primary' refers to the full urban demand in the relevant year (see Table B7.1), with 'reduced' representing 60% of the primary demand and 'irrigation' referring to the irrigation demands. The 'target' reliabilities for these three components are 95%, 99% and 90%. The primary demands are based on the assumption that Shashe transfer continues to operate at maximum capacity. Trigger levels have been selected from the steady-state analyses, with some minor adjustments. It may be anticipated that a more systematic approach to establishing trigger levels in the initial years of operation could lead to some minor improvements in the reliabilities for meeting primary demand.

Figure B7.1

Primary Demand Reliability after Commissioning

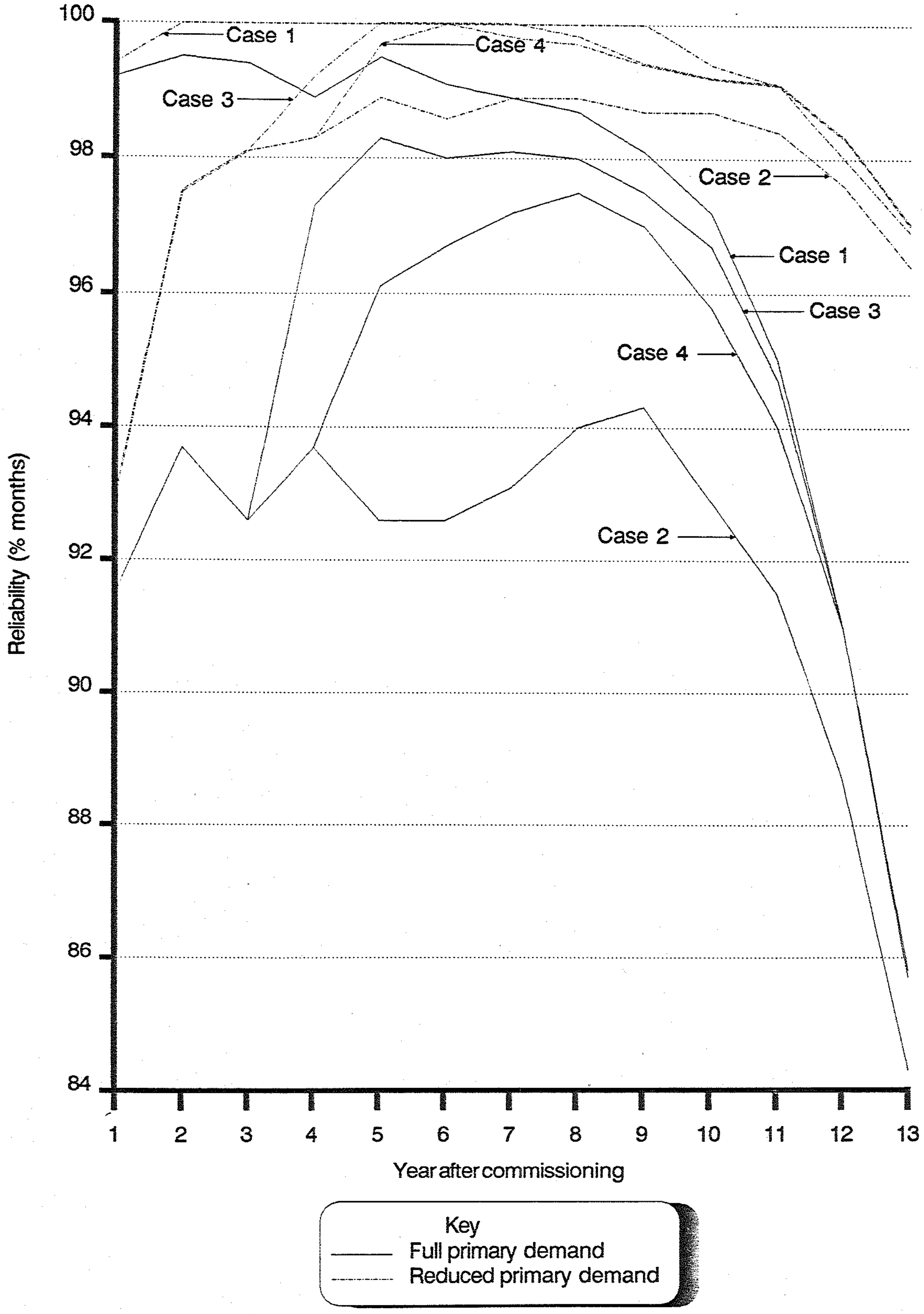


Table B7.3

Primary and Secondary Demand Reliabilities for 1995 to 2007

	Reliability as months (%)					
Year after	Irrigation for 1019 ha			Irrigation for 559 ha		
commissioning	Primary	Reduced	Irrigation	Primary	Reduced	Irrigation
1	97.2*	98.0	90.3	97.2	98.0	90.3
2	98.9	99.1	82.2	99.2	99.2	84.9
3	98.9	100.0	89.6	99.4	100.0	93.1
4	98.1	100.0	89.8	98.9	100.0	94.7
5	97.5	99.7	91.4	98.6	100.0	95.9
6	96.9	99.5	89.2	98.1	99.7	95.1
7	96.1	99.1	88.8	97.6	99.4	93.9
8	94.8	98.4	87.6	97.0	98.6	92.8
9	91.0	96.9	83.0	95.4	98.3	90.6
10	87.1	94.8	74.5	93.2	97.8	86.3
11	82.9	92.1	67.5	90.1	95.6	80.7
12	79.1	88.4	60.4	85.5	92.6	72.5
13	74.4	85.5	56.6	80.7	89.9	65.4

*Irrigation in year 1 taken as 559 ha for both options

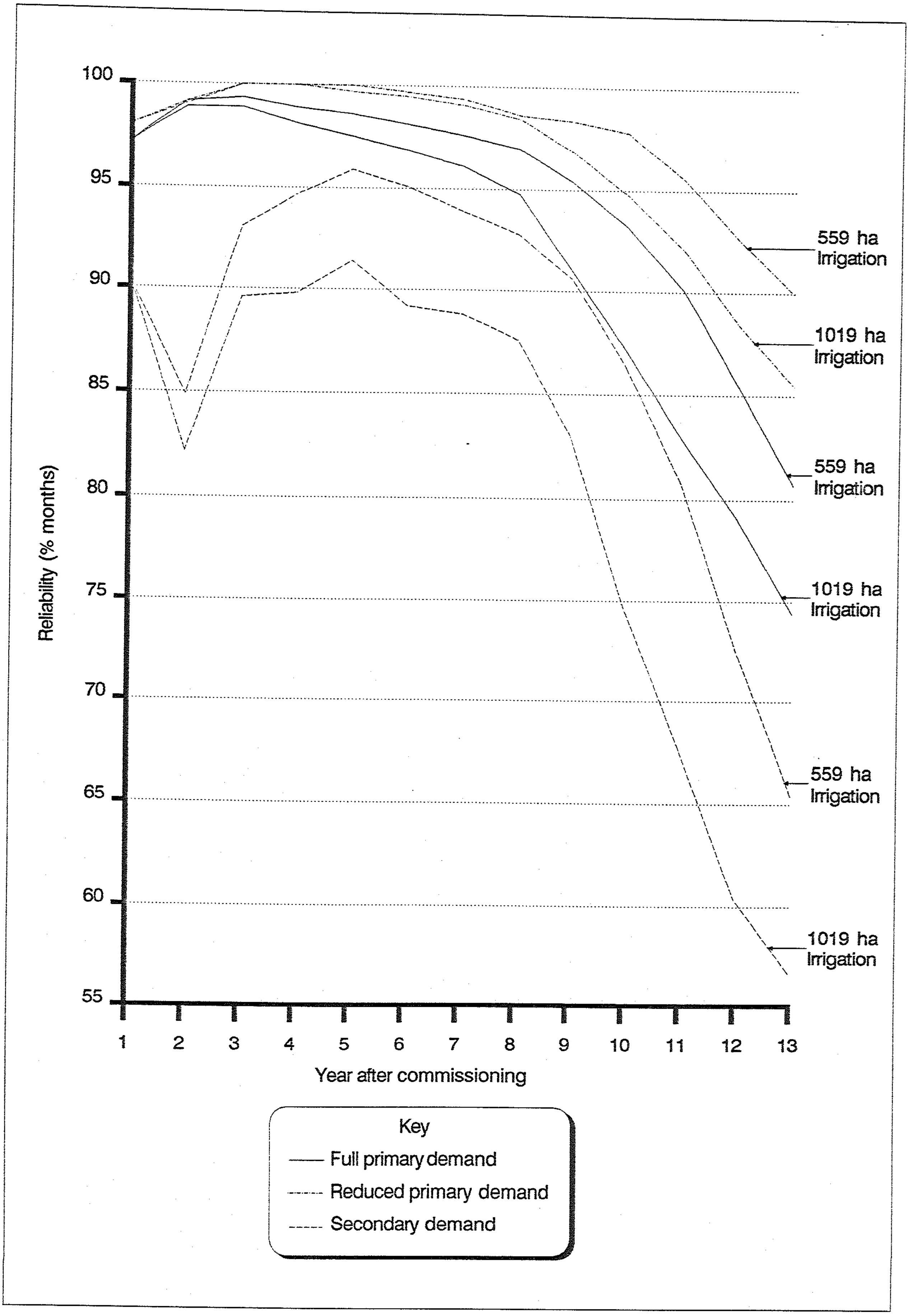
The impact of the larger irrigation development is to reduce reliability for urban demand marginally below the target in year 7, although year 8 may also be considered acceptable. To maintain target reliabilities would thus require the introduction of a new resource in year 9, three years earlier than the 'without irrigation' case. In practise it may prove more attractive to reduce the irrigated area, or perhaps attempt only one crop per year for those critical years immediately prior to the introduction of a new resource.

The option for a smaller irrigated area obviously imposes slightly less strain on the resources, with the reliability of urban supply maintained at acceptable levels up to year 9. The reliabilities in year 10 and 11 are also quite high although the fact that urban demand is greater than the 95/99% long term yield in those years must result in low reliabilities in attempting to meet additional demand. Halving the irrigation demands in years 10 and 11 has the effect of improving the reliability of urban demand to 94.0/98.0% and 91.4/96.5% with the reliability for irrigation supplies at 86.6% and 84.0%.

Given the marginal economic status of irrigation (see Annex J) it is unlikely that the Lower Shashe dam could be brought forward by three years to fully satisfy all demands associated with a 1 019 ha irrigation development. It is also unlikely that an irrigation development would be considered viable with such an extended period of doubtful supply. The smaller development represents something of a compromise. It is more likely that the water resource development programme could be adjusted to advance the construction of Lower Shashe dam by one year. In which case irrigation supplies would be available with the required reliability for the first nine years, with the a reasonable guarantee of supplies to half of the area in the tenth year. After the introduction of Lower Shashe in year eleven adequate supplies will again become available, as the new dam should be able to safeguard urban supplies with a reduced contribution from the Letsibogo dam. After the introduction of Lower Shashe dam there should be sufficient 'spare' water for a adequate length of time to allow consideration of an extension to the irrigated area.

A final point that must be stressed, however, is that the evaluation of the amount of spare water there is available from Letsibogo dam in these crucial early years is dependent on the overall operation of the system, particularly the NSC. It may be anticipated that more sophisticated analysis of the water resource potential will reveal operational procedures that will enable each resource to be used more fully. In broad terms this must reduce the amount of truly free water that is available for irrigation.

Primary and Secondary Demand Reliability after Commissioning



REFERENCES

AGC	1974	Letlhakane Groundwater Investigations Selebi-Phikwe Project, Unpublished, Bamangwato Concessions Ltd
Gibb	1969	Shashe Complex-Phikwe Temporary Water Supply, Sir Alexander Gibb and Partners for Government of Botswana
Gibb	1986	Lobatse Water Supply Refurbishment Pre-Investment Study, Sir Alexander Gibb and Partners for Water Utilities Corporation
Gibb	1987	Francistown Water Development Pre-Investment Study. Sir Alexander Gibb & Partners for Water Utilities Corporation.
Minster	1989	Selibi-Phikwe Regional Development Project: Small-scale irrigation in the Selibi-Phikwe Region, for the Ministry of Finance and Development, Botswana.
MacDonald	1987	Limpopo Water Utilisation Study, Sir M. Macdonald & Partners for the Department of Water Affairs.
MacDonald	1988	Motloutse Dam Feasibility/Preliminary Design Study. Scheme Identification Report. Sir M MacDonald & Partners for Department of Water Affairs.
MacDonald	1989	Motloutse Dam Feasibility/Preliminary Design Study. Interim Report. Sir M MacDonald & Partners for Department of Water Affairs.
Nord M.	1985	A Study of the Major Sand Rivers of Botswana, Phase II, Department of Water Affairs.
Robins	1971	Pump test to determine the characteristics of the aquifer (at Selebi-Phikwe) drawn by borehole 2403. Botswana Geological Survey Report 1971, and Supplementary Report 1971.
SMEC	1987	A study of Open Water Evaporation in Botswana, Snowy Mountain Engineering Corporation for Department of Water Affairs.
SMEC	1988	Water Consumption and Demand Estimates for an Integrated Supply System in Eastern Botswana Discussion Paper, Snowy Mountain Engineering Corporation for Department of Water Affairs.
SMEC	1989	Feasibility/Preliminary Design Study for Lower Shashe Dam, Interim Report, January 1989. Snowy Mountains Engineering Corportion for Department of Water Affairs.
Thomas E.G and Hyde L.W	1972	Water Storage in the Sand Rivers of Eastern Botswana with Particular Reference to Storage in the Mahalapshwe River, UNDP/SF/FAO Project Bot. 1, Tech Note 33.
University of Botswana	1986	A Profile of Environment and Development in Botswana, University of Botswana, 1986.

REFERENCES (Continued)

Wikner T.	1980	Sand Rivers of Botswana, Volume 1, SIDA, for Department of Water Affairs.
WLPU	1985	Ramotswa Wellfield Pollution Study Watermeyer Legge Piesold Ullman for Department of Water Affairs

APPENDIX B – A

DATA INPUTS FOR RESERVOIR SIMULATIONS

Table B-A1.1

Synthesised/Recorded Flows for Tobane Gauge used for Reservoir Simulations

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1922	211P	778P	470P	17918P	6407P	1564P	474P	16P	5P	4P	1P	13P	27861.
1923	8P	218P	405P	308P	570P	1730P	521P	90P	30P	0P	0P	2P	3882.
1924	221P	981P	5109P	4467P	1092P	8694P	3237P	434P	156P	23P	2P	660P	25076.
1925	284P	173P	287P	275P	1547P	722P	84P	34P	11P	65P	22P	0P	3504.
1926	107P	327P	723P	730P	428P	85P	20P	10P	1P	2P	1P	0P	2434.
1927	232P	152P	483P	8081P	2662P	133P	48P	2P	0P	1P	93P	39P	11926.
1928	16P	841P	1851P	4788P	2970P	902P	155P	17P	4P	1P	0P	36P	11581.
1929	251P	734P	623P	2156P	1113P	700P	432P	82P	0P	0P	0P	2P	6093.
1930	1P	211P	2031P	946P	270P	423P	710P	196P	1P	6P	2P	2P	4799.
1931	178P	1844P	808P	882P	1020P	4257P	1779P	172P	8P	0P	0P	0P	10948.
1932	35P	96P	890P	1966P	582P	27P	89P	30P	1P	0P	0P	2P	3718.
1933	4P	1892P	1676P	907P	703P	552P	160P	17P	2P	0P	2P	1P	5916.
1934	52P	311P	1199P	479P	409P	577P	175P	19P	4P	0P	0P	28P	3253.
1935	10P	16P	290P	590P	853P	902P	313P	149P	40P	0P	0P	5P	3168.
1936	326P	830P	779P	880P	5828P	1976P	42P	2P	0P	0P	0P	12P	10675.
1937	87P	60P	509P	597P	304P	289P	270P	64P	0P	0P	6P	23P	2209.
1938	107P	341P	2019P	2472P	7933P	3478P	350P	16P	5P	31P	16P	36P	16804.
1939	88P	932P	412P	542P	323P	3201P	1347P	99P	403P	135P	1P	66P	7549.
1940	107P	860P	6681P	2816P	696P	190P	198P	65P	42P	13P	2P	11P	11681.
1941	232P	144P	490P	584P	193P	1101P	383P	75P	32P	3P	30P	23P	3290.
1942	275P	125P	861P	473P	612P	1264P	926P	242P	18P	34P	23P	11P	4864.
1943	161P	758P	625P	1312P	18516P	6160P	108P	23P	56P	19P	0P	0P	27738.
1944	126P	341P	118P	261P	401P	2145P	700P	8P	0P	0P	0P	0P	4100.
1945	123P	292P	231P	14653P	9597P	1706P	48P	11P	3P	0P	0P	0P	26664.
1946	39P	133P	223P	191P	166P	257P	88P	5P	3P	2P	1P	4P	1112.
1947	138P	123P	641P	883P	1130P	10807P	3758P	191P	35P	2P	1P	8P	17717.
1948	339P	466P	580P	4152P	1578P	577P	168P	5P	6P	6P	2P	0P	7879.
1949	72P	230P	813P	594P	558P	161P	96P	61P	10P	0P	0P	7P	2602.
1950	30P	445P	4539P	2097P	232P	1295P	652P	648P	191P	61P	20P	0P	10210.
1951	253P	390P	328P	318P	852P	367P	43P	11P	5P	1P	0P	0P	2568.
1952	177P	424P	4631P	2295P	1236P	1950P	951P	179P	16P	1P	0P	0P	11860.
1953	83P	428P	578P	607P	505P	228P	160P	52P	4P	0P	0P	3P	2648.
1954	96P	332P	2303P	2493P	17062P	7568P	786P	152P	78P	12P	0P	0P	30882.
1955	93P	592P	1673P	677P	819P	777P	239P	54P	11P	0P	0P	64P	4999.
1956	142P	349P	1852P	750P	3744P	1564P	123P	38P	13P	61P	20P	12P	8668.
1957	161P	201P	254P	4150P	1570P	211P	95P	19P	1P	0P	1P	72P	6735.
1958	539P	358P	1671P	929P	891P	634P	184P	72P	21P	4P	5P	1P	5309.
1959	25P	194P	656P	384P	542P	624P	301P	72P	19P	4P	10P	23P	2854.
1960	16P	818P	2125P	855P	1497P	2150P	917P	152P	39P	11P	1P	22P	8603.
1961	19P	468P	371P	1348P	559P	111P	176P	55P	42P	14P	0P	33P	3196.
1962	11P	1344P	878P	1233P	473P	75P	958P	347P	121P	39P	1P	0P	5480.
1963	199P	261P	868P	773P	295P	60P	21P	5P	0P	0P	2P	1P	2485.
1964	154P	683P	566P	385P	176P	33P	57P	19P	0P	0P	0P	1P	2074.
1965	3P	188P	159P	396P	5454P	1831P	42P	27P	8P	1P	1P	9P	8119.
1966	58P	427P	2142P	4252P	6546P	1835P	227P	70P	0P	0P	0P	0P	15557.
1967	66P	339P	197P	344P	551P	293P	759P	408P	66P	3P	0P	0P	3026.
1968	37P	670P	790P	353P	1910P	4258P	1370P	92P	13P	0P	1P	116P	9610.
1969	0	10	670	0	290	40	80	0	0	0	0	0	1090.
1970	0	0	1170	6690	260	0	240	0	0	0	0	0	8360.
1971	0	370	1620	20750	610	860	10	0	0	0	0	0	24220.
1972	1730	300	470	620	2150	0	0	0	0	0	0	0	5270.
1973	0	1480	7770	1640	320	1550	0	0	0	0	0	0	12760.
1974	0	2670	1470	9110	6700	120	380	0	0	0	0	0	20450.
1975	0	0	2020	470	110	260	20	0	0	0	0	0	2880.
1976	0	1120	260	30	5250	3620	10	0	0	0	0	0	10290.
1977	0	40	190	9260	1100	130	0	0	0	0	0	160	10880.
1978	0	10	10	0	0	1300	0	0	0	10	0	0	1330.
1979	150	0	30	500	5150	670	0	0	0	0	0	0	6500.
1980	0	820	330	6010	9090	190	0	0	0	0	0	0	16440.
1981	10	110	120	210	0	0	80	0	0	0	0	0	530.
1982	0	0	650	140	190	0	630	0	0	0	0	0	1610.
1983	0	250	580	870	140	2930	40	0	0	0	0	0	4810.
1984	0	1630	1190	4300	190	110	0	0	0	0	0	0	7420.
1985	1110	1730	0	90	30	940	6130	110	0	0	0	0	10140.
1986	1050	1070	1250	2780	920	170	0	0	0	0	0	0	7240.
1987	0	310	10900	890	31490	10430	120	0	0	0	0	0	54140.
AVE	152	531	1350	2483	2687	1572	492	71	23	9	4	23	9398.
SDV	282	541	1908	4030	5111	2368	972	119	59	22	13	84	9244.
NOBS	66	66	66	66	66	66	66	66	66	66	66	66	66

Notes: All values in $m^3 10^4$
P indicates flows generated by Pitman model

Table B – A1.2

Tobane Catchment Rainfall Record

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1922	3001	8295	4055	29210	6097	10285	73	288	0	73	0	254	61631.
1923	64	3891	5319	3629	6411	10724	0	1668	0	0	0	30	31736.
1924	3973	9241	18193	15218	2580	20231	4648	3922	976	125	0	7250	86357.
1925	1264	2885	4162	3616	10574	3887	159	628	0	1238	0	4	28417.
1926	2094	4842	7731	7078	4214	13	383	69	0	39	0	0	26463.
1927	4137	1471	6506	22046	383	2404	125	0	0	13	1767	168	39020.
1928	262	8892	11838	17651	10767	5487	520	163	34	0	0	709	56323.
1929	4235	7869	6037	13283	5943	6699	3762	0	0	0	0	34	47862.
1930	4	3797	12956	4902	3152	5310	6024	0	26	107	0	47	36325.
1931	3324	12392	3848	8909	7835	15381	5242	482	0	0	0	0	57413.
1932	684	1673	9073	12319	434	391	1591	56	0	0	0	39	26260.
1933	69	12685	9924	7349	6502	5431	662	107	13	0	34	13	42789.
1934	1028	4872	10156	2180	5392	6016	469	224	9	0	0	563	30909.
1935	9	314	4777	6871	7516	7387	1707	2107	0	0	0	95	30783.
1936	5293	8273	7129	8286	17484	2150	103	0	0	0	0	236	48954.
1937	1638	641	6828	6325	2967	3977	3178	0	0	0	125	417	26096.
1938	1952	5035	12835	12771	19234	9026	73	288	0	606	120	666	62606.
1939	1518	9236	2141	6953	2872	14074	4210	0	3861	21	21	1290	46197.
1940	1686	8866	20167	8170	6162	666	3117	64	791	0	39	206	49934.
1941	4089	1337	6579	6304	1002	9202	421	1307	181	0	585	254	31261.
1942	4653	679	9008	3517	6704	9189	5912	1049	0	666	224	138	41739.
1943	3019	8174	5900	10608	26337	2283	1329	0	1066	0	0	0	58716.
1944	2442	4932	357	4438	4876	11928	396	21	0	0	0	0	29390.
1945	2391	4343	2808	27266	16460	2460	99	185	0	0	0	0	56012.
1946	778	2326	3397	2511	2339	3741	314	0	52	30	0	77	15565.
1947	2636	1531	7663	8148	8548	21650	3848	1918	0	47	0	163	56152.
1948	5418	5525	6540	17238	4115	6317	47	90	86	90	0	0	45466.
1949	1423	3737	8449	5504	5973	267	1746	615	0	0	0	133	27847.
1950	546	6287	17608	7860	426	9903	3517	5246	0	1178	0	9	52580.
1951	4429	5009	4025	4274	7942	2124	120	168	43	0	0	0	28134.
1952	3315	5633	17776	8811	8832	10900	5027	847	30	0	0	0	61171.
1953	1634	5973	6390	6570	5216	2133	2257	224	0	0	0	60	30457.
1954	1866	4949	13566	12556	25490	12010	1793	2128	735	0	0	0	75093.
1955	1823	7258	11563	3384	7878	6510	1264	641	0	0	0	1264	41585.
1956	2343	5048	12371	3143	15037	5031	224	679	39	1157	4	232	45308.
1957	2980	2838	3711	17372	3655	2649	946	60	4	0	17	1410	35642.
1958	7061	3431	11954	5973	7886	5439	1122	1041	56	60	73	0	44096.
1959	486	3427	7521	3453	6244	6097	2597	456	219	0	202	387	31089.
1960	181	8780	12663	4205	10384	11038	4678	649	550	39	0	430	53597.
1961	236	6519	3887	10969	2541	1311	2709	77	795	0	4	649	29697.
1962	9	11012	6265	10230	2124	757	7448	628	1858	34	0	4	40369.
1963	3664	3569	8768	6949	2412	353	297	4	0	0	43	0	26059.
1964	2928	7731	5560	4592	1698	86	1096	0	0	0	0	13	23704.
1965	47	3444	1901	5693	17187	1049	473	378	39	0	13	172	30396.
1966	1096	6041	13072	16555	17208	1019	3375	0	0	0	9	0	58375.
1967	1303	5130	1789	5147	5998	2705	6575	2726	176	0	0	0	31549.
1968	727	7890	7366	3070	11580	14848	2748	783	0	0	21	2214	51247.
1969	6295	5306	8892	198	7667	2219	3143	0	1509	9	0	0	35238.
1970	877	3737	13424	13080	2064	697	2847	1294	0	0	0	1187	39207.
1971	5345	9675	3195	28466	3436	8179	869	916	0	0	0	305	60386.
1972	1483	2816	4008	6502	3285	1462	1591	374	17	0	279	1772	23589.
1973	6446	5018	15549	14241	8393	3775	5220	460	0	90	0	4386	63578.
1974	193	11851	8290	23757	9189	5074	6149	1139	17	0	0	0	65659.
1975	138	2176	14014	6674	12126	10105	1058	3621	21	0	0	770	50703.
1976	3535	8381	5065	8015	12427	14985	26	47	0	0	236	3745	56462.
1977	1311	4592	16361	22540	8093	2967	3160	236	0	0	4	1363	60627.
1978	6454	2778	3969	6996	6145	5341	288	56	26	0	881	26	32960.
1979	5590	3444	5392	9400	18111	1707	774	4	0	0	103	563	45088.
1980	2090	10500	4825	21397	10363	4842	2300	146	0	4	17	13	56497.
1981	2739	5702	4863	2958	1965	460	3259	804	0	4	73	0	22827.
1982	9963	4489	3126	4502	2847	6437	2442	254	60	26	116	4	34266.
1983	1389	7116	5052	2141	3397	11059	675	13	215	1294	0	1101	33452.
1984	2270	5874	2116	8432	3337	1329	254	155	0	0	146	168	24081.
1985	4915	645	5306	783	4541	2920	9417	4	0	0	0	697	29228.
1986	4390	8071	4072	6433	4403	1810	357	0	0	0	0	666	30202.
1987	1002	5224	26088	11292	28203	10161	3539	52	0	0	0	0	85561.
AVE.	2518	5532	8117	9408	7767	5880	2209	630	205	105	78	551	43000.
SDV.	2115	3000	5117	6828	6252	5002	2160	1010	585	306	253	1164	15572.
NOBS	66	66	66	66	66	66	66	66	66	66	66	66	66

Notes: All values in mm 10^{-2}

APPENDIX B – B

SAMPLE OUTPUTS FOR RESERVOIR SIMULATIONS

Table B – B1.1

Sample Output for Reservoir Simulation for Tobane Dam

```
TOBANE        reservoir simulations

                  Parameters read from file : tobdam.dat

        TOBANE        inflows read from file   : L31-A        with adjustment factor  .978
                      Rainfalls read from file : AYSTOBA      with adjustment factor  .950


                    Month    1    2    3    4    5    6    7    8    9   10   11   12
  Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
      Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1
 Reduced supply to be met = 60.0 % of demand


TOBANE        Storage/Area/Stage curves
      Volume (mcm)     .00    1.80    4.80    9.00   15.00   30.00   45.00   50.00   75.00
        Area (km2)     .00    1.00    2.00    3.10    4.40    7.20    9.60   10.40   14.20
     Elevation (m)  777.20  780.00  783.00  786.00  788.00  790.00  792.60  793.00  795.00
      Volume (mcm)   82.00  100.00  125.00
        Area (km2)   15.20   17.00   19.20
     Elevation (m)  795.80  797.00  799.00
 Maximum reservoir storage =   100.000
 Minimum reservoir storage =     1.000


Initial conditions set by three year warm-up
Starting from empty, with mean inflows, rainfalls etc


 SUMMARY VALUES : AVERAGES PER YEAR


Key to summary:
Trigger (1) is reservoir volume (%) for reduced release, trigger (2) not applicable
Demand and reliability (1) and (2) refer to full and reduced demand respectively
General results (1) refer to TOBANE        reservoir
General results (2) not applicable
Additional sups (1)(a) is additional inflow, 1(b) is external portion of demand
                (2)(a) is backup supply,     2(b) is emergency supply


      Triggers     Demand  Range  Reliability  Initial Inflow Spill Release  Evap   Rain Additional sups
    Value  Range   (mcm)          Months Years  volume  (mcm)  (mcm)  (mcm)  (mcm)  (mcm)   (a)     (b)
(1)  50.00 100.00  50.00 100.00  59.22  16.67  69.67  91.92  32.44  41.67  22.68   4.80    .00     .00
(2)    .00    .00  30.00    .00  98.99  93.94    .00    .00    .00    .00    .00    .00    .00     .00

(1)  50.00 100.00  25.00  50.00  91.29  75.76  81.67  91.92  45.34  24.13  28.43   5.92    .00     .00
(2)    .00    .00  15.00    .00 100.00 100.00    .00    .00    .00    .00    .00    .00    .00     .00

(1)  25.00  50.00  25.00  50.00  98.23  95.45  81.67  91.92  44.85  24.82  28.18   5.87    .00     .00
(2)    .00    .00  15.00    .00 100.00 100.00    .00    .00    .00    .00    .00    .00    .00     .00

(1)  25.00  50.00  37.50  25.00  92.17  80.30  75.66  91.92  36.21  36.33  24.62   5.17    .00     .00
(2)    .00    .00  22.50    .00 100.00 100.00    .00    .00    .00    .00    .00    .00    .00     .00

(1)  12.50  25.00  37.50  25.00  96.21  90.91  75.66  91.92  35.93  36.82  24.35   5.12    .00     .00
(2)    .00    .00  22.50    .00  99.24  95.45    .00    .00    .00    .00    .00    .00    .00     .00

(1)  12.50  25.00  43.75  12.50  92.68  80.30  72.67  91.92  32.26  42.14  22.30   4.71    .00     .00
(2)    .00    .00  26.25    .00  98.23  92.42    .00    .00    .00    .00    .00    .00    .00     .00

(1)  12.50  25.00  40.63   6.25  94.57  86.36  74.16  91.92  34.02  39.55  23.34   4.92    .00     .00
(2)    .00    .00  24.38    .00  98.86  93.94    .00    .00    .00    .00    .00    .00    .00     .00

(1)  12.50  25.00  39.06   3.13  95.33  87.88  74.91  91.92  34.97  38.18  23.86   5.02    .00     .00
(2)    .00    .00  23.44    .00  98.99  93.94    .00    .00    .00    .00    .00    .00    .00     .00

(1)  18.75  12.50  39.06   3.13  93.56  84.85  74.91  91.92  35.07  37.99  23.97   5.04    .00     .00
(2)    .00    .00  23.44    .00  99.37  95.45    .00    .00    .00    .00    .00    .00    .00     .00
```

Table B – B1.1 (Continued)

(1)	15.63	6.25	39.06	3.13	94.70	86.36	74.91	91.92	34.98	38.14	23.89	5.03	.00	.00
(2)	.00	.00	23.44	.00	99.24	95.45	.00	.00	.00	.00	.00	.00	.00	.00
(1)	14.06	3.13	39.06	3.13	94.95	86.36	74.91	91.92	34.98	38.15	23.88	5.03	.00	.00
(2)	.00	.00	23.44	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.28	1.56	39.06	3.13	95.20	87.88	74.91	91.92	34.97	38.18	23.86	5.02	.00	.00
(2)	.00	.00	23.44	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.67	.78	39.06	3.13	94.95	86.36	74.91	91.92	34.98	38.15	23.88	5.03	.00	.00
(2)	.00	.00	23.44	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.48	.39	39.06	3.13	95.08	87.88	74.91	91.92	34.97	38.17	23.87	5.03	.00	.00
(2)	.00	.00	23.44	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.48	.39	39.84	1.56	94.82	86.36	74.54	91.92	34.49	38.86	23.60	4.97	.00	.00
(2)	.00	.00	23.91	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.48	.39	39.45	.78	94.95	86.36	74.73	91.92	34.74	38.51	23.74	5.00	.00	.00
(2)	.00	.00	23.67	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.48	.39	39.26	.39	94.95	86.36	74.82	91.92	34.86	38.33	23.81	5.01	.00	.00
(2)	.00	.00	23.55	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.38	.20	39.26	.39	94.95	86.36	74.82	91.92	34.86	38.33	23.81	5.01	.00	.00
(2)	.00	.00	23.55	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.33	.10	39.26	.39	94.95	86.36	74.82	91.92	34.86	38.33	23.81	5.01	.00	.00
(2)	.00	.00	23.55	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.31	1.05	39.23	.34	95.08	87.88	74.83	91.92	34.86	38.33	23.81	5.01	.00	.00
(2)	.00	.00	23.54	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.31	1.05	39.32	.17	94.95	86.36	74.79	91.92	34.82	38.39	23.79	5.01	.00	.00
(2)	.00	.00	23.59	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.04	.52	39.32	.17	95.08	87.88	74.79	91.92	34.81	38.41	23.78	5.01	.00	.00
(2)	.00	.00	23.59	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.04	.52	39.36	.09	95.08	87.88	74.77	91.92	34.78	38.44	23.77	5.00	.00	.00
(2)	.00	.00	23.62	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.17	.26	39.36	.09	94.95	86.36	74.77	91.92	34.80	38.42	23.77	5.01	.00	.00
(2)	.00	.00	23.62	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.17	.26	39.34	.04	94.95	86.36	74.78	91.92	34.81	38.41	23.78	5.01	.00	.00
(2)	.00	.00	23.60	.00	98.99	93.94	.00	.00	.00	.00	.00	.00	.00	.00
(1)	13.04	.00	39.32	.00	95.08	87.88	74.79	91.92	34.81	38.41	23.78	5.01	.00	.00
(2)	.00	.00	23.59	.00	99.12	93.94	.00	.00	.00	.00	.00	.00	.00	.00

Table B – B1.2

Sample Output for Reservoir Simulation for Lerala Dam

```
LERALA        reservoir simulations

                 Parameters read from file : lerdam.dat

         LERALA        inflows read from file    : L31-A         with adjustment factor 1.033
                       Rainfalls read from file : AYSTOBA        with adjustment factor  .940


                  Month    1    2    3    4    5    6    7    8    9   10   11   12
  Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
       Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                    1 1 1 1 1 1 1 1 1 1 1 1
 Reduced supply to be met = 60.0 % of demand


LERALA        Storage/Area/Stage curves
       Volume (mcm)     .00     3.00     5.00    10.00    20.00    27.00    50.00    75.00   100.00
         Area (km2)     .00     1.90     2.60     4.10     6.30     7.60    11.50    15.10    18.30
      Elevation (m)  744.00   746.00   748.00   750.00   752.00   754.90   756.00   758.00   760.00
       Volume (mcm)  136.00   160.00   200.00   250.00   300.00   350.00   406.00
         Area (km2)   22.50    25.20    29.50    34.50    39.30    43.80    48.60
      Elevation (m)  762.20   763.00   764.00   765.00   767.00   768.00   769.20
Maximum reservoir storage =  100.000
Minimum reservoir storage =    1.000


Initial conditions set by three year warm-up
Starting from empty, with mean inflows, rainfalls etc


SUMMARY VALUES : AVERAGES PER YEAR


Key to summary:
Trigger (1) is reservoir volume (%) for reduced release, trigger (2) not applicable
Demand and reliability (1) and (2) refer to full and reduced demand respectively
General results (1) refer to LERALA       reservoir
General results (2) not applicable
Additional sups (1)(a) is additional inflow, 1(b) is external portion of demand
                (2)(a) is backup supply,     2(b) is emergency supply


     Triggers        Demand  Range  Reliability   Initial Inflow Spill Release  Evap   Rain Additional sups
   Value  Range      (mcm)          Months Years  volume  (mcm)  (mcm)  (mcm)  (mcm)  (mcm)   (a)     (b)

(1)  12.89      .00  39.43    .00  95.08  86.36   74.32  97.08  38.16  38.50  25.90   5.40    .00     .00
(2)    .00      .00  23.66    .00  99.12  93.94     .00    .00    .00    .00    .00    .00    .00     .00
```

Table B – B1.3

Sample Output for Reservoir Simulation for a Dam at Site 40

```
SITE - 40    reservoir simulations

             Parameters read from file : site-40.dat

       SITE - 40    inflows read from file    : L31-A       with adjustment factor 1.173
                    Rainfalls read from file : AYSTOBA     with adjustment factor  .810


                    Month    1    2    3    4    5    6    7    8    9   10   11   12
  Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
     Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1

 Reduced supply to be met = 60.0 % of demand


SITE - 40    Storage/Area/Stage curves
       Volume (mcm)      .00    2.00    5.00    7.00   10.00   14.00   20.00   30.00   48.00
         Area (km2)      .00     .30     .90    1.40    2.20    3.40    4.40    5.90    8.40
      Elevation (m)   597.40  603.50  605.00  607.00  608.00  609.60  611.00  613.00  615.70
       Volume (mcm)    60.00   75.00  100.00  120.00  150.00  175.00  200.00  220.00  240.00
         Area (km2)     9.80   11.50   14.10   16.00   18.60   20.60   22.60   24.10   25.50
      Elevation (m)   617.00  618.00  620.00  621.80  623.00  624.00  625.00  626.00  627.90
       Volume (mcm)   260.00  275.00  290.00
         Area (km2)    26.90   28.00   29.00
      Elevation (m)   628.30  628.70  629.40
 Maximum reservoir storage =  100.000
 Minimum reservoir storage =    1.000


 Initial conditions set by three year warm-up
 Starting from empty, with mean inflows, rainfalls etc


  SUMMARY VALUES : AVERAGES PER YEAR


 Key to summary:
 Trigger (1) is reservoir volume (%) for reduced release, trigger (2) not applicable
 Demand and reliability (1) and (2) refer to full and reduced demand respectively
 General results (1) refer to SITE - 40     reservoir
 General results (2) not applicable
 Additional sups (1)(a) is additional inflow, 1(b) is external portion of demand
                 (2)(a) is backup supply,     2(b) is emergency supply


      Triggers      Demand  Range  Reliability  Initial Inflow Spill Release  Evap  Rain Additional sups
    Value  Range    (mcm)          Months Years  volume  (mcm) (mcm)  (mcm)  (mcm) (mcm)   (a)     (b)

 (1) 15.04    .00  47.41    .00  95.08  86.36  74.00 110.24  47.50  46.31  20.13  3.62    .00     .00
 (2)   .00    .00  28.45    .00  99.12  93.94    .00    .00    .00    .00    .00   .00    .00     .00
```

Table B – B1.4

Sample Output for Reservoir Simulation for a Dam at Site 70

```
SITE-70        reservoir simulations

                    Parameters read from file : site-70.dat

      SITE-70        inflows read from file    : L31-A        with adjustment factor 1.381
                     Rainfalls read from file : AYSTOBA       with adjustment factor  .800


                  Month     1    2    3    4    5    6    7    8    9   10   11   12
  Primary demand factor  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
       Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1
 Reduced supply to be met = 60.0 % of demand


SITE-70        Storage/Area/Stage curves
        Volume (mcm)      .00     8.20    10.00    15.00    20.00    25.00    50.00    75.00   100.00
          Area (km2)      .00      .10      .14      .26      .42      .60     2.80     6.80    12.80
      Elevation (m)    563.90   567.00   568.00   569.00   570.00   571.50   573.00   575.00   577.00
        Volume (mcm)   118.00   150.00   175.00   200.00   250.00   300.00   327.00   350.00   400.00
          Area (km2)    18.40    21.60    24.00    26.30    30.50    34.50    36.60    38.20    41.50
      Elevation (m)    579.10   581.00   582.00   583.00   584.00   585.00   586.70   587.00   588.00
        Volume (mcm)   450.00   500.00   550.00   600.00   650.00   688.00
          Area (km2)    44.70    47.70    50.60    53.40    56.20    58.20
      Elevation (m)    589.00   590.00   591.00   592.00   593.00   594.40
 Maximum reservoir storage =  100.000
 Minimum reservoir storage =    1.000


Initial conditions set by three year warm-up
Starting from empty, with mean inflows, rainfalls etc


 SUMMARY VALUES : AVERAGES PER YEAR


Key to summary:
Trigger (1) is reservoir volume (%) for reduced release, trigger (2) not applicable
Demand and reliability (1) and (2) refer to full and reduced demand respectively
General results (1) refer to SITE-70        reservoir
General results (2) not applicable
Additional sups (1)(a) is additional inflow, 1(b) is external portion of demand
                (2)(a) is backup supply,     2(b) is emergency supply


    Triggers      Demand  Range  Reliability   Initial Inflow Spill Release  Evap   Rain Additional sups
  Value  Range    (mcm)          Months Years  volume (mcm)   (mcm)  (mcm)  (mcm)  (mcm)    (a)     (b)

(1)  16.06    .00  59.89    .00  95.08  86.36  71.21 129.79  61.22  58.50  12.53   2.37     .00     .00
(2)    .00    .00  35.93    .00  99.12  95.45    .00    .00    .00    .00    .00    .00     .00     .00
```

Table B-B1.5

Sample Output for Twin Reservoir Simulation for Letsibogo and Letlhakane

```
LETSIBOGO    and LETLHAKANE   joint reservoir simulations

                 Parameters read from file : twolet.dat

      LETSIBOGO    inflows read from file    : L31-A        with adjustment factor  .690
                   Rainfalls read from file  : AYSTOBA      with adjustment factor 1.000

      LETLHAKANE   inflows read from file    : L31-A        with adjustment factor  .166
                   Rainfalls read from file  : AYSTOBA      with adjustment factor 1.000


                  Month     1    2    3    4    5    6    7    8    9   10   11   12
 Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
     Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1

 Reduced supply to be met = 60.0 % of demand

 Pumping capacity, LETLHAKANE   to LETSIBOGO    =  20.0 mcm/year
 Transfers from LETLHAKANE   only when LETSIBOGO    less than 100.00 % full

 Transfers not dependent on total areas


 LETSIBOGO    Storage/Area/Stage curves
       Volume (mcm)     .00     .09     .41    1.21    3.00    6.52   12.50   22.08   36.58
         Area (km2)     .00     .09     .23     .57    1.22    2.30    3.68    5.90    8.60
      Elevation (m)  828.00  830.00  832.00  834.00  836.00  838.00  840.00  842.00  844.00
       Volume (mcm)   56.99   84.61  121.42  168.67  228.30  298.64
         Area (km2)   11.81   15.81   21.00   26.25   33.38   36.96
      Elevation (m)  846.00  848.00  850.00  852.00  854.00  856.00
  Maximum reservoir storage =  125.000
  Minimum reservoir storage =    1.000


 LETLHAKANE   Storage/Area/Stage curves
       Volume (mcm)     .00     .03     .23     .70    1.46    4.28    9.38   17.18   28.36
         Area (km2)     .00     .06     .34     .60     .91    1.91    3.19    4.61    6.57
      Elevation (m)  830.00  833.00  834.00  835.00  836.00  838.00  840.00  842.00  844.00
       Volume (mcm)   35.41
         Area (km2)    7.53
      Elevation (m)  845.00
  Maximum reservoir storage =   10.000
  Minimum reservoir storage =     .250


 Initial conditions set by three year warm-up
 Starting from empty, with mean inflows, rainfalls etc


  SUMMARY VALUES : AVERAGES PER YEAR


 Key to summary:
 Triggers (1) and (2) are reservoir volume (%) for reduced release and for eliminating transfer
 Demand and reliability (1) and (2) refer to full and reduced demand respectively
 General results (1) refer to LETSIBOGO    reservoir
 General results (2) refer to LETLHAKANE   reservoir
 Additional sups (1)(a) is additional inflow, 1(b) is external portion of demand
                 (2)(a) is backup supply,     2(b) is emergency supply


     Triggers      Demand  Range  Reliability   Initial Inflow Spill Release  Evap   Rain Additional sups
   Value  Range    (mcm)          Months Years  volume (mcm)  (mcm)  (mcm)   (mcm)  (mcm)   (a)     (b)
 (1)  50.00 100.00  62.50 125.00  35.48   3.03  55.06  64.85  11.55  45.47  21.97   4.91    .00     .00
 (2) 100.00    .00  37.50 100.00  96.84  87.88    .21  15.60   4.53   9.76   1.81    .50    .00     .00

 (1)  50.00 100.00  31.25  62:50  79.55  50.00  97.16  64.85  20.74  28.69  32.08   7.03    .00     .00
 (2) 100.00    .00  18.75 100.00 100.00 100.00    .21  15.60   4.55   9.74   1.82    .50    .00     .00

 (1)  25.00  50.00  31.25  62.50  94.95  86.36  90.09  64.85  19.50  30.62  31.10   6.82    .00     .00
 (2) 100.00    .00  18.75 100.00 100.00 100.00    .21  15.60   4.54   9.75   1.81    .50    .00     .00
```

Table B-B1.5 (Continued)

(1)	12.50	25.00	31.25	62.50	98.11	93.94	89.53	64.85	19.34	31.01	30.80	6.77	.00	.00
(2)	100.00	.00	18.75	100.00	99.87	98.48	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	12.50	25.00	46.88	31.25	86.62	69.70	57.15	64.85	12.15	43.88	23.10	5.12	.00	.00
(2)	100.00	.00	28.13	100.00	97.60	90.91	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	12.50	25.00	39.06	15.63	93.69	84.85	73.28	64.85	15.28	37.89	26.99	5.97	.00	.00
(2)	100.00	.00	23.44	100.00	98.86	95.45	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	12.50	25.00	35.16	7.81	96.09	89.39	81.39	64.85	17.22	34.54	28.91	6.37	.00	.00
(2)	100.00	.00	21.09	100.00	99.49	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	12.50	25.00	37.11	3.91	94.82	86.36	77.33	64.85	16.25	36.21	27.94	6.17	.00	.00
(2)	100.00	.00	22.27	100.00	99.24	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	6.25	12.50	37.11	3.91	96.84	90.91	76.68	64.85	16.16	36.46	27.74	6.13	.00	.00
(2)	100.00	.00	22.27	100.00	98.74	95.45	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	9.38	6.25	37.11	3.91	95.83	87.88	76.68	64.85	16.19	36.35	27.84	6.15	.00	.00
(2)	100.00	.00	22.27	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	9.38	6.25	38.09	1.95	95.33	86.36	74.64	64.85	15.72	37.19	27.35	6.05	.00	.00
(2)	100.00	.00	22.85	100.00	98.86	95.45	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.94	3.13	38.09	1.95	94.82	86.36	75.30	64.85	15.75	37.13	27.40	6.06	.00	.00
(2)	100.00	.00	22.85	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.94	3.13	37.60	.98	94.95	86.36	76.32	64.85	16.00	36.69	27.66	6.11	.00	.00
(2)	100.00	.00	22.56	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.16	1.56	37.60	.98	95.33	86.36	76.32	64.85	15.98	36.74	27.62	6.10	.00	.00
(2)	100.00	.00	22.56	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.55	.78	37.60	.98	95.33	86.36	76.32	64.85	15.98	36.74	27.62	6.10	.00	.00
(2)	100.00	.00	22.56	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.74	.39	37.60	.98	95.33	86.36	76.32	64.85	15.98	36.74	27.62	6.10	.00	.00
(2)	100.00	.00	22.56	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.84	.20	37.60	.98	95.20	86.36	76.32	64.85	15.98	36.73	27.63	6.11	.00	.00
(2)	100.00	.00	22.56	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.84	.20	37.84	.49	94.95	86.36	75.81	64.85	15.87	36.92	27.52	6.08	.00	.00
(2)	100.00	.00	22.71	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.79	.10	37.84	.49	94.95	86.36	75.81	64.85	15.87	36.92	27.52	6.08	.00	.00
(2)	100.00	.00	22.71	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.77	1.05	37.81	.43	94.95	86.36	75.87	64.85	15.88	36.89	27.54	6.09	.00	.00
(2)	100.00	.00	22.69	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.50	.52	37.81	.43	95.08	86.36	75.87	64.85	15.88	36.91	27.52	6.08	.00	.00
(2)	100.00	.00	22.69	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.50	.52	37.92	.21	94.95	86.36	75.65	64.85	15.83	36.99	27.48	6.07	.00	.00
(2)	100.00	.00	22.75	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.50	.52	37.86	.11	95.08	86.36	75.76	64.85	15.85	36.96	27.49	6.08	.00	.00
(2)	100.00	.00	22.72	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.50	.52	37.89	.05	94.95	86.36	75.71	64.85	15.84	36.97	27.49	6.08	.00	.00
(2)	100.00	.00	22.73	100.00	98.99	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00
(1)	10.50	.00	37.86	.00	95.08	86.36	75.76	64.85	15.85	36.96	27.49	6.08	.00	.00
(2)	100.00	.00	22.72	100.00	99.12	96.97	.21	15.60	4.53	9.76	1.81	.50	.00	.00

APPENDIX B – C

GROUNDWATER INVESTIGATIONS IN LETLHAKANE FAULT ZONE

APPENDIX B-C

Groundwater Investigation in Letlhakane Fault Zone

B-C1.1 Introduction

The Letlhakane Fault Zone lies some 8 km north of Selebi-Phikwe township. It has been geologically mapped at a scale of 1:125 000 and can be seen on satellite imagery extending at least 20 km both east and west along the Letlhakane and Motloutse rivers. The Fault Zone represents, at least in part, a linear groundwater reservoir which has been exploited as a water supply source. The abstraction was of the order of 25 l/s.

A previous study by Australian Groundwater Consultants (1973 and 1974) included seismic and resistivity surveys combined with some uncompleted test drilling. The results were considered to substantiate their previous conclusion that the Fault Zone contained sufficient water to supply 22 770 m^3/d for 1000 days (22.7 $m^3 10^6$). The reservoir volume was estimated at 12 km long and 600 m wide with a drainable thickness of 35 m. The storage coefficient was considered to be 0.2, a value which is almost certainly too high.

B-C1.2 Present Situation

The Letlhakane Fault Zone is located in Basement Complex along most of its length. Slivers of Karoo formations (mudstones and sandstones) are however found along the zone in the Selebi-Phikwe area near the Letlhakane and Motloutse rivers. Geophysical traverses, in the area of the Shashe pipeline crossing of the Letlhakane river, show decreases both in seismic velocities and electrical resistivity suggesting that the Fault Zone may be up to 1.2 km wide, although the average width is around 600 m.

The location of 9 boreholes are shown on Water Source maps along the Fault Zone and the location of an additional 3 boreholes are described in the AGC report. Little is known about these holes except that there was considerable variation in yield (from less than 1 to more than 15 l/s) and salinity (from EC of 0.7 to over 4.5 mmhos/cm).

Three boreholes (2397, 2401 and 2403) located 2 km east of the Selebi-Phikwe to Mmadinare road crossing of the Letlhakane, produced over 20 l/s from fractured anorthsites in the Basement Complex. No Karoo sediments were encountered. The five boreholes situated near the Shashe pipeline crossing of the Letlhakane river, located Karoo mudstones above Karoo sandstones. The underlying fractured gneisses also contained water. Two of the boreholes had yields in excess of 7 l/s. The remainder were of low yield. Karoo sediments were also encountered in EL2, 5 km east of the Shashe pipeline crossing.

Additional information is expected to be found in various reports to the BCL mine and the Geological Survey. Review of this data, particularly on the total volume previously pumped and any changes in water level, will add considerably to knowledge of the present situation.

B-C1.3 Objectives of Further Investigation

The Letlhakane Fault Zone has a potential part to play in the develpoment of water resources in Eastern Botswana. The key factor in evaluating this potential is an accurate estimate of the total exploitable volume in the zone. Currently estimates in the range of 9 to 36 $m^3 10^6$ have been used in a preliminary assessment of the possible significance of the resource.

A review of potential recharge sources to the catchment of the Fault Zone has also been made; a total of 5 $m^3 10^6$ per year was estimated. Much of this recharge is presumably lost to evaporation and evapotranspiration by vegetation, particularly riparian vegetation, resulting in a low subsurface discharge at the Motloutse confluence. Groundwater development would make much of this potential recharge available to boreholes, thus allowing exploitation on a long term basis.

The groundwater potential could be exploited by a variety of methods and operation schedules particularly when used in conjunction with proposed Letsibogo reservoir. Essentially, the options are :

- construction of groundwater scheme only; extracting the long term sustainable yield

- operating in conjunction with the Letsibogo dam to extract relatively high volumes in periods of low river flows

- various combinations of these options

The possibility of artificial recharge by a dam on the Letlhakane river should also be considered, both to quantify any potential gains from such a possibility and to assess the efficiency of any potential reservoir along the river

Possible drawbacks to the groundwater scheme include :

- variation in well yields ranging for a high to low or dry depending on degree of fracturing encountered

- variation in chemical quality

Presently available data is considered inadequate to cost and quantify any drawbacks or to cost and compare the various options with any degree of reliability. Further investigations including data review are required to proceed with the quantification of the groundwater resource.

B-C1.4 Further Investigations

- aquifer storage and transmission properties
- variation in Fault Zone width
- variation in fracturing intensity and aquifer properties
- variation in chemical quality
- response of aquifer to recharge

Quantification of these factors will require a large programme of drilling and testing. It is recommended that the programme is carried out in four phases as follows:-

phase 1 - assessment of existing data
- initiating water level monitoring
- estimation of groundwater availability
- outline well field design and costing

phase 2 – drilling of 10 observation/monitoring boreholes

- test pumping
- survey for water level altitude
- chemical analysis of Fault Zone
- computer modelling of Fault Zone
- estimation of groundwater availability
- optimization of wellfield design

phase 3 – additional drilling

- long term testing and monitoring
- final wellfield design and costing

phase 4 – wellfield construction

The phase 1 study would involve a collection and review of previous reports, drilling logs and test results including records in the Geological Survey and BCL mine offices. Existing boreholes in the vicinity would be located and water levels and salinities measured where possible. Data tables and reconnaissance maps would be compiled. Calculations would be made to estimate recharge, storage available in Fault Zone, wellfield design and wellfield costing. These calculations would not be final but should be sufficient to establish the feasibility of proceeding to phase 2.

The monitoring of water levels of a period of 12 months is an important aspect of the estimation of recharge. The network would be selected during phase 1 and a start made to the monitoring. A decrease in hydrography amplitude away from the river would reflect the reduction in recharge.

In a fractured aquifer the best method of investigation would be continuous coring. However, this method is expected to be expensive and experience shows that the use of air flush percussion drilling combined with geophysical logging (particularly caliper, gamma ray and fluid resistivity/temperature) are likely to give more cost effective results.

The data resulting from the phase 2 investigations should be sufficient to calibrate a computer model of the Fault Zone which could be used to predict the changes in water level resulting from various wellfield layouts and abstraction rates.

Additional drilling to further define any hydrogeological changes along the Fault Zone would be made in phase 3 combined with long term testing of the phase 2 test boreholes. The model would be recalibrated, if necessary, on the basis of these results, allowing final design of wellfield layout and abstraction rates.

Phase 4 would comprise construction of the wellfield incorporating any suitable boreholes from the previous phases.

APPENDIX B – D

SAND RIVER MODEL DATA

Table B – D1.1

Data Inputs for Sand River Model

Cell Nr	Sand level (m)	Rock level (m)	Catchment area (sq km)	Chainage (km)	Irrigation area (ha)	Consumptive use (l/s/km) (Apr-Oct)	Consumptive use (l/s/km) (Nov-Mar)
1	831.00	825.20	5460.00	-1.20	0.00	0.11	0.16
2	828.80	823.10	0.00	-0.10	0.00	0.11	0.16
3	828.30	827.30	0.00	0.00	0.00	0.11	0.16
4	827.90	823.20	0.00	0.38	0.00	0.11	0.16
5	827.40	822.50	0.00	0.68	0.00	0.11	0.16
6	826.90	822.70	0.00	1.02	0.00	0.11	0.16
7	826.50	822.70	0.00	1.36	0.00	0.11	0.16
8	826.30	822.60	4.80	1.70	0.00	0.11	0.16
9	826.20	821.10	0.00	2.00	3.00	1.84	0.64
10	823.70	820.70	0.00	3.60	0.00	0.11	0.16
11	822.50	816.10	10.80	4.80	0.00	0.11	0.16
12	820.30	815.90	17.80	6.13	0.00	0.11	0.16
13	816.40	813.80	0.00	7.93	0.00	0.11	0.16
14	816.40	813.00	9.90	8.25	0.00	0.11	0.16
15	815.30	812.00	1.70	9.05	0.00	0.11	0.16
16	813.50	808.90	1.50	9.78	0.00	0.11	0.16
17	812.40	805.20	0.90	10.52	0.00	0.11	0.16
18	811.90	803.40	2.50	10.95	0.00	0.11	0.16
19	809.40	803.40	1.30	12.30	0.00	0.11	0.16
20	809.20	807.00	2.20	12.84	0.00	0.11	0.16
21	809.00	803.50	60.10	13.71	0.30	0.11	0.16
22	808.20	803.60	0.00	15.12	0.00	0.11	0.16
23	806.50	801.90	6.50	15.66	2.50	0.11	0.16
24	800.94	796.44	5.30	16.98	0.00	0.11	0.16
25	798.40	794.20	0.00	17.95	11.00	0.11	0.16
26	795.60	792.80	1939.00	19.14	0.00	0.11	0.16
27	790.84	788.44	8.90	21.39	0.00	0.11	0.16
28	788.02	783.52	21.30	22.43	0.00	0.11	0.16
29	786.53	783.33	0.00	22.84	0.00	0.11	0.16
30	785.16	783.06	15.40	23.24	0.00	0.11	0.16
31	784.28	781.38	13.00	23.48	0.00	0.11	0.16
32	782.87	779.87	0.00	23.83	3.50	0.11	0.16
33	781.85	776.55	4.40	24.61	0.00	0.11	0.16
34	779.80	773.10	20.80	25.50	0.00	0.11	0.16
35	779.39	776.59	0.00	25.85	0.00	0.11	0.16
36	775.88	772.88	9.40	26.53	0.00	0.11	0.16
37	774.66	772.26	0.00	27.23	0.00	0.11	0.16
38	770.87	768.07	7.25	28.58	0.00	0.11	0.16
39	768.71	766.31	2.40	29.73	0.00	0.11	0.16
40	766.00	761.00	2.60	30.33	0.00	0.11	0.16
41	762.79	756.59	404.10	31.53	0.00	0.11	0.16
42	760.84	756.44	0.00	31.83	0.00	0.11	0.16
43	758.93	753.43	4.40	33.45	0.00	0.11	0.16
44	757.42	752.22	3.00	33.71	0.00	0.11	0.16
45	756.21	751.11	34.10	34.14	0.00	0.11	0.16
46	754.77	752.27	34.90	34.85	0.00	0.11	0.16
47	751.45	747.85	0.00	36.06	0.00	0.11	0.16
48	749.31	744.31	153.50	36.77	0.00	0.11	0.16
49	746.37	741.37	23.70	38.25	5.75	0.63	0.16
50	745.64	745.04	0.00	38.53	0.00	0.11	0.16
51	740.53	737.03	0.00	40.06	0.00	0.11	0.16
52	738.00	730.40	4.20	41.10	0.00	0.11	0.16
53	736.10	734.60	0.00	42.01	0.00	0.11	0.16
54	735.00	728.90	3.40	43.17	0.00	0.11	0.16
55	732.30	728.80	37.10	44.65	0.00	0.11	0.16
56	729.80	724.60	254.70	46.15	0.00	0.11	0.16
57	729.70	724.10	7.50	46.27	0.00	0.11	0.16
58	728.70	724.80	24.90	47.35	0.00	0.11	0.16
59	726.80	721.00	4.50	48.57	0.00	0.11	0.16
60	726.20	721.40	3.50	49.15	0.00	0.11	0.16
61	725.10	721.90	10.60	49.98	0.00	0.11	0.16
62	724.80	718.80	117.70	51.10	0.00	0.11	0.16
63	723.20	721.60	0.00	51.64	0.00	0.11	0.16
64	723.10	718.00	3.80	52.21	0.00	0.11	0.16
65	720.90	716.90	99.10	53.55	0.00	0.11	0.16
66	720.70	718.70	4.10	54.57	0.00	0.11	0.16
67	719.30	713.00	9.50	56.00	0.00	0.11	0.16
68	717.60	713.00	27.00	57.41	0.00	0.11	0.16
69	717.40	712.80	2.90	57.85	0.00	0.11	0.16
70	716.40	710.00	0.00	59.80	0.00	0.11	0.16

Table B – D1.2

Moisture Characteristics of Sand River as used in Computer Model

Cell Nr	Total available water (m^3)	Available water at depths (m^3/m)						Surface width (m)
		0 m	1 m	2 m	3 m	4 m	5 m	
1	55500	46.25	27.50	12.80	3.15	0.00	0.00	100.50
2	50875	46.25	27.50	12.80	3.15	0.00	0.00	100.35
3	4625	46.25	27.50	12.80	3.15	0.00	0.00	100.50
4	17575	46.25	27.50	12.80	3.15	0.00	0.00	100.35
5	13875	46.25	27.50	12.80	3.15	0.00	0.00	100.25
6	15725	46.25	27.50	12.80	3.15	0.00	0.00	99.40
7	15725	46.25	27.50	12.80	3.15	0.00	0.00	99.00
8	15725	46.25	27.50	12.80	3.15	0.00	0.00	96.40
9	12585	41.95	27.24	14.33	4.81	0.48	0.00	92.00
10	67120	41.95	27.24	14.33	4.81	0.48	0.00	80.40
11	48492	40.41	27.63	15.56	7.37	3.15	0.96	77.00
12	53745	40.41	27.63	15.56	7.37	3.15	0.96	73.00
13	60606	33.67	21.20	10.27	3.53	0.67	0.07	119.30
14	6995	21.86	7.91	0.93	0.00	0.00	0.00	79.60
15	17488	21.86	7.91	0.93	0.00	0.00	0.00	79.60
16	24769	33.93	20.00	9.22	3.52	0.25	0.00	84.50
17	25108	33.93	20.00	9.22	3.52	0.25	0.00	98.60
18	14590	33.93	20.00	9.22	3.52	0.25	0.00	79.70
19	45806	33.93	20.00	9.22	3.52	0.25	0.00	84.00
20	18322	33.93	20.00	9.22	3.52	0.25	0.00	98.00
21	43378	49.86	33.39	19.30	10.02	4.21	1.61	105.00
22	70303	49.86	33.39	19.30	10.02	4.21	1.61	152.00
23	26924	49.86	33.39	19.30	10.02	4.21	1.61	152.00
24	65815	49.86	33.39	19.30	10.02	4.21	1.61	90.00
25	26394	27.21	16.92	5.41	0.78	0.05	0.00	88.00
26	75553	63.49	39.48	12.62	1.81	0.11	0.00	66.70
27	142853	63.49	39.48	12.62	1.81	0.11	0.00	66.70
28	67714	65.11	40.49	12.95	1.86	0.11	0.00	95.90
29	26695	65.11	40.49	12.95	1.86	0.11	0.00	132.00
30	26044	65.11	40.49	12.95	1.86	0.11	0.00	165.00
31	15626	65.11	40.49	12.95	1.86	0.11	0.00	143.00
32	16779	47.94	29.81	9.53	1.37	0.08	0.00	67.30
33	37393	47.94	29.81	9.53	1.37	0.08	0.00	117.50
34	42667	47.94	29.81	9.53	1.37	0.08	0.00	97.00
35	14084	40.24	25.03	8.00	1.15	0.07	0.00	79.00
36	27363	40.24	25.03	8.00	1.15	0.07	0.00	77.00
37	38164	54.52	33.90	10.84	1.56	0.09	0.00	70.50
38	73602	54.52	33.90	10.84	1.56	0.09	0.00	119.70
39	32718	28.45	17.69	5.66	0.81	0.05	0.00	105.70
40	24762	41.27	25.67	8.21	1.18	0.07	0.00	107.00
41	49524	41.27	25.67	8.21	1.18	0.07	0.00	101.00
42	12549	41.83	26.01	8.32	1.19	0.07	0.00	134.00
43	67765	41.83	26.01	8.32	1.19	0.07	0.00	142.00
44	15148	58.26	36.23	11.58	1.66	0.10	0.00	175.10
45	25052	58.26	36.23	11.58	1.66	0.10	0.00	144.00
46	41365	58.26	36.23	11.58	1.66	0.10	0.00	109.00
47	114950	95.00	59.07	18.89	2.71	0.17	0.00	139.00
48	43466	61.22	38.07	12.17	1.75	0.11	0.00	119.10
49	90606	61.22	38.07	12.17	1.75	0.11	0.00	132.00
50	17142	61.22	38.07	12.17	1.75	0.11	0.00	158.70
51	73241	47.87	29.77	9.52	1.37	0.08	0.00	120.20
52	91468	87.95	62.77	40.31	23.69	12.82	5.74	122.00
53	80034	87.95	62.77	40.31	23.69	12.82	5.74	114.00
54	88601	76.38	47.59	24.22	8.88	4.22	1.72	111.00
55	87276	58.97	37.95	18.74	6.23	1.26	0.00	152.70
56	88455	58.97	37.95	18.74	6.23	1.26	0.00	127.70
57	7076	58.97	37.95	18.74	6.23	1.26	0.00	131.80
58	63688	58.97	37.95	18.74	6.23	1.26	0.00	136.80
59	80191	65.73	45.79	28.71	16.52	8.09	2.02	133.30
60	38123	65.73	45.79	28.71	16.52	8.09	2.02	141.80
61	53900	64.94	38.94	16.71	7.76	4.00	1.76	162.10
62	56325	50.29	27.94	10.29	3.47	0.94	0.00	133.00
63	27157	50.29	27.94	10.29	3.47	0.94	0.00	134.40
64	25616	44.94	21.01	4.78	0.67	0.00	0.00	134.40
65	60220	44.94	21.01	4.78	0.67	0.00	0.00	122.00
66	51714	50.70	28.33	14.04	6.49	3.25	1.23	192.10
67	127770	89.35	60.19	36.90	20.77	11.29	5.87	133.00
68	79030	56.05	32.53	14.90	4.24	1.02	0.00	135.10
69	24662	56.05	32.53	14.90	4.24	1.02	0.00	121.90
70	109297	56.05	32.53	14.90	4.24	1.02	0.00	124.10

Table B – D1.3

Water Levels Measured at Mmadinare and Tobane

Mmadinare

Date	Sand level	Water level	Depth
14/03/79	825.49	825.33	0.160
18/04/79	825.36	825.11	0.250
03/05/79	825.36	825.02	0.340
14/06/79	825.54	825.08	0.460
14/07/79	825.36	825.16	0.200
31/08/79	825.688	824.733	0.955
09/10/79	825.526	824.733	0.793
25/01/80	825.693	825.615	0.078
12/05/80	827.098	826.733	0.365
09/04/80	825.91	825.28	0.630
18/07/80	825.554	825.731	(0.177)
03/09/80	825.622	824.582	1.040
12/05/81	825.461	825.187	0.274
11/06/81	825.411	824.926	0.485
17/07/81	825.37	824.96	0.410
18/08/81	825.44	824.83	0.610
16/09/81	825.443	824.781	0.662
08/10/81	825.438	824.728	0.710
07/12/81	805.531	825.428	(19.897)
11/01/82	825.308	825.218	0.090
31/03/82	925.16	924.895	0.265
19/05/82	825.59	825.135	0.455
01/07/82	825.343	825.103	0.240
05/08/82	825.464	824.964	0.500
25/08/82	826.037	825.037	1.000
06/09/82	825.519	824.82	0.699

Tobane

Date	Sand level	Water level	Depth
02/03/79	739.8	739.47	0.330
18/04/79	739.82	738.94	0.880
15/06/79	741.093	740.143	0.950
17/07/79	739.85	739.37	0.480
01/09/79	741.188	740.213	0.975
09/10/79	739.85	739.37	0.480
08/01/80	741.195	740.915	0.280
17/02/80	739.371	739.311	0.060
12/05/80	739.484	738.795	0.689
13/06/80	739.156	738.336	0.820
25/07/80	739.532	738.436	1.096
03/09/80	739.5	738.307	1.193
15/05/81	739.583	728.2	11.383
12/06/81	739.645	739.049	0.596
17/07/81	741.005	740.565	0.440
19/08/81	739.22	739.19	0.030
16/09/81	739.578	739.178	0.400
08/10/81	739.576	739.149	0.427
07/12/81	739.443	739.217	0.226
04/01/82	739.785	739.625	0.160
02/02/82	739.362	737.032	2.330
10/03/82	739.33	738.6	0.730
05/04/82	739.38	738.38	1.000
19/05/82	739.433	739.056	0.377
01/07/82	739.465	738.576	0.889
05/08/82	739.503	738.31	1.193
25/08/82	739.494	738.197	1.297
07/09/82	739.419	738.129	1.290

Notes:

All levels in metres
(Surface water is indicated with brackets)

APPENDIX B – E

RESERVOIR SIMULATION WITH SECONDARY DEMAND

Table B – E1.1

Letsibogo Reservoir Simulation with Secondary Demand at 80% Reliability

```
LETSIBOGO     reservoir simulations

                    Parameters read from file : letsibog.sec

          LETSIBOGO   inflows read from file    : L31-A         with adjustment factor  .690
                      Rainfalls read from file : AYSTOBA       with adjustment factor 1.000


                    Month    1    2    3    4    5    6    7    8    9   10   11   12
   Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 Secondary demand factor 1.50 1.32  .96  .44 1.01  .31  .52  .49  .95 1.41 1.45 1.63
        Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1
 When LETSIBOGO      resevoir less than   5.43 % full
 Reduced supply to be met = 60.0 % of demand
 Trigger for secondary demand when LETSIBOGO    16.22 % full
Crop planting in months  1 and  8


LETSIBOGO    Storage/Area/Stage curves
        Volume (mcm)    .00     .09     .41    1.21    3.00    6.52   12.50   22.08   36.58
          Area (km2)    .00     .09     .23     .57    1.22    2.30    3.68    5.90    8.60
      Elevation (m)  828.00  830.00  832.00  834.00  836.00  838.00  840.00  842.00  844.00
        Volume (mcm)   56.99   84.61  121.42  168.67  228.30  298.64
          Area (km2)   11.81   15.81   21.00   26.25   33.38   36.96
      Elevation (m)  846.00  848.00  850.00  852.00  854.00  856.00
Maximum reservoir storage =   125.000
Minimum reservoir storage =     1.000


Initial conditions set by three year warm-up
Starting from empty, with mean inflows, rainfalls etc


 Summary of results

              Demand (mcm)     Reliability (% of time)
                                Monthly            Yearly
                            Target     Actual
Full             20.00       95.00      95.83       86.36
Reduced          12.00       99.00      99.24       93.94
Secondary        20.32       80.00      80.43       68.18

  Deficit as proportion of primary demand 98.03%

Deficit as proportion of secondary demand 79.75%

Area transfer rule never applied
```

Table B-E1.1 (Continued)

Annual results summary for LETSIBOGO

	Demand		Deficit		Initial volume	Inflow	Spillage	Transfer	Evaporation	Rainfall	Releases
	Prime	Second	Prime	Second							
1922	20.00	20.32	.00	.00	44.13	192.24	79.85	.00	32.98	9.49	40.32
1923	20.00	20.32	.00	.00	92.71	26.79	.00	.00	29.24	4.70	40.32
1924	20.00	20.32	.00	.00	54.63	173.02	60.81	.00	35.12	14.65	40.32
1925	20.00	20.32	.00	.00	106.06	24.18	.00	.00	32.65	4.77	40.32
1926	20.00	20.32	.00	.00	62.03	16.79	.00	.00	20.45	3.01	40.32
1927	20.00	20.32	.00	.00	21.06	82.29	.00	.00	20.31	3.08	40.32
1928	20.00	20.32	.00	.00	45.80	79.91	.00	.00	27.54	7.20	40.32
1929	20.00	20.32	.00	.00	65.05	42.04	.00	.00	25.94	6.30	40.32
1930	20.00	20.32	.00	.00	47.13	33.11	.00	.00	19.01	3.57	40.32
1931	20.00	20.32	.00	.00	24.49	75.54	.00	.00	18.96	4.94	40.32
1932	20.00	20.32	.00	.00	45.69	25.65	.00	.00	17.30	2.39	40.32
1933	20.00	20.32	.00	10.27	16.11	40.82	.00	.00	14.59	3.14	30.05
1934	20.00	20.32	.00	20.32	15.43	22.45	.00	.00	9.54	1.51	20.00
1935	20.00	20.32	1.33	20.32	9.85	21.86	.00	.00	6.58	1.03	18.67
1936	20.00	20.32	.00	10.27	7.48	73.66	.00	.00	16.04	2.81	30.05
1937	20.00	20.32	.00	.00	37.86	15.24	.00	.00	12.07	1.75	40.32
1938	20.00	20.32	2.00	10.27	2.46	115.95	.00	.00	21.40	5.26	28.05
1939	20.00	20.32	.00	.00	74.22	52.09	.00	.00	27.99	6.42	40.32
1940	20.00	20.32	.00	.00	64.42	80.60	.00	.00	34.09	8.11	40.32
1941	20.00	20.32	.00	.00	78.72	22.70	.00	.00	25.36	4.12	40.32
1942	20.00	20.32	.00	.00	39.86	33.56	.00	.00	16.21	3.46	40.32
1943	20.00	20.32	.00	.00	20.36	191.39	59.80	.00	26.52	6.02	40.32
1944	20.00	20.32	.00	.00	91.12	28.29	.00	.00	28.98	4.33	40.32
1945	20.00	20.32	.00	.00	54.43	183.98	84.19	.00	33.42	9.31	40.32
1946	20.00	20.32	.00	.00	89.79	7.67	.00	.00	25.66	2.16	40.32
1947	20.00	20.32	.00	.00	33.65	122.25	.00	.00	25.07	6.02	40.32
1948	20.00	20.32	.00	.00	96.52	54.37	.00	.00	36.36	8.21	40.32
1949	20.00	20.32	.00	.00	82.42	17.95	.00	.00	25.99	3.87	40.32
1950	20.00	20.32	.00	.00	37.93	70.45	.00	.00	23.39	5.96	40.32
1951	20.00	20.32	.00	.00	50.63	17.72	.00	.00	17.14	2.70	40.32
1952	20.00	20.32	.00	10.27	13.59	81.83	.00	.00	20.72	5.83	30.05
1953	20.00	20.32	.00	.00	50.48	18.27	.00	.00	17.22	2.89	40.32
1954	20.00	20.32	.00	10.27	14.10	213.09	81.57	.00	27.65	9.44	30.05
1955	20.00	20.32	.00	.00	97.35	34.49	.00	.00	32.98	7.04	40.32
1956	20.00	20.32	.00	.00	65.58	59.81	.00	.00	28.43	6.25	40.32
1957	20.00	20.32	.00	.00	62.88	46.47	.00	.00	25.78	4.54	40.32
1958	20.00	20.32	.00	.00	47.78	36.63	.00	.00	20.57	4.70	40.32
1959	20.00	20.32	.00	10.05	28.22	19.69	.00	.00	10.18	1.66	30.27
1960	20.00	20.32	.00	10.27	9.12	59.36	.00	.00	14.22	3.55	30.05
1961	20.00	20.32	.00	10.05	27.76	22.05	.00	.00	11.02	1.72	30.27
1962	20.00	20.32	.00	10.27	10.25	37.81	.00	.00	10.60	2.12	30.05
1963	20.00	20.32	1.33	20.32	9.54	17.15	.00	.00	6.31	.90	18.67
1964	20.00	20.32	7.26	20.32	2.60	14.31	.00	.00	3.73	.49	12.74
1965	20.00	20.32	4.33	10.27	.94	56.02	.00	.00	10.25	1.14	25.72
1966	20.00	20.32	.00	.00	22.14	107.34	.00	.00	24.45	5.80	40.32
1967	20.00	20.32	.00	.00	70.51	20.88	.00	.00	22.53	3.67	40.32
1968	20.00	20.32	.00	.00	32.21	66.31	.00	.00	18.70	4.45	40.32
1969	20.00	20.32	.00	.67	43.94	7.52	.00	.00	12.81	2.73	39.65
1970	20.00	20.32	3.38	10.27	1.73	57.68	.00	.00	13.09	1.90	26.67
1971	20.00	20.32	.00	.00	21.55	167.12	38.45	.00	29.55	7.62	40.32
1972	20.00	20.32	.00	.00	87.96	36.36	.00	.00	31.15	3.75	40.32
1973	20.00	20.32	.00	.00	56.60	88.04	.00	.00	33.77	10.59	40.32
1974	20.00	20.32	.00	.00	81.15	141.10	68.58	.00	37.04	12.30	40.32
1975	20.00	20.32	.00	.00	88.61	19.87	.00	.00	28.65	7.61	40.32
1976	20.00	20.32	.00	.00	47.11	71.00	.00	.00	24.60	6.55	40.32
1977	20.00	20.32	.00	.00	59.75	75.07	.00	.00	30.44	8.54	40.32
1978	20.00	20.32	.00	.00	72.60	9.18	.00	.00	21.33	3.82	40.32
1979	20.00	20.32	.00	.00	23.95	44.85	.00	.00	13.18	2.54	40.32
1980	20.00	20.32	.00	10.27	17.84	113.44	.00	.00	26.34	5.83	30.05
1981	20.00	20.32	.00	.00	80.72	3.66	.00	.00	22.81	2.94	40.32
1982	20.00	20.32	2.00	10.05	24.18	11.11	.00	.00	6.69	1.47	28.27
1983	20.00	20.32	2.97	10.27	1.80	33.19	.00	.00	6.03	.89	27.08
1984	20.00	20.32	1.33	10.27	2.78	51.20	.00	.00	12.54	1.35	28.72
1985	20.00	20.32	.00	10.27	14.06	69.97	.00	.00	15.75	2.10	30.05
1986	20.00	20.32	.00	.00	40.33	49.96	.00	.00	21.56	3.23	40.32
1987	20.00	20.32	.00	.00	31.63	373.57	255.42	.00	32.58	13.91	40.32

Table B – E1.2

Letsibogo Reservoir Simulation with Secondary Demand at 90% Reliability

```
LETSIBOGO    reservoir simulations

                 Parameters read from file : letsibog.sec

      LETSIBOGO    inflows read from file    : L31-A         with adjustment factor  .690
                   Rainfalls read from file : AYSTOBA        with adjustment factor 1.000


                     Month    1    2    3    4    5    6    7    8    9   10   11   12
   Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 Secondary demand factor 1.50 1.32  .96  .44 1.01  .31  .52  .49  .95 1.41 1.45 1.63
       Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
  Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   1 1 1 1 1 1 1 1 1 1 1 1
 When LETSIBOGO      resevoir less than   5.44 % full
 Reduced supply to be met = 60.0 % of demand
 Trigger for secondary demand when LETSIBOGO      6.30 % full
Crop planting in months  1 and  8


LETSIBOGO    Storage/Area/Stage curves
      Volume (mcm)     .00      .09      .41     1.21     3.00     6.52    12.50    22.08    36.58
        Area (km2)     .00      .09      .23      .57     1.22     2.30     3.68     5.90     8.60
     Elevation (m)  828.00   830.00   832.00   834.00   836.00   838.00   840.00   842.00   844.00
      Volume (mcm)   56.99    84.61   121.42   168.67   228.30   298.64
        Area (km2)   11.81    15.81    21.00    26.25    33.38    36.96
     Elevation (m)  846.00   848.00   850.00   852.00   854.00   856.00
 Maximum reservoir storage =  125.000
 Minimum reservoir storage =    1.000


Initial conditions set by three year warm-up
Starting from empty, with mean inflows, rainfalls etc


 Summary of results

             Demand (mcm)     Reliability (% of time)
                               Monthly          Yearly
                           Target    Actual
Full            20.00       95.00     95.08      86.36
Reduced         12.00       99.00     99.12      93.94
Secondary       15.41       90.00     90.03      83.33

  Deficit as proportion of primary demand 97.75%

Deficit as proportion of secondary demand 88.40%

Area transfer rule never applied
```

Table B – E1.2 (Continued)

Annual results summary for LETSIBOGO

	Demand		Deficit		Initial volume	Inflow	Spillage	Transfer	Evaporation	Rainfall	Releases
	Prime	Second	Prime	Second							
1922	20.00	15.41	.00	.00	53.42	192.24	90.80	.00	34.15	9.96	35.41
1923	20.00	15.41	.00	.00	95.25	26.79	.00	.00	30.46	4.89	35.41
1924	20.00	15.41	.00	.00	61.05	173.02	69.14	.00	36.42	15.32	35.41
1925	20.00	15.41	.00	.00	108.43	24.18	.00	.00	33.81	4.92	35.41
1926	20.00	15.41	.00	.00	68.31	16.79	.00	.00	22.82	3.29	35.41
1927	20.00	15.41	.00	.00	30.17	82.29	.00	.00	23.67	3.80	35.41
1928	20.00	15.41	.00	.00	57.18	79.91	.00	.00	31.16	8.23	35.41
1929	20.00	15.41	.00	.00	78.75	42.04	.00	.00	30.12	7.29	35.41
1930	20.00	15.41	.00	.00	62.55	33.11	.00	.00	23.91	4.45	35.41
1931	20.00	15.41	.00	.00	40.80	75.54	.00	.00	24.27	6.50	35.41
1932	20.00	15.41	.00	.00	63.16	25.65	.00	.00	22.88	3.11	35.41
1933	20.00	15.41	.00	.00	33.64	40.82	.00	.00	18.36	4.03	35.41
1934	20.00	15.41	.00	.00	24.72	22.45	.00	.00	10.38	1.75	35.41
1935	20.00	15.41	4.15	10.55	3.14	21.86	.00	.00	3.98	.70	20.71
1936	20.00	15.41	2.00	7.79	1.00	73.66	.00	.00	14.43	2.31	25.62
1937	20.00	15.41	.00	.00	36.91	15.24	.00	.00	12.55	1.79	35.41
1938	20.00	15.41	2.00	7.79	5.99	115.95	.00	.00	22.72	5.68	25.62
1939	20.00	15.41	.00	.00	79.27	52.09	.00	.00	29.86	6.84	35.41
1940	20.00	15.41	.00	.00	72.93	80.60	1.35	.00	36.60	8.75	35.41
1941	20.00	15.41	.00	.00	88.92	22.70	.00	.00	28.60	4.62	35.41
1942	20.00	15.41	.00	.00	52.24	33.56	.00	.00	20.46	4.33	35.41
1943	20.00	15.41	.00	.00	34.26	191.39	74.57	.00	29.16	7.14	35.41
1944	20.00	15.41	.00	.00	93.66	28.29	.00	.00	30.20	4.49	35.41
1945	20.00	15.41	.00	.00	60.83	183.98	92.36	.00	34.29	9.57	35.41
1946	20.00	15.41	.00	.00	92.33	7.67	.00	.00	26.90	2.25	35.41
1947	20.00	15.41	.00	.00	39.94	122.25	7.06	.00	26.89	6.68	35.41
1948	20.00	15.41	.00	.00	99.51	54.37	.00	.00	37.68	8.48	35.41
1949	20.00	15.41	.00	.00	89.27	17.95	.00	.00	28.36	4.19	35.41
1950	20.00	15.41	.00	.00	47.65	70.45	.00	.00	26.62	6.81	35.41
1951	20.00	15.41	.00	.00	62.88	17.72	.00	.00	21.34	3.26	35.41
1952	20.00	15.41	.00	.00	27.10	81.83	.00	.00	23.22	6.66	35.41
1953	20.00	15.41	.00	.00	56.97	18.27	.00	.00	19.79	3.25	35.41
1954	20.00	15.41	.00	.00	23.29	213.09	82.79	.00	28.68	9.80	35.41
1955	20.00	15.41	.00	.00	99.31	34.49	.00	.00	34.04	7.24	35.41
1956	20.00	15.41	.00	.00	71.59	59.81	.00	.00	30.56	6.72	35.41
1957	20.00	15.41	.00	.00	72.14	46.47	.00	.00	28.79	5.07	35.41
1958	20.00	15.41	.00	.00	59.49	36.63	.00	.00	24.42	5.53	35.41
1959	20.00	15.41	.00	.00	41.82	19.69	.00	.00	15.07	2.47	35.41
1960	20.00	15.41	.00	.00	13.51	59.36	.00	.00	13.92	3.46	35.41
1961	20.00	15.41	.00	.00	27.01	22.05	.00	.00	11.01	1.76	35.41
1962	20.00	15.41	1.33	7.79	4.41	37.81	.00	.00	8.99	1.76	26.29
1963	20.00	15.41	3.51	11.27	8.70	17.15	.00	.00	4.94	.72	20.63
1964	20.00	15.41	8.40	15.41	1.00	14.31	.00	.00	3.17	.39	11.60
1965	20.00	15.41	4.33	7.79	.94	56.02	.00	.00	10.36	1.14	23.29
1966	20.00	15.41	.00	.00	24.46	107.34	.00	.00	25.77	6.18	35.41
1967	20.00	15.41	.00	.00	76.81	20.88	.00	.00	24.81	4.01	35.41
1968	20.00	15.41	.00	.00	41.49	66.31	.00	.00	22.05	5.31	35.41
1969	20.00	15.41	.00	.00	55.65	7.52	.00	.00	17.35	3.46	35.41
1970	20.00	15.41	.00	3.60	13.88	57.68	.00	.00	15.19	2.31	31.81
1971	20.00	15.41	.00	.00	26.87	167.12	45.03	.00	30.61	8.04	35.41
1972	20.00	15.41	.00	.00	90.98	36.36	.00	.00	32.47	3.89	35.41
1973	20.00	15.41	.00	.00	63.37	88.04	.00	.00	36.11	11.32	35.41
1974	20.00	15.41	.00	.00	91.21	141.10	80.24	.00	38.21	12.80	35.41
1975	20.00	15.41	.00	.00	91.26	19.87	.00	.00	29.93	7.91	35.41
1976	20.00	15.41	.00	.00	53.71	71.00	.00	.00	26.97	7.22	35.41
1977	20.00	15.41	.00	.00	69.55	75.07	.00	.00	33.63	9.52	35.41
1978	20.00	15.41	.00	.00	85.11	9.18	.00	.00	25.35	4.46	35.41
1979	20.00	15.41	.00	.00	37.99	44.85	.00	.00	18.43	3.80	35.41
1980	20.00	15.41	.00	.00	32.80	113.44	.04	.00	29.18	6.75	35.41
1981	20.00	15.41	.00	.00	88.35	3.66	.00	.00	25.48	3.22	35.41
1982	20.00	15.41	.00	.67	34.35	11.11	.00	.00	10.80	2.24	34.74
1983	20.00	15.41	2.67	7.79	2.15	33.19	.00	.00	6.20	.90	24.95
1984	20.00	15.41	1.33	7.79	5.09	51.20	.00	.00	13.48	1.46	26.29
1985	20.00	15.41	.00	.00	17.98	69.97	.00	.00	15.27	2.04	35.41
1986	20.00	15.41	.00	.00	39.30	49.96	.00	.00	21.89	3.25	35.41
1987	20.00	15.41	.00	.00	35.21	373.57	261.02	.00	33.35	14.34	35.41

APPENDIX B – F

RESERVOIR SIMULATION WITH GROWING DEMAND

Table B – F1.1

Letsibogo Reservoir Simulation for the Early Years with Primary Demand Only

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LETSIBOGO    reservoir simulations

                Parameters read from file : LETGROW.DAT

         LETSIBOGO    inflows read from file    : L31-A        with adjustment factor  .690
                      Rainfalls read from file : AYSTOBA      with adjustment factor 1.000


                    Month    1    2    3    4    5    6    7    8    9   10   11   12
  Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
       Evaporation  (mm) 182. 191. 204. 226. 205. 223. 182. 140. 101.  95. 110. 139.
 Evaporation factor = 1.000

Operating procedure applied in following months :  O N D J F M A M J J A S
                                                   0 0 0 0 0 0 0 0 0 0 0 0
 Reduced supply to be met = 60.0 % of demand


LETSIBOGO    Storage/Area/Stage curves
      Volume (mcm)      .00     .09     .41    1.21    3.00    6.52   12.50   22.08   36.58
        Area (km2)      .00     .09     .23     .57    1.22    2.30    3.68    5.90    8.60
     Elevation (m)   828.00  830.00  832.00  834.00  836.00  838.00  840.00  842.00  844.00
      Volume (mcm)    56.99   84.61  121.42  168.67  228.30  298.64
        Area (km2)    11.81   15.81   21.00   26.25   33.38   36.96
     Elevation (m)   846.00  848.00  850.00  852.00  854.00  856.00
Maximum reservoir storage =  125.000
Minimum reservoir storage =    1.000


Simulations based on demand growth pattern for 13 years
Demand first applied in month  4 held constant for each year as:
  Year          1      2      3      4      5      6      7      8      9     10     11     12     13
  Primary    7.10  11.80  14.00  16.20  18.40  21.00  23.70  26.70  29.80  33.20  37.10  41.30  44.90


           Number of months of failure in each year

     Year         1    2    3    4    5    6    7    8    9   10   11   12   13

Dam commissioned in 1922
Primary           0    0    0    0    0    0    0    0    0    0    0    0    5
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    1
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0

Dam commissioned in 1923
Primary           0    0    0    0    0    0    0    0    0    0    0    2   11
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    0
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0

Dam commissioned in 1924
Primary           0    0    0    0    0    0    0    0    0    0    0    6    1
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    0
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0

Dam commissioned in 1925
Primary           0    3    0    0    0    0    0    0    0    0    3    0    7
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    1
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0

Dam commissioned in 1926
Primary           0    0    0    0    0    0    0    0    0    0    0    5    0
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    0
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0

Dam commissioned in 1927
Primary           0    0    0    0    0    0    0    0    0    0    2    0    0
Reduced           0    0    0    0    0    0    0    0    0    0    0    0    0
Secondary         0    0    0    0    0    0    0    0    0    0    0    0    0
```

Table B – F1.1 (Continued)

Dam commissioned in 1928													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1929													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1930													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1931													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1932													
Primary	1	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1933													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1934													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1935													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1936													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1937													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1938													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1939													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1940													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1941													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	1
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B – F1.1 (Continued)

Dam commissioned in 1942													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1943													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1944													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1945													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1946													
Primary	1	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	1	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1947													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	4
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1948													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1949													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	5
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1950													
Primary	0	0	0	0	0	0	0	0	0	0	0	1	5
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1951													
Primary	0	0	0	0	0	0	0	0	0	0	0	3	10
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	4
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1952													
Primary	0	0	0	0	0	0	0	0	0	0	0	8	12
Reduced	0	0	0	0	0	0	0	0	0	0	0	2	9
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1953													
Primary	0	0	0	0	0	0	0	0	0	0	5	12	4
Reduced	0	0	0	0	0	0	0	0	0	0	0	7	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1954													
Primary	0	0	0	0	0	0	0	0	0	1	10	2	0
Reduced	0	0	0	0	0	0	0	0	0	0	6	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1955													
Primary	0	0	0	0	0	0	0	0	1	10	2	0	0
Reduced	0	0	0	0	0	0	0	0	0	4	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B – F1.1 (Continued)

Dam commissioned in 1956													
Primary	0	0	0	0	0	0	0	0	8	2	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1957													
Primary	0	0	0	0	0	0	0	6	2	0	0	0	4
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1958													
Primary	0	0	0	0	0	0	5	2	0	0	0	2	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1959													
Primary	0	0	0	0	0	4	2	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1960													
Primary	0	0	0	0	1	2	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1961													
Primary	0	0	0	5	2	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1962													
Primary	0	0	4	2	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1963													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1964													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1965													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1966													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1967													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1968													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1969													
Primary	3	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	3	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B – F1.1 (Continued)

Dam commissioned in 1970													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	9
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	3
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1971													
Primary	0	0	0	0	0	0	0	0	0	0	0	7	9
Reduced	0	0	0	0	0	0	0	0	0	0	0	2	1
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1972													
Primary	0	0	0	0	0	0	0	0	0	0	5	8	2
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1973													
Primary	0	0	0	0	0	0	0	0	0	3	5	1	1
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1974													
Primary	0	0	0	0	0	0	0	0	1	2	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0

Summary of reliability (% of months)													
Primary	99.2	99.5	99.4	98.9	99.5	99.1	98.9	98.7	98.1	97.2	95.0	91.0	85.8
Reduced	99.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	99.1	98.3	97.0
Secondary	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Summary of reliability (% of years)													
Primary	94.3	98.1	98.1	96.2	96.2	96.2	96.2	96.2	92.5	90.6	86.8	77.4	69.8
Reduced	96.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.1	98.1	94.3	88.7
Secondary	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table B – F1.2

Letsibogo Reservoir Simulation for the Early Years with Irrigation

```
LETSIBOGO     reservoir simulations

                  Parameters read from file : letsgrow.dat

         LETSIBOGO    inflows read from file    : L31-A         with adjustment factor  .690
                      Rainfalls read from file : AYSTOBA        with adjustment factor 1.000


                      Month    1    2    3    4    5    6    7    8    9   10   11   12
   Primary demand factor 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 Secondary demand factor 1.41 1.45 1.63 1.51 1.32  .96  .44 1.01  .31  .52  .50  .94
       Evaporation  (mm) 182. 191. 204. 228. 205. 223. 182. 140. 101.  95. 110. 139.
  Evaporation factor = 1.000

 Operating procedure applied in following months :  O N D J F M A M J J A S
                                                    0 0 0 0 0 0 0 0 0 0 0 0

  Reduced supply to be met = 60.0 % of demand


 LETSIBOGO    Storage/Area/Stage curves
        Volume (mcm)      .00      .09      .41     1.21     3.00     6.52    12.50    22.08    36.58
          Area (km2)      .00      .09      .23      .57     1.22     2.30     3.68     5.90     8.60
      Elevation (m)    828.00   830.00   832.00   834.00   836.00   838.00   840.00   842.00   844.00
        Volume (mcm)    56.99    84.61   121.42   168.67   228.30   298.64
          Area (km2)    11.81    15.81    21.00    26.25    33.38    36.96
      Elevation (m)    846.00   848.00   850.00   852.00   854.00   856.00
  Maximum reservoir storage =  125.000
  Minimum reservoir storage =    1.000


 Simulations based on demand growth pattern for 13 years
 Demand first applied in month  4 held constant for each year as:
   Year          1      2      3      4      5      6      7      8      9     10     11     12     13
   Primary    7.10  11.80  14.00  16.20  18.40  21.00  23.70  26.70  29.80  33.20  37.10  41.30  44.90
 Secondary    8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80   8.80


           Number of months of failure in each year

     Year        1     2     3     4     5     6     7     8     9    10    11    12    13

 Dam commissioned in 1922
 Primary         0     0     0     0     0     0     0     0     0     0     0     2     8
 Reduced         0     0     0     0     0     0     0     0     0     0     0     0     7
 Secondary       0     0     0     0     0     0     0     0     0     0     0     3    12

 Dam commissioned in 1923
 Primary         0     0     0     0     0     0     0     0     0     0     0     7     9
 Reduced         0     0     0     0     0     0     0     0     0     0     0     6     4
 Secondary       3     4     0     0     0     0     0     0     0     0     0     8    12

 Dam commissioned in 1924
 Primary         0     0     0     0     0     0     0     0     0     0     4     9     0
 Reduced         0     0     0     0     0     0     0     0     0     0     2     3     0
 Secondary       0     0     0     0     0     0     0     0     0     0     8    12     4

 Dam commissioned in 1925
 Primary         0     0     0     0     0     0     0     0     0     3     8     0     8
 Reduced         0     0     0     0     0     0     0     0     0     0     2     0     5
 Secondary       3    12     4     0     0     0     0     0     0     3    12     4     8

 Dam commissioned in 1926
 Primary         0     0     0     0     0     0     0     0     0     5     0     7     0
 Reduced         0     0     0     0     0     0     0     0     0     1     0     4     0
 Secondary       0     0     0     0     0     0     0     0     3    12     4     8     4

 Dam commissioned in 1927
 Primary         0     0     0     0     0     0     0     0     3     0     5     0     0
 Reduced         0     0     0     0     0     0     0     0     0     0     2     0     0
 Secondary       0     0     0     0     0     0     0     0     8     4     8     4     0
```

Table B – F1.2 (Continued)

Dam commissioned in 1928													
Primary	0	0	0	0	0	0	0	2	0	4	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	8	4	4	4	0	0
Dam commissioned in 1929													
Primary	0	0	0	0	0	0	1	0	3	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	8	4	3	4	0	0	0
Dam commissioned in 1930													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	3
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	3	4	3	4	0	0	0	3
Dam commissioned in 1931													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	3	4	3	4	0	0	0	3	4
Dam commissioned in 1932													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	3	7	4	0	0	0	0	0	0	0	0
Dam commissioned in 1933													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	3	7	4	0	0	0	0	0	0	0	0	0
Dam commissioned in 1934													
Primary	2	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	7	4	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1935													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1936													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1937													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1938													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1939													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	5
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	2
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	5
Dam commissioned in 1940													
Primary	0	0	0	0	0	0	0	0	0	0	0	3	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	3	4
Dam commissioned in 1941													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	5
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	3
Secondary	3	4	0	0	0	0	0	0	0	0	3	4	5

Table B – F1.2 (Continued)

Dam commissioned in 1942													
Primary	0	0	0	0	0	0	0	0	0	0	0	3	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	0	0	0	0	0	0	3	4
Dam commissioned in 1943													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	3	4	0
Dam commissioned in 1944													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1945													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1946													
Primary	5	0	0	0	0	0	0	0	0	0	0	0	2
Reduced	5	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	8	4	0	0	0	0	0	0	0	0	0	0	3
Dam commissioned in 1947													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	9
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	4
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	9
Dam commissioned in 1948													
Primary	0	0	0	0	0	0	0	0	0	0	0	5	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	3	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	8	7
Dam commissioned in 1949													
Primary	0	0	0	0	0	0	0	0	0	0	3	0	6
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	4
Secondary	0	0	0	0	0	0	0	0	0	0	3	7	12
Dam commissioned in 1950													
Primary	0	0	0	0	0	0	0	0	0	0	0	5	5
Reduced	0	0	0	0	0	0	0	0	0	0	0	3	3
Secondary	0	0	0	0	0	0	0	0	0	3	4	8	12
Dam commissioned in 1951													
Primary	0	0	0	0	0	0	0	0	0	0	3	5	11
Reduced	0	0	0	0	0	0	0	0	0	0	1	2	6
Secondary	0	0	0	0	0	0	0	0	0	0	8	12	12
Dam commissioned in 1952													
Primary	0	0	0	0	0	0	0	0	0	1	4	10	12
Reduced	0	0	0	0	0	0	0	0	0	0	0	6	9
Secondary	0	0	0	0	0	0	0	0	0	3	8	12	12
Dam commissioned in 1953													
Primary	0	0	0	0	0	0	0	0	0	0	8	12	2
Reduced	0	0	0	0	0	0	0	0	0	0	5	9	0
Secondary	0	0	0	0	0	0	0	0	3	7	12	12	7
Dam commissioned in 1954													
Primary	0	0	0	0	0	0	0	0	0	6	11	2	0
Reduced	0	0	0	0	0	0	0	0	0	3	9	0	0
Secondary	0	0	0	0	0	0	0	0	3	12	12	7	4
Dam commissioned in 1955													
Primary	0	0	0	0	0	0	0	0	7	11	2	0	0
Reduced	0	0	0	0	0	0	0	0	3	8	0	0	0
Secondary	3	4	0	0	0	0	0	3	12	12	4	0	3

Table B – F1.2 (Continued)

Dam commissioned in 1956													
Primary	0	0	0	0	0	0	0	6	10	2	0	0	0
Reduced	0	0	0	0	0	0	0	2	8	0	0	0	0
Secondary	0	0	0	0	0	0	0	8	12	4	0	0	0
Dam commissioned in 1957													
Primary	0	0	0	0	0	0	4	9	2	0	0	0	8
Reduced	0	0	0	0	0	0	0	7	0	0	0	0	6
Secondary	0	0	3	4	0	0	8	12	4	0	0	0	8
Dam commissioned in 1958													
Primary	0	0	0	0	0	2	8	2	0	0	0	6	1
Reduced	0	0	0	0	0	0	4	0	0	0	0	3	0
Secondary	0	3	4	0	0	8	12	4	0	0	0	8	7
Dam commissioned in 1959													
Primary	0	0	0	0	2	8	2	0	0	0	3	0	0
Reduced	0	0	0	0	0	2	0	0	0	0	2	0	0
Secondary	0	0	0	0	3	12	4	0	0	0	3	7	4
Dam commissioned in 1960													
Primary	0	0	0	0	5	2	0	0	0	1	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	3	12	4	0	0	0	3	4	0	0
Dam commissioned in 1961													
Primary	1	0	0	5	2	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	3	12	4	0	0	0	0	0	0	0	0
Dam commissioned in 1962													
Primary	0	0	4	2	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	3	12	4	0	0	0	0	0	0	0	0	0
Dam commissioned in 1963													
Primary	0	5	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	5	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	8	4	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1964													
Primary	2	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	1	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	4	4	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1965													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0
Dam commissioned in 1966													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	3
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	1
Secondary	0	0	0	0	0	0	0	0	0	0	0	0	3
Dam commissioned in 1967													
Primary	1	0	0	0	0	0	0	0	0	0	0	0	2
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	3	4	0	0	0	0	0	0	0	0	0	3	7
Dam commissioned in 1968													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	0	0	0	3	4
Dam commissioned in 1969													
Primary	7	0	0	0	0	0	0	0	0	0	0	0	3
Reduced	7	0	0	0	0	0	0	0	0	0	0	0	1
Secondary	8	4	0	0	0	0	0	0	0	0	0	0	3

Table B – F1.2 (Continued)

Dam commissioned in 1970													
Primary	0	0	0	0	0	0	0	0	0	0	0	0	11
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	7
Secondary	0	0	0	0	0	0	0	0	0	0	0	3	12
Dam commissioned in 1971													
Primary	0	0	0	0	0	0	0	0	0	0	0	9	6
Reduced	0	0	0	0	0	0	0	0	0	0	0	6	2
Secondary	0	0	0	0	0	0	0	0	0	0	0	9	12
Dam commissioned in 1972													
Primary	0	0	0	0	0	0	0	0	0	0	7	6	1
Reduced	0	0	0	0	0	0	0	0	0	0	4	2	0
Secondary	3	4	0	0	0	0	0	0	0	0	8	9	7
Dam commissioned in 1973													
Primary	0	0	0	0	0	0	0	0	0	5	5	1	1
Reduced	0	0	0	0	0	0	0	0	0	2	1	0	0
Secondary	0	0	0	0	0	0	0	0	0	8	8	7	4
Dam commissioned in 1974													
Primary	0	0	0	0	0	0	0	0	4	5	0	0	2
Reduced	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary	0	0	0	0	0	0	0	0	4	8	7	4	3
Summary of reliability (% of months)													
Primary	97.2	99.2	99.4	98.9	98.6	98.1	97.6	97.0	95.4	93.2	90.1	85.5	80.7
Reduced	98.0	99.2	100.0	100.0	100.0	99.7	99.4	98.6	98.3	97.8	95.6	92.6	89.9
Secondary	90.3	84.9	93.1	94.7	95.9	95.1	93.9	92.8	90.6	86.3	80.7	72.5	65.4
Summary of reliability (% of years)													
Primary	88.7	98.1	98.1	96.2	94.3	94.3	92.5	92.5	88.7	81.1	77.4	69.8	56.6
Reduced	94.3	98.1	100.0	100.0	100.0	98.1	98.1	96.2	96.2	92.5	83.0	79.2	71.7
Secondary	67.9	60.4	83.0	88.7	90.6	90.6	88.7	84.9	79.2	73.6	64.2	49.1	37.7