Land Resource Study

26 Prospects for irrigation development around Lake Zwai Ethiopia

Land Resources Division, Ministry of Overseas Development

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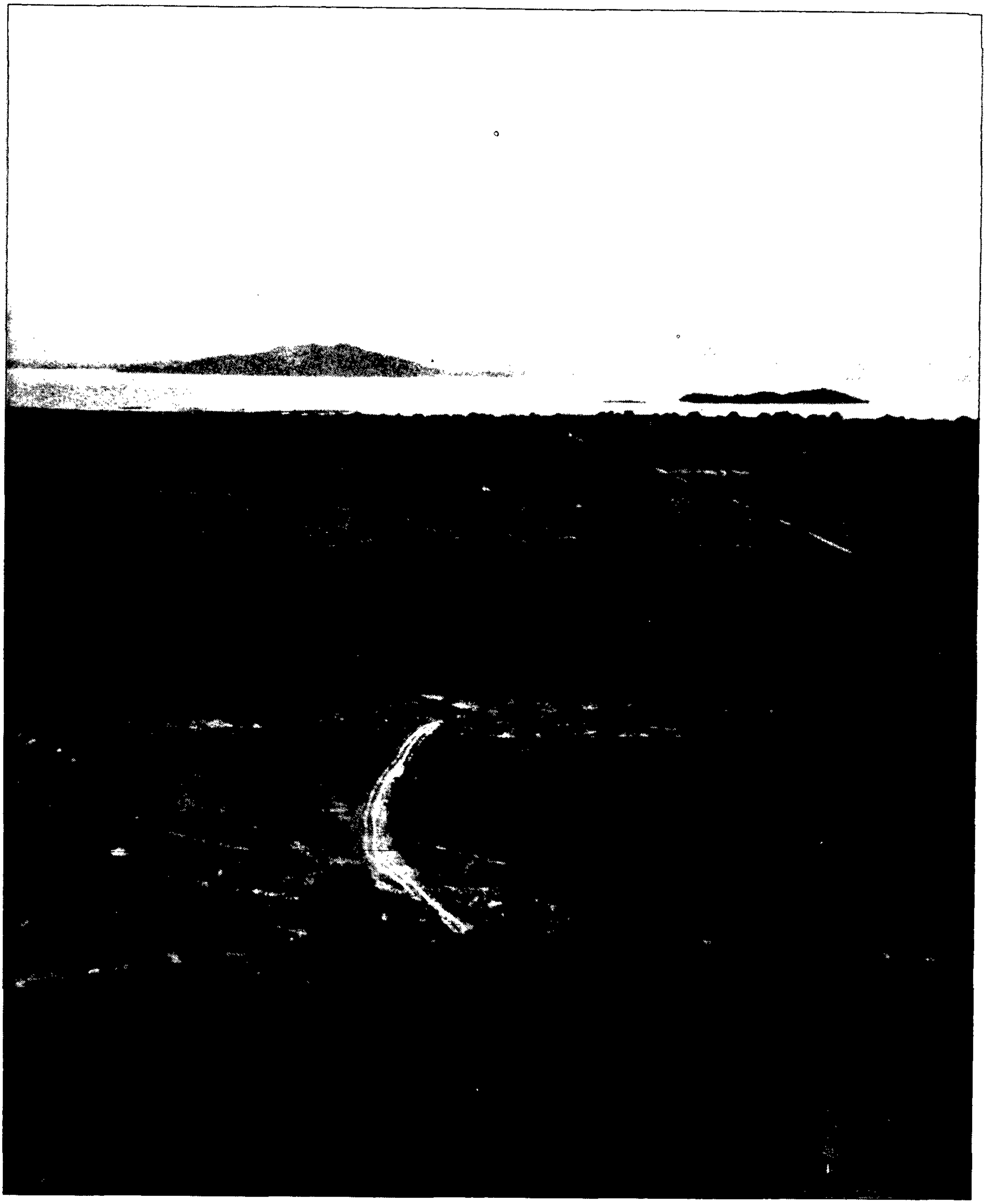

View towards Lake Zwai from the West

Land Resources Division

Prospects for irrigation development around Lake Zwai, Ethiopia

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Land Resource Study 26

Land Resources Division, Ministry of Overseas Development
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THE LAND RESOURCES DIVISION

The Land Resources Division of the Ministry of Overseas Development assists developing countries in mapping, investigating and assessing land resources, and makes recommendations on the use of these resources for the development of agriculture, livestock husbandry and forestry; it also gives advice on related subjects to overseas governments and organisations, makes scientific personnel available for appointment abroad and provides lectures and training courses in the basic techniques of resource appraisal.

The Division works in close co-operation with government departments, research institutes, universities and international organisations concerned with land resources assessment and development planning.

Contents

APPENDIXES (continued)

FIGURES

FIGURES (continued)

PLATES

PLATES (continued)

TEXT MAPS

SEPARATE MAPS (in carton)

Abstract and keywords

ABSTRACT

This report draws attention to the opportunities for developing pump irrigation around Lake Zwai, the northernmost of a chain of natural lakes lying within the southern Rift Valley of Ethiopia. Following evaluation of the natural resources of the Lake Zwai area, including detailed analysis of the catchment hydrology, attention is given to the factors influencing the selection of viable cropping systems. Projected gross margins of crops selected on the basis of promising market prospects and technical feasibility are used as an aid in devising appropriate rotations. Proposals are advanced for a study to assess the prospects for dehydrated vegetable production. A two-phased development is proposed for selected areas covering a total of 5 500 ha based on irrigation by electrically-driven pumps. The main constraints to irrigation development would include alkaline soil, uneven topography and the current pattern of land holdings. The engineering capital input would be modest, essentially comprising flood control on the Meki Delta and lake level regulation by means of a sluice on the Bulbula River outlet. Ancillary infrastructure should include a controlling authority and organisations for undertaking agricultural research and extension. Consideration is given to the ecological and economic implications of development, and a social cost-benefit analysis is carried out to determine whether society as a whole would benefit from the proposed developments.

RESUMÉ

Le présent rapport attire l'attention sur la possibilité de développer l'irrigation au moyen de pompes aux alentours du lac Zwai, le lac le plus septentrional d'une chaîne de lacs naturels situés dans la vallée méridionale du Rift en Ethiopie. A la suite de l'évaluation des ressources naturelles de l'aire du lac Zwai, comprenant une analyse de l'hydrologie du bassin versant, l'on s'est penché sur les facteurs influençant la sélection de systèmes de mise en culture viables. Des marges brutes projetées de cultures choisies sur la base de perspectives de vente prometteuses et de praticabilité technique sont utilisées pour aider à décider les assolements appropriés. Des propositions ont été formulées en vue d'une étude visant à estimer les perspectives de production de légumes déshydratés. Une mise en valeur en deux phases est proposée pour des régions choisies couvrant un total de 5.500 hectares, basée sur l'irrigation au moyen de pompes actionnées par électromoteur. Parmi les principaux obstacles au développement de l'irrigation figureraient les sols à alcalis, une topographie inégale et la distribution actuelle des propriétés terriennes. L'apport de capital relatif au génie civil serait modeste, comprenant essentiellement les ressources nécessaires pour la lutte contre les inondations dans le delta de Meki et pour le nivellement du lac au moyen d'une écluse sur la bouche de la rivière Bulbula. L'infrastructure auxiliaire devrait comprendre une autorité de contrôle et des organisms pour l'entreprise des recherches et de la vulgarisation agricole. Les implications écologiques et économiques de la mise en valeur sont prises en considération, et on a fait une analyse sociale coût-et-bénéfice pour déterminer si la société dans son ensemble bénéficierait de l'exploitation proposée.

DESCRIPTORS FOR CO-ORDINATE INDEXING

Climate/evaporation/hydrometeorological network/rainfall/landform/alkaline soil/soil classification/soil mapping/ground survey/drainage basin/irrigation planning/lake/pump/water analysis/water resource assessment/agricultural development/crop marketing/irrigated farming/land use (current)/livestock management/crop produce/crop yield/fodder crop/grain crop/ vegetable crop/plant water requirement/cost benefit analysis/economics/land tenure/bibliography/map/Ethiopia.

List of abbreviations

a.l.s.	above lake (Lake Zwai) surface
a.s.l.	above sea level
^oC	degree centigrade
cal	calorie
cec	cation exchange capacity
c.i.f.	cost/insurance/freight
cm	centimetre
EC	electrical conductivity
exch	exchangeable
ESP	exchangeable sodium percentage
f.o.b.	free on board
g	gram
ha	hectare
hp	horse power
kg	kilogram
km	kilometre
km^2	square kilometre
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
l	litre
lat.	latitude
long.	longitude
£	pound sterling (UK)
m	metre
mcm	million cubic metres (=$m^3 \times 10^6$)
meg	milliequivalent
mm	millimetre
n.a.	not available
q	quintal (= 100 kg)
s	second
SAR	sodium adsorption ratio
TEB	total exchangeable base

LIST OF ABBREVIATIONS (continued)

sp,spp	species
$	dollar (Ethiopian): all financial estimates are given in *Ethiopian* dollars unless otherwise stated
US $	dollar (US)
t	ton (metric)
UK	United Kingdom
USA	United States of America

NAMES OF ORGANISATIONS (in Ethiopia, unless otherwise stated)

AVA	Awash Valley Authority
CAA	Civil Aviation Administration
CADU	Chilalo Agricultural Development Unit
CSO	Central Statistical Office
DDA	Dairy Development Agency
DOS	Directorate of Overseas Surveys (UK)
EEC	European Economic Community (Common Market)
EELPA	Ethiopian Electric Light and Power Authority
EGB	Ethiopian Grain Board
EPID	Extension and Project Implementation Department of the Ministry of Agriculture
IAR	Institute of Agricultural Research
IOH	Institute of Hydrology (UK)
IRAT	Institute de Recherches Agronomiques Tropicales et des Cultures Vivrières
LMB	Livestock and Meat Board
LRD	Land Resources Division (of ODM)
MLRA	Ministry of Land Reform and Administration
NWRC	Executive Organ of the National Water Resources Commission
ODA ODM	Ministry of Overseas Development (UK)
SMD	Survey and Mapping Division of the MLRA
SORADEP	Southern Regional Agriculture Development Project
TPI	Tropical Products Institute (UK)
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organisation
USBR	United States Bureau of Reclamation (USA)
USDA	United States Department of Agriculture (USA)
WCO	Wildlife Conservation Organisation
ZDD	Zwai Development Division (proposed)

Parts 1-11

Part 1

Introduction

PREFACE

This report presents the results of a pre-feasibility land and water resource investigation of the Lake Zwai area of Ethiopia, undertaken between December 1973 and May 1974 under British technical assistance by the Land Resources Division (LRD) operating in close collaboration with the Ethiopian National Water Resources Commission (NWRC). The investigation was aimed at ascertaining the prospects for irrigation development on about 750 km^2 around Lake Zwai and on 25 km^2 in the Meki Valley, the potential of this area having been identified during a reconnaissance study of the southern Rift Valley which has been reported separately (Makin *et al.*, 1975). The draft of this report was produced in March 1975 and was discussed subsequently at a meeting of the project steering committee.

ACKNOWLEDGEMENTS

The LRD wishes to record its appreciation for the co-operation provided by the Executive Organ of the National Water Resources Commission (NWRC) and to those individual employees of the NWRC whose assistance was essential for the completion of the project. In addition, invaluable assistance and advice was provided by the project Steering Committee and by the following Ethiopian organisations: the Ministry of Agriculture; the Institute of Agricultural Research; the State Forest Development Agency; the Awash Valley Authority; the Electric Light and Power Authority; the Dairy Development Agency; the Livestock and Meat Board; the University Institute of Pathobiology; the Survey and Mapping Department of the Ministry of Land Reform and Administration; Awassa Research Farm; the Chilalo Agricultural Development Unit; local officials of the Ministry of Land Reform; *awraja* and *woreda* officials and local *balabats.* To all these organisations and the various individuals who helped the project grateful thanks are extended. Thanks are also due to the British Embassy in Addis Ababa, the Directorate of Overseas Survey team in Ethiopia and the UK Institute of Hydrology for their support throughout the project. Computer projections of electrical conductivity/sodium adsorption ratio combinations at steady state in the lower root zone of certain Zwai soils were undertaken by the US Salinity Laboratory (Riverside, California); this assistance has been especially appreciated. The support provided by Rothamsted Experimental Station and by Aberdeen University Soil Science Department, both in the UK, is also gratefully acknowledged.

READERS GUIDE TO THE TEXT

The purpose of this guide is to indicate the content and significance of each part of the report.

Part 1, Introduction, and explanatory material.

Part 2, Summary of recommendations.

Part 3, The Physical and Economic Setting. The physical, social and agricultural background information essential for a general understanding of the opportunities and constraints which should guide future development strategy in the project area are set out. The climate, soils, water resources, population and land use are described in outline; accompanying maps show the rainfall, land use, soils and irrigation suitability.

Part 4, Evaluation of Water Resources. The hydrological characteristics of the Lake Zwai catchment are reviewed. This includes an assessment of seasonal discharge into the Meki River and of the prospects for river regulation and storage in the Meki catchment. The potential for abstraction is related to various lake levels under different conditions pertaining in the Bulbula outlet channel. Varying flows in the Bulbula are in turn considered in relation to their effect on Lake Abiyata. While this analysis forms the basis for the proposals advanced in Part 5, a study of Part 3 is not obligatory for the non-technical reader.

Part 5, Evaluation of Agricultural Potential. The prospects for raising agricultural production are described with particular reference to irrigation. Following detailed appraisal of the main factors influencing the selection of cropping systems (climate, soils, current standards of husbandry and land tenure), critical consideration is given to each crop, its domestic and export market prospects, agronomic requirements and likely profitability. Account is also taken of irrigation water consumption and the use of hired labour.

Part 6, Proposals for Irrigation Development. Each of the potentially irrigable areas is described in relation to the land use, topography, soils and irrigation suitability. Where appropriate, the form of irrigation is indicated including the distance of pumping, irrigation structures, possible cropping patterns and land management. On the Meki Delta, outline designs are presented both for flood control and for development of a nucleus estate to support a vegetable processing plant. Emphasis is given to the need for phasing of proposed developments to coincide with the availability of technical and capital resources, and the acquisition of results from crop trials. Associated measures for flood protection, the construction of lake level controlling sluices and the completion of associated dredging are described. Consideration is also given to the alternative sources of power available for lifting irrigation water. Essential ancillary infrastructure is proposed, including the establishment of a controlling authority and the promotion of agricultural research, extension, credit and marketing.

Part 7, Ecological Implications of the Proposed Developments. The possible long-term effects of irrigation and the associated changes in lake levels and river flows are considered with particular reference to the future state of fish stocks in Lake Zwai, the possible spread of bilharzia, and conservation of the Lake Abiyata bird sanctuary.

Part 8, Economic Analysis of the Proposed Developments. The capital costs of all major development proposals are evaluated. A projection of potential farm income under irrigation is compared with farm incomes under rainfed conditions. Projected net present values and internal rates of return, taken together with an indicative social cost-benefit analysis, point to the potential viability of a two-phased irrigation development extending to 5 500 ha.

Part 9, Possible Diversion of Lake Zwai Water into the Awash Valley. Several investigations into the development potential of the Awash Valley are briefly reviewed, including preliminary proposals for diverting Lake Zwai water across the watershed into Lake Galila. These diversion proposals are rejected on grounds of capital cost, projections of future power requirements and general practicability.

Part 10. Conclusions, based on the foregoing analyses and Recommendations for future action.

Part 11. References.

PROJECT DESCRIPTION

In 1971 the Ethiopian Government requested British assistance for a comprehensive resource study of the southern Rift Valley and detailed development planning in the Bilate River basin. Although the British Government was not then prepared to support a programme of this magnitude, the 1972 ODA Aid Mission to Ethiopia recommended early implementation of a land use study in the southern Rift Valley to be undertaken by the LRD. Agreement was eventually concluded for a reconnaissance of the area as a whole, coupled with a commitment towards more detailed studies in a subsequent phase.

The reconnaissance of the southern Rift Valley has already been reported (Makin *et al.,* 1975). In that report, several arguments were advanced against the proposed development planning exercise in the Bilate River basin. Instead, several alternative development options were identified, although, for budgetary and technical reasons, few of these constituted appropriate subjects for study in the second phase. At a meeting of the project Steering Committee on October 8, 1973, it was decided that the second phase study should be of an area around Lake Zwai, with a view to evaluating its potential for irrigation development. At subsequent meetings of the Steering Committee the area of study and terms of reference were agreed. In particular, because of the limited time available, it was agreed that the study should be confined to pre-feasibility investigations of possible uses for the water within the Zwai catchment. It was also proposed, and later agreed, that the area of study would include certain potentially irrigable areas in the middle reaches of the Meki Valley; and that all investigations should be conducted at a 'semi-detailed' level.

The overall objectives of the project were defined in the terms of reference ('Outline Proposals and Terms of Reference for Phase Two') as follows:

1. 'To determine the quantity of water that can be made available in the Lake Zwai area, while maintaining the requisite level of outflow in the Bulbula River'

2. 'To determine the net returns that might be obtained from using this water in the vicinity of Lake Zwai and two of its related rivers, the Meki and the Bulbula'

To fulfill these objectives, the NWRC agreed to provide goods and services estimated at £26 500, while the British Government was to contribute £37 000. Actual expenditure slightly exceeded this total allocation of £63 500.

The project timetable allowed 5 months for field survey (December 1973 – April 1974). In the event the survey was delayed somewhat, most field operations only starting during January 1974; the topographic survey was so postponed that it could not be completed. The unstable security situation also caused some delay. Consequently, the field survey was not concluded until June 1974. A short visit by the Project Manager in May 1975 enabled certain aspects of land tenure to be reviewed following the land nationalisation proclamation of March 4, 1975.

The following professional staff were employed on the project:

Project Manager/Agriculturalist	M J Makin
Civil Engineer/Hydrologist	T J Kingham
Agricultural Economists	A E Waddams
	Tamene Teferra
Soil Scientist	C J Birchall
Agronomist	B W Eavis
Hydrogeologist	J V Goldhawk

Additional support was provided by P H Goll, University Institute of Pathobiology (Micropathology), and by the following LRD headquarters staff: J F Laurence (Irrigation Engineering) and R B King (Geomorphology). Certain of the hydrological and meteorological characteristics of the project area were investigated in detail for the project team by A I McKerchar and J R Douglas (Hydrologists) of the British Institute of Hydrology.

Part 2

Summary of recommendations

This report presents the findings of a pre-feasibility study of the land and surface water resources around Lake Zwai in the southern Rift Valley. A more complete review of the conclusions and recommendations based on this study is contained in Part 10.

A two-phased irrigation development is proposed for selected areas (see Text Map 8) covering a total of 5 500 ha, the overall area suitable for irrigation being limited by soil and topography rather than availability of water. It is recommended that irrigation be based on electrically-driven pumps. Hence development should be preceded by construction of a 132 kV transmission line from the Awash Valley (projected for 1978). Other essential preliminaries include detailed cadastral, soil and topographic surveys to define the irrigable areas with greater precision and prepare final designs for irrigation layouts; reorganisation of holding boundaries to accord with the technical requirements of irrigation; and successful implementation of trials to confirm the viability of the cropping patterns proposed.

Settlement will be an important element in both phases. Between 15 – 20 000 people could benefit from the introduction of irrigation, over 10 000 of whom would be new settlers, (i.e. some 2 250 families). The measure for rural land nationalisation promulgated in March 1975 is considered to favour this development, especially as regards the increased flexibility in the tenure system and the potential for sharing pump irrigation on a communal basis.

The first phase irrigation development covering 1 730 ha represents a relatively straightforward extension of current irrigation practice. To expand the irrigated area beyond this requires prior lake level regulation through construction of a controlling sluice on the Bulbula River outlet, associated with the dredging and rock blasting essential for ensuring the maintenance of flow downstream to Lake Abiyata. In addition, irrigation on the Meki Delta (representing over half the area to be developed in the second phase) will have to be preceded by flood control measures. Regulation of the Meki River requires construction of a flood release channel and of flood control dykes, together with the straightening and dredging of the Meki outlet channel. Other proposals for the Meki Delta area, where it is envisaged that major development will be based on pumping water inland from Lake Zwai along raised embankments, include 10 ha of crop trials to be expanded subsequently into a pilot scheme. Favourable agronomic trials could presage a feasibility study to assess the prospects for dehydrated vegetable production.

The total capital expenditure is projected at $19 138 000 over 20 years (i.e. (i.e. $3 480/ha). With a high internal rate of return on capital of 18-20% and a benefit - cost ratio exceeding 1.2, it is concluded that the proposed developments are likely to be viable, providing the assumptions upon which the projections are based remain valid; certainly they compare favourably with alternative proposals for utilising Lake Zwai water in the Awash Valley (Italconsult, 1970).

A particular feature of these proposals is their relatively low cost of both capital and technical requirements; this is essentially due to use of an existing reservoir of water and the absence of any need for major controlling structures. The most crucial single input, and one of the largest, will be an intensive farm and irrigation advisory service, the expertise for which would be steadily acquired during the proposed 17-year development period. Major benefits could also accrue from the intensification of dryland farming on neighbouring non-irrigable areas, especially if associated with the introduction of high-capacity grain silos to tide farmers over periods of subnormal rainfall.

Part 3

Physical and economic setting

LOCATION AND COMMUNICATIONS

The project area (Text Map 1) is composed of two distinct geographic entities within the southern Rift Valley of Ethiopia; the Lake Zwai area, and the middle valley of the Meki River. The general environs and the relationship of Lake Zwai with lakes Abiyata and Langano are shown on Plate 1, a composite airphoto mosaic compiled by DOS from 1971-2 aerial photographs.

The Lake Zwai area

This is situated about 150 km south of Addis Ababa at the northern end of the southern Rift Valley. The area of study comprises Lake Zwai and its immediate surrounds, a total of some 750 km^2 of which almost three-quarters is lake surface. Lake Zwai is the northernmost of a group of four lakes within the Galla Plain; it is also the highest-lying (1 636 m), the most extensive (about 450 km^2) and the shallowest (8 m maximum depth). The western and northern shorelines of Lake Zwai, including the Meki Delta, lie within Shoa Province, whereas the southern and eastern lake-shores are in Arussi (Chilalo). The provincial boundary continues south along the Bulbula River dividing Shoa from Arussi to the east. A low ridge, 10-15 km north of Meki, separates the Zwai catchment from that of the Awash River.

The area is traversed by the tarmac road south from Addis Ababa to Awassa, which should, by 1976, extend the 1 200 km to Nairobi. Meki Town is 120 km from Addis Ababa. Rough motorable tracks passing to the north and south of Lake Zwai connect the project area with Asella, the provincial capital of Arussi. There are also two main tracks west across Haikoch and Butajira *awraja** from Meki and from Zwai but neither is motorable after heavy rain. An improved road running the 48 km from Zwai to Butajira is due to be completed early in 1976 at an estimated cost of $4.46 million.

Middle valley of the Meki River

Part of the middle valley of the Meki River, some 25 km^2 north-east of Inseno (referred to hereafter as the 'mid-Meki Valley'), forms a subsidiary study area. This lies along the right (south) bank of the Meki River immediately upstream of its confluence with the Weja. Several tracks connect this area with the road between Inseno and Butajira.

Certain aspects of the study inevitably extended beyond the boundaries of the project area to cover the Meki and Catar catchments and the hydrology of terminal Lake Abiyata.

*An *awraja* is a unit of local government being a sub-division of the province; the *awraja* is itself divided into several *woredas*.

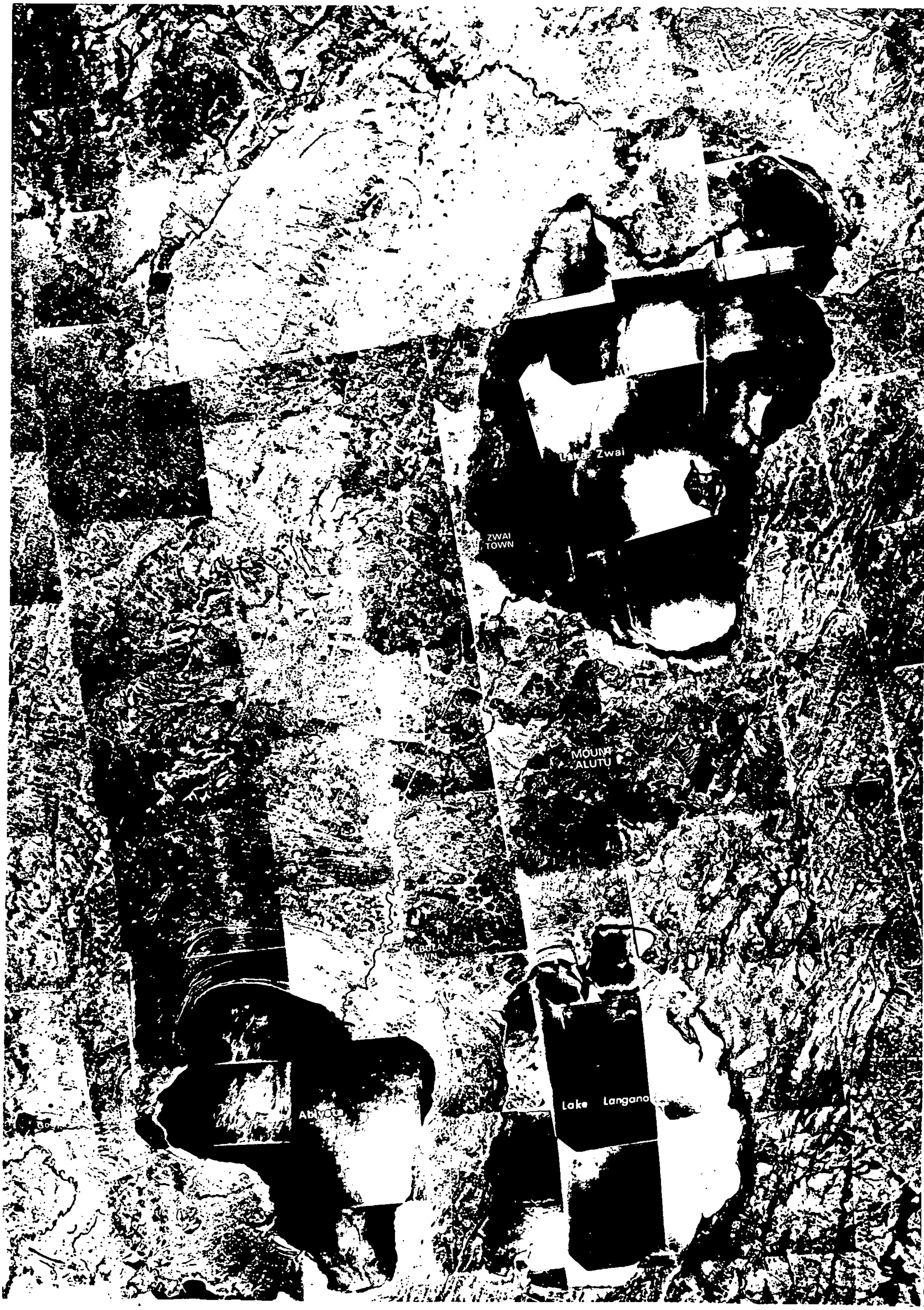
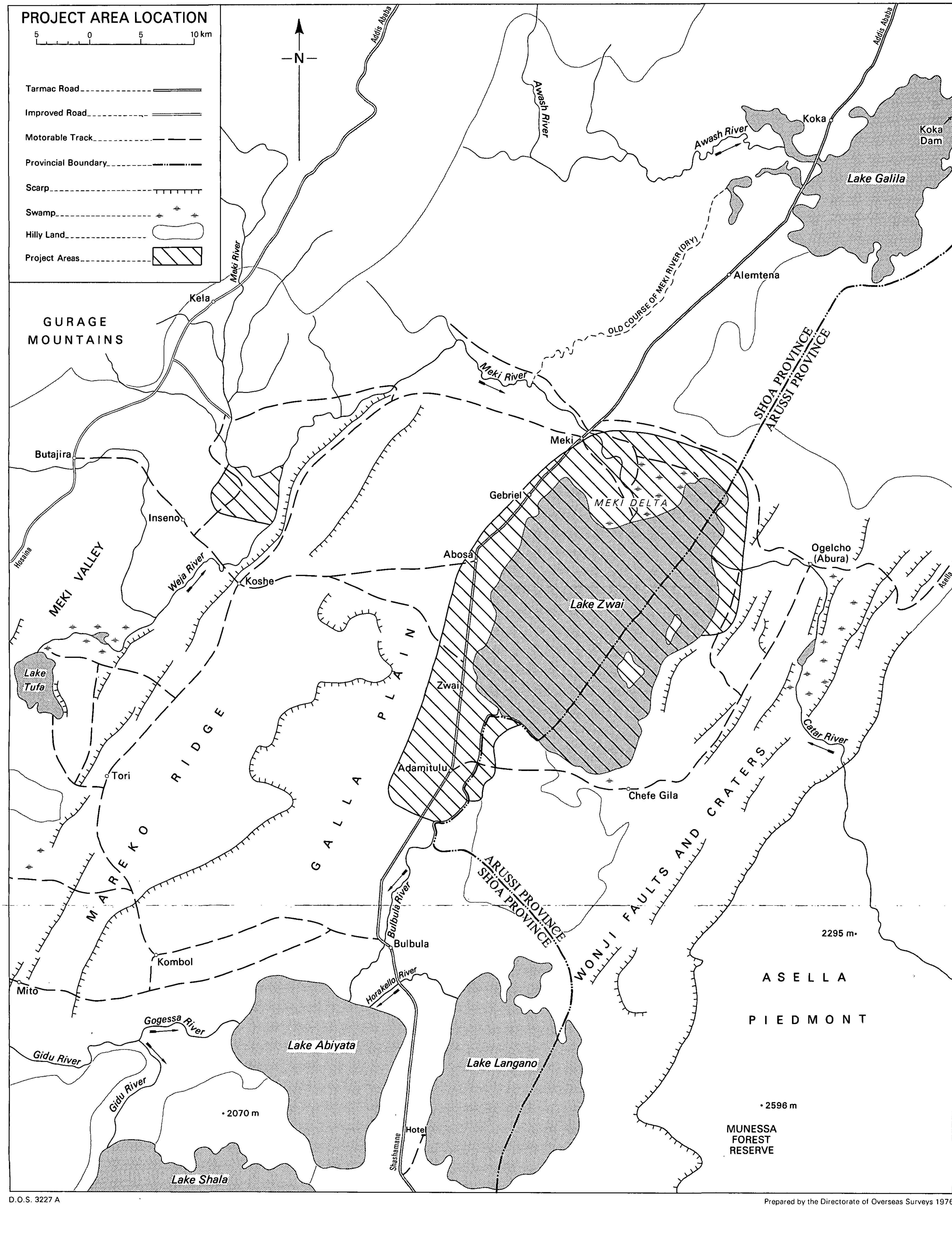


PLATE 1

PLATE 1 Aerial view of the country around Lakes Zwai and Abiyata
Derived from D.O.S. Printlaydowns Nos. 0838D, 0839C, 1972 and 0738A, 0738B 1973.

Prepared by the Directorate of Overseas Surveys 1976



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TEXT MAP 1

CLIMATE

The project area has a wet season from July to September, a dry season from October to January and a season of highly variable rainfall from February to June. The Lake Zwai basin climate has arid characteristics for most of the year and monthly average rainfall never exceeds evaporation. The climate becomes more humid, however, with increasing altitude on the rift valley flanks constituting the catchments of rivers draining into Lake Zwai.

The available climatic data are presented in Appendix 1; some mean values are plotted on Figure 1. Text Map 2 shows the positions of all meteorological stations in the area. Whereas over 50% of the annual rainfall is received during the 3-month wet season, rainfall distribution is variable and long dry periods common. The wet season winds are generally south-easterly or south-westerly, depending on the location of low pressure convergence zones towards the north of the country.

At the beginning of the dry season, the convergence zone moves south across the project area and thereafter a dry north-easterly airstream is established with very stable conditions. The climate is characterised by low rainfall and humidity, moderate but persistent winds and by a high rate of evaporation which averages 5.3 mm/day. Night temperatures commonly fall to less than 10^{o}C and frosts can occur on land above 1 800 m.

Between February and June rain-bearing winds are channelled northwards through the Rift Valley with the northward movement of low pressure convergence zones. Rainfall is sporadic and unpredictable. Sometimes the stable dry season conditions persist until March, though there is great variation from year to year.

Rainfall

Text Map 2 shows the estimated mean annual rainfall in the Lake Zwai catchment. All raingauges except those at Tori and Gogetti are observed daily and recording raingauges are installed at Zwai, Kulumsa and Bokoji. Monthly rainfall data for selected stations are presented in Appendix 1. The records of most stations are of less than 10 years duration but Adamitulu has a daily record from 1956 to 1969, and a monthly record from 1914 to 1940. Rainfall is lowest in the vicinity of the lakes. Figure 1 shows the seasonal distribution of rainfall at Adamitulu, Meki and Ogelcho, and Table 1 the number of years over a 41-year period in which the monthly rainfall was nil or less than 25 mm at Adamitulu.

TABLE 1 **Number of years in which the monthly rainfall was nil or less than 25 mm at Adamitulu (1914-40 and 1956-69)**

	J	F	M	A	M	J	J	A	S	O	N	D
Zero rainfall	16	7	3	1	0	0	0	0	0	6	12	24
<25 mm rainfall	31	23	15	7	9	8	0	0	2	26	32	33
No. of years observations	37	38	38	37	37	36	37	38	37	37	36	36

Figure 2 shows that there have been long-term variations in annual rainfall, the pre-1920's rainfall being above average, while rainfall in the 30's and 40's was below average. From the mid 1950's to 1969, annual rainfall again tended to be above average. Extreme annual rainfall totals at Adamitulu are presented in Table 2.

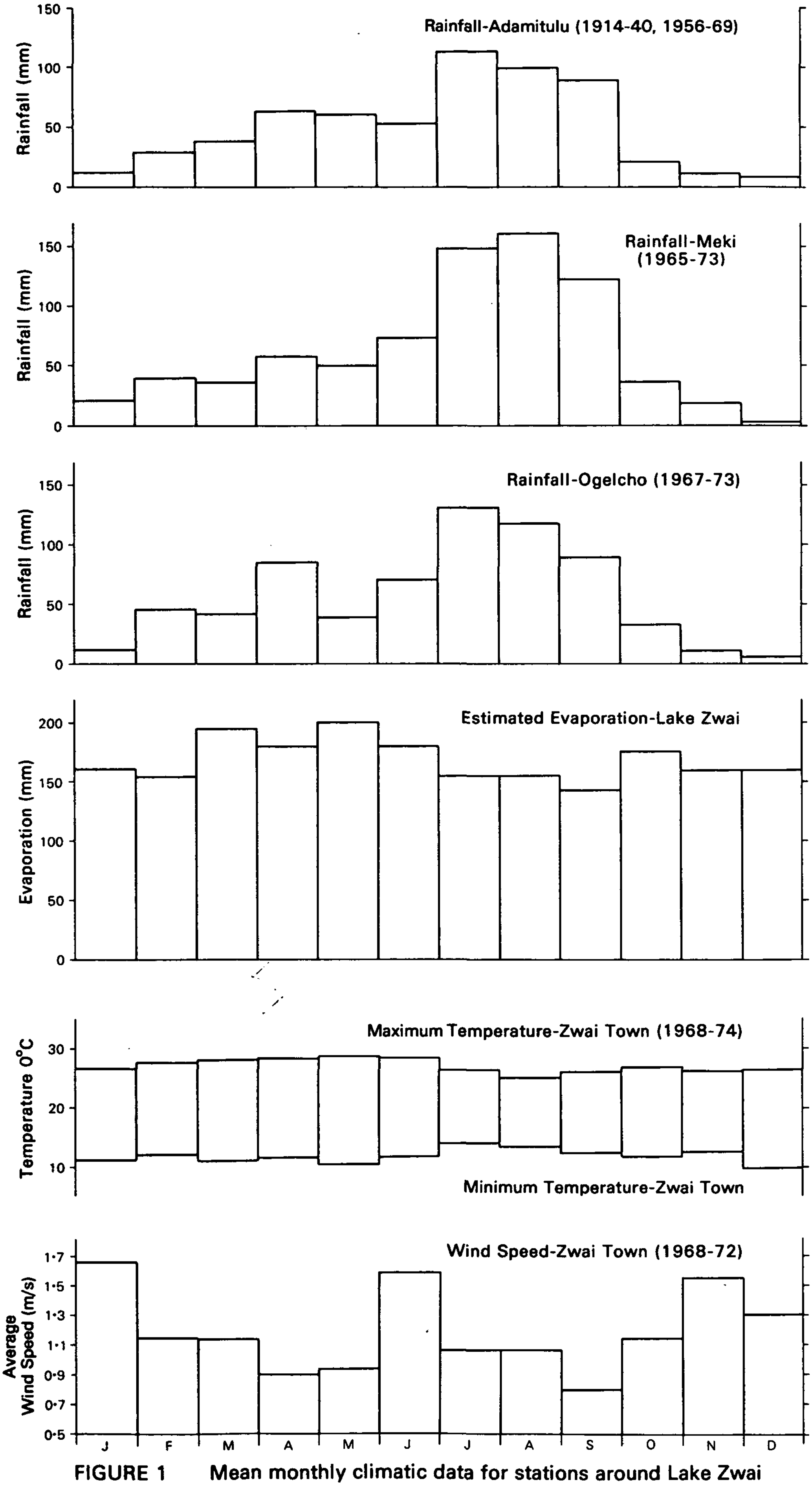
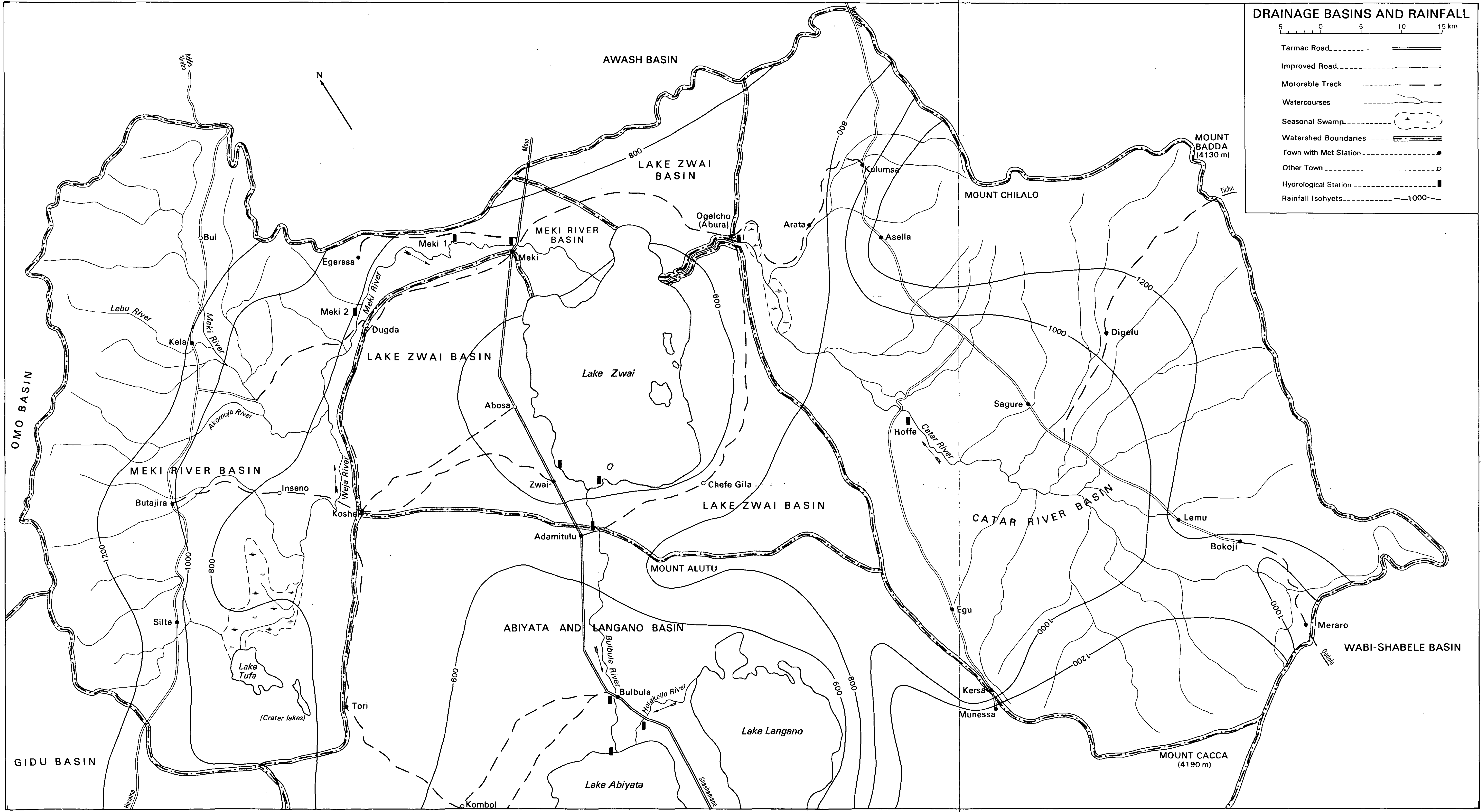


FIGURE 1 Mean monthly climatic data for stations around Lake Zwai

Prepared by the Directorate of Overseas Surveys 1976



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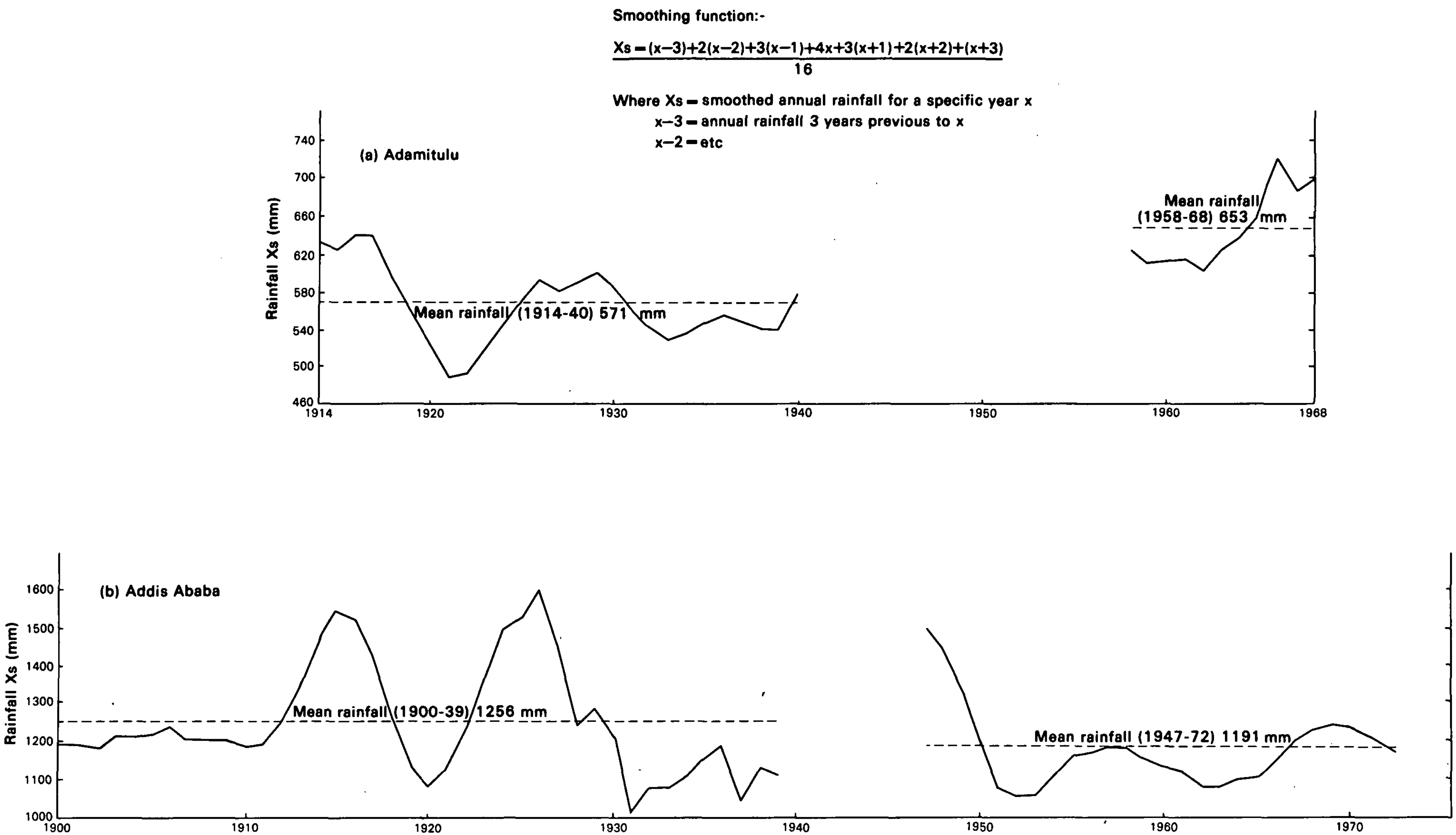

FIGURE 2 Smoothed values of annual rainfall at (a) Adamitulu (1914-40 and 1958-68) (b) Addis Ababa (1900-39 and 1947-72)

FIGURE 2

TABLE 2 Extreme annual rainfall totals at Adamitulu (1914-40 and 1956-69) compared with the mean

	Year	Rainfall (mm)
Max.	1926 1917 1958	880.6 860.4 720.3
Min.	1933 1932 1921	383.2 387.6 406.3
Mean		602.1

Maximum daily rainfall data for Adamitulu, Meki and Ogelcho are presented in Table 3.

TABLE 3 Maximum recorded daily rainfall values

Station	Record examined	Maximum daily rainfall (mm)	Date
Adamitulu	July 1956 – April 1970	81.1	14.3.70
Meki	Aug. 1965 – Dec. 1973	81.2	12.7.67
Ogelcho	Sept. 1967 – Dec. 1973	82.0	15.2.69

Table 4 gives an indication of rainfall reliability over consecutive 10-day periods, based on daily records at Adamitulu (1956-70) extended by those from Meki (1971-3). The minimum rainfall expected in 80 out of 100 years (80% probability) or in 90 out of 100 years (90% probability) in any consecutive 10-day period indicates that, under rainfed conditions, crops are at considerable risk if planted before the beginning of July. Rainfall is again very unreliable by the middle of September.

TABLE 4 Minimum rainfall (mm) at two levels of probability for consecutive 10-day periods, based on records at Adamitulu (1956-70) and Meki (1971-3)

Probability %	Jan. – Mar.	April I	April II	April III	May I	May II	May III
80 90	0 0	0 0	0 0	1 0	0 0	0 0	2 0
	June I	June II	June III	July I	July II	July III	Aug. I
80 90	2 0	3 0	9 2	12 5	18 11	17 9	20 10
	Aug. II	Aug. III	Sept. I	Sept. II	Sept. III	Oct. – Dec.	
80 90	23 16	12 6	23 13	12 2	5 0	0 0	

Evaporation

The only measurements of evaporation in the project area are undertaken at Zwai town with a Piche instrument and a Class 'A' evaporation pan; these records are, however, too fragmented to be of value. Likewise, there are few reliable data from which to compute Penman estimates of evaporation. Now that sunshine data are being recorded at Zwai it will become possible to make these estimates and, for this purpose, the method is explained in Appendix I. In this report, however, evaporation estimates have been derived from equivalent data at Wonji (30 km north of Zwai and at a similar elevation) adjusted for differences in altitude (McKerchar and Douglas, 1974). These are presented in Figure 1 in terms of monthly estimates for Lake Zwai. The estimate of mean annual potential evaporation of 2 010 mm is in reasonable agreement with the 1 920 mm estimation based on the projected lake water balance (Makin *et al,* 1974). Seasonal variation in evaporation, of 142-154 mm in the wet season and 155-201 mm between October and May, is relatively small.

Temperature

The mean daily temperature at Zwai is 19.3°C. The highest temperatures occur between March and June prior to the start of the main rains (Figure 1), though seasonal variation in daily temperature is relatively slight. While frost has not been recorded at Zwai, the minimum temperature in the dry season frequently falls below 10°C and sometimes to 4°C. Temperatures at ground level may therefore occasionally fall below freezing point, with implications for crop production that are discussed in Part 5.

Relative humidity

Humidity is highest in the wet season, and least in February and March when there is also marked diurnal variation. Throughout the dry season and generally between 1200 and 1500 hours, relative humidity is below 50%. However, the Zwai data are suspect, and the average of 67.2% (mean of daily readings at 0600, 1200 and 1800 hours) is almost certainly an overestimate due to errors in recording, poorly maintained instruments and the siting of the recording station close by the lakeshore.

Wind

Strong and persistent daytime winds are a significant feature of the Lake Zwai area. During the afternoons in the dry season, the prevailing north-easterly winds are reinforced to the west and south of the lake by a local on-shore air flow. The mean wind speed is relatively high, averaging 1.19 m/s throughout the year (measured by cup-counter anemometer at 1 m above ground level). The windiest periods are November-January, and immediately preceding the main rains in June (Figure 1).

Radiation

There are no long-term records of radiation or sunshine. However, a fair indication of solar radiation can be derived from the Wonji sunshine records; estimates are presented in Table 5.

TABLE 5 Estimates of monthly net solar radiation at Zwai, based on data from Wonji (cal/cm^2/day)

J	F	M	A	M	J	J	A	S	O	N	D
475	450	500	490	510	480	440	450	460	510	450	460

Between February and May 1974, sunshine and incoming radiation (measured with a bimetallic actinograph) were recorded and the coefficients in the Angstrom equation were determined (Appendix 1).

GEOLOGY AND LANDFORM

Lake Zwai Hinterland

Lake Zwai lies at an altitude of 1 636 m within a broad downfaulted basin of internal drainage formed through local subsidence of the rift-valley floor. Both to the east and west, the land rises within 10 km of the lake to higher-lying faulted ridges. This is especially apparent to the east where multiple displacements along the Wonji fault belt permit an abrupt increase in elevation over a comparatively short distance. By contrast, the fault line west of the lake immediately to the north of Abosa, though aligned with the general trend of the Wonji faults, is of minor dimensions. Otherwise the country to the west of Lake Zwai, comprising a series of low lacustrine terraces, exhibits only subdued relief. To the north, the land rises gently towards the watershed with the Awash at a minimum elevation of 1 670 m. To the south of the lake, the landscape is dominated by Mount Alutu, a major centre of Quaternary silicic volcanism rising to about 1 880 m.

Laury and Albritton (1975) have synthesised the later Quaternary history of the Zwai area from successional deposition on the lake terraces but more especially from that on Gademotta Ridge, the high-lying rhyolitic caldera rim 5-15 km to the west of Zwai town. Rich Middle Stone Age sites occur in paleosols of the late Pleistocene Gademotta Formation. Laury and Albritton have suggested that certain rhyolitic strandline gravels situated some 100 m above the present surface of Lake Zwai may represent the high-water level of an immense lake which occupied the entire Galla Basin sometime during the late Pleistocene. Gademotta Ridge, together with the lower colluvial slopes, are now undergoing significant gullying due to the lowered base level resulting from recent lake recession.

The Lacustrine terraces were formed from interbedded ash, pumice and siltstone during late Quaternary times (Plate 3). Five terraces are recognised to the west of Lake Zwai ('the Western Terraces'). Since these are constructional features laid down comparatively recently during periods when the lake level recession was halted for a significant time span, the surface of each terrace is almost level. The terrace elevations measured by Laury and Albritton (1975) are 3.5, 11, 18, 25 and 34 m above Lake Zwai. From examination of trenches dug in each of the terraces, Laury and Albritton showed that well sorted, though poorly stratified and essentially unconsolidated, sandy volcaniclastic material overlies more indurated and well stratified basinal sediments. The fault north of Abosa predates lake-terrace development. West and south of Zwai town, the terraces are broad and flat, but between Abosa and Meki they are close together and the area of level land is small. Both west of Zwai town and immediately south of the Catar River, small scarps occur at about 50 m above lake level; these mark the maximum conceivable extent of pump irrigation from the lake.

The deposits on the terraces include coarse-textured pumice sand and gravel and medium-textured volcanic ash derived from Mount Alutu. It has been deduced from the nature of this material that the ash was deposited on the lake bed, whilst the pumice may have floated on the surface so forming the main constituent of the beach deposits. However, in practice the distribution of pumice and ash was found to be extremely complex. While pumice most commonly occurs on lower terraces and at the foot of the 50 m scarp, it also appears unpredictably on the top of terrace scarps and within areas of otherwise uniform ash. West of the Bulbula River, consolidated ash and siltstone outcrop to within 30 cm of the ground surface. Near Adamitulu, lacustrine deposits surround older volcanic plugs which form prominent small hills. A resistant laval intrusion gives rise to a rock sill and waterfall on the Bulbula River near the former road crossing from Adamitulu leading to Chefe Gila ('the Bulbula rock sill').

The Meki and Catar rivers have both formed flat, low-lying deltas where they enter Lake Zwai. The Meki Delta extends over 6 000 ha, and evidence from old channels and levee deposits indicates that the river has changed course several times during delta formation. The Meki has deposited mainly fine-grained material, though sandy layers are common along former channels. The land slopes gently away from the river but the topography is slightly undulating along old levees and channels. The river is still an active depositional agent and capable of flooding as much as 800 ha of lower-lying land. Flooding from the lake occurs periodically along the southern fringes of the delta. The Catar Delta is small by comparison (about 1 000 ha), the river being incised about 10 m. The fine materials comprising the Catar Delta are more uniform than those of the Meki.

Lake Zwai is bordered by swamp, except along the south-eastern and southern margins where the shores are relatively steep. A high proportion of the lake bed and the swampy lake margins is composed of coarse pumice material, though fine-grained deposits border the Meki and Catar deltas. Zones of alkaline seepage tend to occur along the boundary between the marginal swamps and the lowest lacustrine terrace, particularly along the north-east shoreline where there are several alkaline sand bars. Hot springs occur on the island of Tulu Gudo.

Mid-Meki Valley

The mid-Meki Valley is a broad downfaulted plain lying at about 1 800 m and composed of Pliocene ash deposits. It is bordered by lava and ash cones to the west and by an ignimbrite and basalt scarp to the east. The Meki River, with its source in the Gurage Mountains (Text Map 1), is incised into the northern part of the plain before flowing north-east in a deep valley towards its delta. The Weja River flows north from Lake Tufa and its associated swamps to join the Meki at the north-east corner of the plain.

The ash deposits of the plain itself have weathered to form poorly consolidated fine-grained material which is probably underlain at depth by basalt and ignimbrite. In the west, the products of weathering are uniform friable clays. Towards the Weja River in the east, however, the presence of stratified paleosols and ash layers near the ground surface would suggest several phases of deposition.

SOILS

A summary of the main soil types follows. The soil classification is outlined in Table 6; and the soil properties are summarised in Part 5 (Table 33). More detailed soil descriptions and analyses are contained in Appendix 6. The distribution of the main soil series is shown on Separate Map 2 and described in Part 6. Soil mapping has been based on interpretation of 1971-2 1:60 000 scale aerial photography supplemented by field observations in 1974. The positions of the majority of soil sampling points, symbolised in terms of surface soil texture, are also shown on Separate Map 2.

The soils of the Zwai area have been classified according to the nature of the soil-forming parent material, the topsoil texture, the morphology and arrangement of subsoil layers, the presence or absence of alkalinity or salinity and the drainage characteristics. These criteria have been used as a basis for grouping the soil series into four associations:

1. Soils formed on the alluvium of the Meki and Catar deltas

2. Soils formed on the Lake Zwai terraces

3. Soils formed on ash in the mid-Meki Valley

4. Swamp soils around Lake Zwai

The alluvial soils and those in the mid-Meki Valley are mainly fine textured but on the lake terraces coarse and medium-textured soils predominate. The presence of distinct subsoil layering is restricted to alluvium along former channels of the Meki and, to a lesser extent, the Catar rivers. Alkaline subsoils occur in all areas except the mid-Meki Valley. Soils which are both saline and alkaline throughout the profile are generally confined to the north-eastern and north-western shores of Lake Zwai.

Meki and Catar Deltas

The soil pattern on the Meki Delta has been influenced by the lateral meandering of the Meki River and its consequent deposition of contrasting layers of material of differing texture. On the upper part of the delta, soils formed on recent levee deposits adjacent to the Meki River do not exhibit marked layering, and comprise rather weakly structured layers of clay loam and clay, often with high proportions of silt. Flanking the present-day levee, there are fairly extensive areas of clay on which indistinctly layered and well structured soils have developed (Plate 2). Away from the Meki River, a complex of soils occurs along former river channels. Clay loams with variable subsoil high in silt and with layers of sand and clay near the surface occur on

PLATE 2

Brown basin clay exposed in a soil pit on the Meki Delta

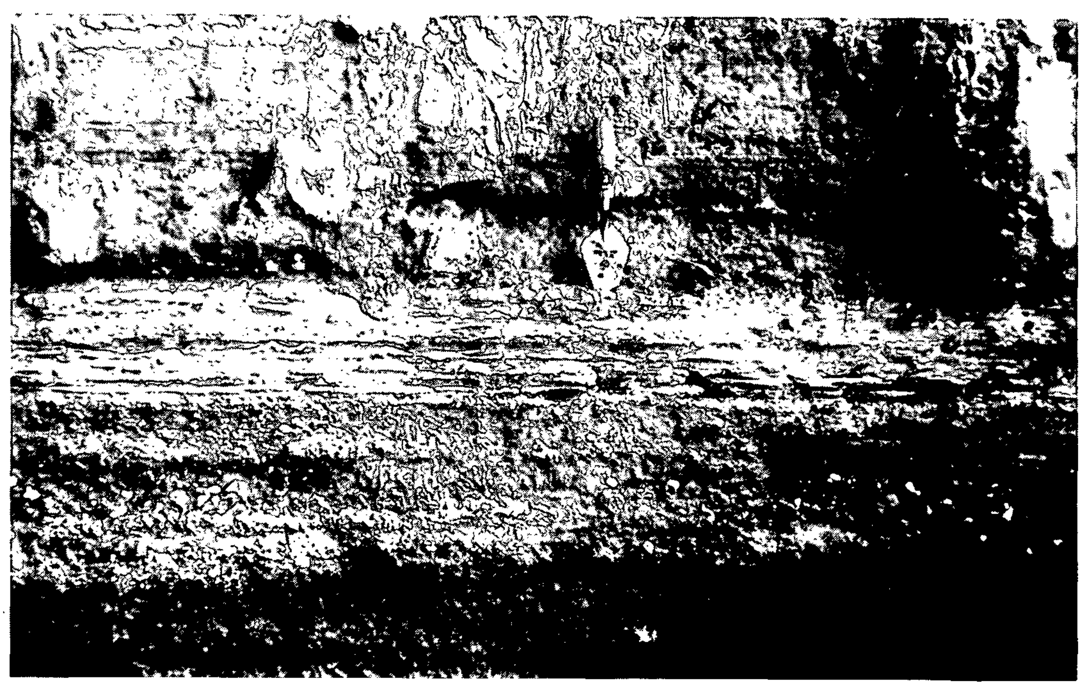

PLATE 3 Bulbula river gorge with interbedded pumiceous tuffs and stratified lacustrine tuffaceous silts and ash, overlying mollusc-rich layers

gently undulating old levee ridges. There is a gradation of soil from such ridges to more level land comprising former lower levee slopes. Soils on these flatter sites contain rather higher proportions of clay and do not have sand layers within 75 cm of the ground surface. On the lower delta, mottled clay occurs extensively in association with seasonal waterlogging. In areas subject to periodic flooding from the Meki River, a variety of soils occur, with medium-textured topsoil overlying clay. Saline groundwater below much of the central part of the delta has given rise to slightly saline subsoil in some areas. Other areas towards the west have subsoils high in sodium, and alkaline phases have been mapped.

TABLE 6 Soil classification and distribution in the project area (also see Separate Map 2)

Soil group	Soil unit	Area (ha)
1. Soils developed on riverine alluvium	A Soils on the Meki River levee	560
	B* Sandy soils on old leveee material	1 210
	Ba Alkaline subsoil phase of B	100
	C* Clay soils on old levee material	1 120
	Ca Alkaline subsoil phase of C	200
	D Basin clays	330
	E Periodically flooded sandy complex	1 040
	F Seasonally flooded clays	1 080
	Fa Alkaline subsoil phase of F	370
	G Loams of the Catar Delta	380
	Total	6 390
2. Soils developed on lacustrine terraces	H Loamy sands on coarse pumice material, generally alkaline in the subsoil	6 950
	Hb Bouldery phase of H	110
	J Loams on ash, generally alkaline in the subsoil	6 340
	Jz Silty phase of J	730
	L Clay loams with variable subsoil	1 390
	M Clays with coarse sandy subsoil	870
	N Saline-alkaline soils	1 340
	P Shallow soils, less than 50 cm deep	540
	Total	18 270
3. Soils developed on Pliocene ash (mid-Meki Valley)	R Well structured clays	700
	S Silt loam ash overlying heavy clay with seasonally impeded drainage	1 460
	Total	2 160
4. Soils of permanent swamps	T Silty soils	1 240
	U Pumice sands	1 370
	Total	2 610
Total Area		29 430

*The area of the B + C complex has been divided equally between soil units B and C

On the Catar Delta, well drained loams and clay loams predominate. Variable silty subsoil, typical of much of the Meki Delta, is not usual in this area, although coarse-textured layers occur locally. Alkaline subsoils are common.

Lake Zwai terraces

Two major soils have developed on the lake terraces: coarse-textured soils on pumice sand and gravel, and medium-textured soils on ash. Their relative distribution is complex and is discussed more fully in Part 6.

The pumice sands have weakly developed profiles which are poorly structured and low in organic matter. Surface texture is usually sandy loam; sand content increases gradually with depth. A bouldery phase, with pumice stones and boulders on the ground surface, occurs locally to the east of the Bulbula River. Seasonally flooded grassland bordering Lake Zwai has about 30 cm of clay over coarse pumice material.

Medium-textured terrace soils generally comprise loam overlying compact ash. A silty phase occurs on terraces near the Meki and Catar deltas, where soil has formed from a mixture of lacustrine and riverine deposits. Heavier-textured clay loams, often with buried topsoils and thin bands of pumice gravel in a clay subsoil, also occur very locally in these areas.

High levels of sodium are present in many subsoils and, below a depth of 75 cm, exchangeable sodium percentages (ESP) of over 20 were found in about 60% of the terrace sites investigated. Soils affected by both high salinity and alkalinity occur fairly extensively along the north-eastern, north-western and south-eastern shores of Lake Zwai and to the north-west of Adamitulu. Such soils have a conductivity in the saturated extract exceeding 4 000 μmhos/cm and an ESP of over 20 throughout the profile.

Mid-Meki Valley

The generally heavy-textured soils derive from layers of weathered ash. Over about half of the area, these take the form of fairly well drained and well structured dark brown clays and silty clays, which are neutral in reaction and show none of the subsoil alkalinity so characteristic of the soils around Lake Zwai. The area is, however, far from uniform in terms of topography; along the sides of drainage gullies and on slopes close by the Meki River, shallow soils and rock outcrops are usual. Towards the east, the land has been covered with up to 50 cm of a highly silty layer of light grey ash. This overlies relatively impermeable clay and shows distinct signs of drainage impedance and other physical drawbacks during the wet season. Local farmers recognise the difference between the two major soils, cultivating the better drained clays and leaving much of the less well aerated land under grass.

Lake Zwai shoreline

Soil type reflects parent material on the swampy lake margins. Along the eastern and western sides of the lake, soils are coarse-textured with an organic loam topsoil over pumice sand. Bordering the Meki and Catar deltas, silty clays have developed on fine-textured alluvium. In some areas, alkaline seepage has given rise to sodium-rich subsoils.

WATER RESOURCES

Surface water resources

Text Map 2 shows the catchments of the two major rivers within the project area, the Meki and the Catar. The Meki River drains an area of 2 300 km^2 of the Gurage Mountains to the west and north-west of Lake Zwai; while the Catar, with a larger catchment of 3 400 km^2, rises in the Arussi Highlands to the east of the lake. The entire outflow from Lake Zwai is carried by the Bulbula River, which flows south for 30 km before discharging into Lake Abiyata, a terminal lake. Other rivers which flow (intermittently) into Lake Abiyata include the Horakello from Lake Langano and the Gogessa, a branch of the Gidu River draining land to the west of Abiyata.

Although the headwaters of the Meki River are at an altitude of about 3 000 m, the river rapidly descends the Rift Valley escarpment to below 2 000 m before being joined by several major tributaries, including the Lebu, the Akomoja and the Weja. The latter, deriving partially from saline swamps to the north of Lake Tufa, contributes some salinity to the main river. Downstream of its confluence with the Weja, the Meki is incised in a steep-sided valley until it reaches Meki Town at the head of its

FIGURE 3

FIGURE 3 Hydrographs of the Meki, Catar and Bulbula Rivers (Source: Italconsult (1970), AVA (1972, 1973) and private communications. Discharges are tabulated in Appendix 3

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delta. Thereafter, the Meki meanders for 15 km between slightly raised natural levees through deltaic alluvium before entering Lake Zwai at an average elevation of 1 636 m (a.s.l.). During the wet season, several shallow overflow channels carry flood waters from the Meki towards Lake Zwai in a variety of directions, so impeding access and causing serious local flooding which raises the watertable.

The Meki has been gauged at Meki Town since 1963. The AVA installed two additional gauging stations on the river in 1968: at 'Meki 1', 5 km upstream of Meki Town, and at 'Meki 2' further upstream near Dugda. However, since no perennial tributaries enter the Meki between these three stations, only the longest record, that from Meki Town, has been used in this report. On the hydrograph for Meki, shown in Figure 3, the marked seasonality of flow is plainly evident as are the especially high flows of 1969-72. In an average year, maximum flows occur in August with a minor secondary peak in April, and minimum flows between December and March. During March and April 1973, the river bed was dry at Meki Town.

The catchment of the Catar River ascends to over 4 000 m on the summits of Mounts Badda and Cacca. Consequently, the gradient of the river is generally steep throughout its course to Lake Zwai, and it is often deeply incised up to 50 m below the surrounding countryside. The physical features of the catchment have been described in the Rift Valley reconnaissance (Makin *et al.*, 1975) and are outlined on Text Map 2. Because of the steep configuration of the Catar valley, areas suitable for irrigation are few in number and very limited in extent. The prime importance of the Catar River is the contribution which it makes to the lake. Gauging was initiated by the AVA in 1968. Two stations were installed, one at Hoffe on the middle reaches of the Catar, and the other near Ogelcho. Since the latter station provides satisfactory information relating to the hydrology of Lake Zwai, data from it alone have been used in this report. The hydrograph of the Catar at Ogelcho is shown in Figure 3. Although the overall pattern of flow is similar to that of the Meki, the peak flows are more clearly defined, the base flows in the dry season are rather higher, and it seems most unlikely that the Catar would ever dry up.

Lake Zwai can be compared to a shallow saucer. Contours of the lake bed are shown on Separate Map 4, and the relationship between lake level, area and volume in Figure 4. At its average surface level of 1 636 m, the lake covers an area of some 450 km^2 and has a maximum depth of 8 m. Apart from the Meki and the Catar, Lake Zwai has its own catchment covering about 1 700 km^2 (Text Map 2). Although the lake catchment has no perennial rivers as such, there are several mineralised springs around the lakeshore and there may also be a significant groundwater flow towards the lake. Despite high evaporation from the lake surface (in excess of 900 mcm* annually), the inflow plus rainfall on the lake surface exceeds evaporation, thus giving rise to the Bulbula River outflow. Records of lake level at Zwai Town since 1967 show marked variations. The exceptionally high levels of 1969-70 were followed in 1973-74 by very low levels. These variations have had a striking impact on flows in the Bulbula; consequently, there is a close correlation between the hydrograph of the lake (Figure 5) and that of the Bulbula River (Figure 3).

The Bulbula descends some 58 m over a distance of 30 km between Lakes Zwai and Abiyata (Text Map 2). The level of this river for the first 6 km of its length is virtually the same as that of Lake Zwai due to a lava rock sill which effectively controls the level of the lake (the position of this sill is shown on Separate Map 6). Below the sill there are a series of minor falls over further banks of lava, before the Bulbula River becomes incised to over 50 m in a steep-sided gorge within poorly consolidated ash deposits. The gorge continues almost to Lake Abiyata, into which the Bulbula flows over a shallow beach. Except periodically during the wet season, the flow in the Bulbula usually derives entirely from Lake Zwai. However, the Bulbula does have a significant catchment of its own with ephemeral tributaries from the east occasionally contributing to the flow. The Bulbula has been gauged at a site near Bulbula village since 1968 (Figure 3). Whenever the level of Lake Zwai falls below that of the controlling sill, as happened in the dry seasons of 1973-5, the Bulbula dries up.

*million cubic metres

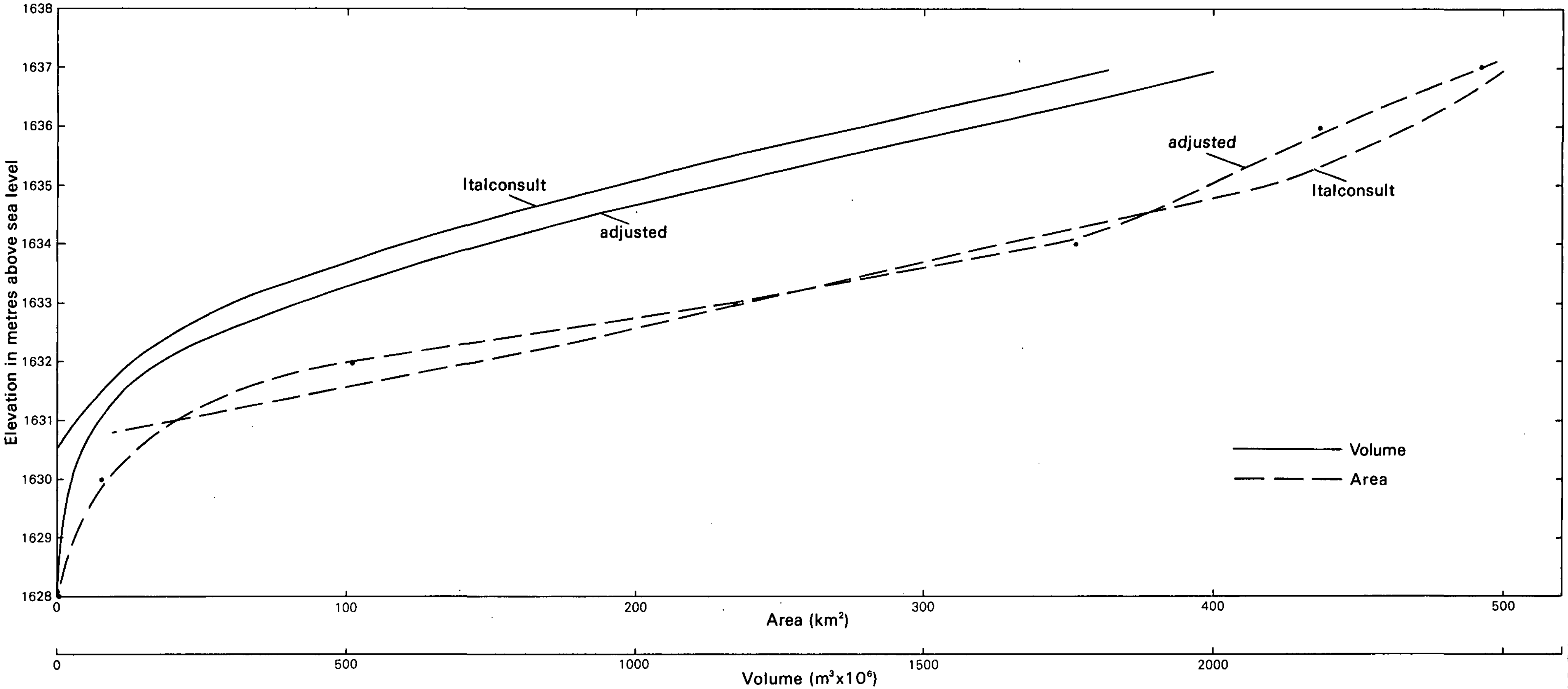

FIGURE 4 Areas and volumes of Lake Zwai in relation to surface elevation (Italconsult, 1970, curves adjusted in the light of new data)

FIGURE 4

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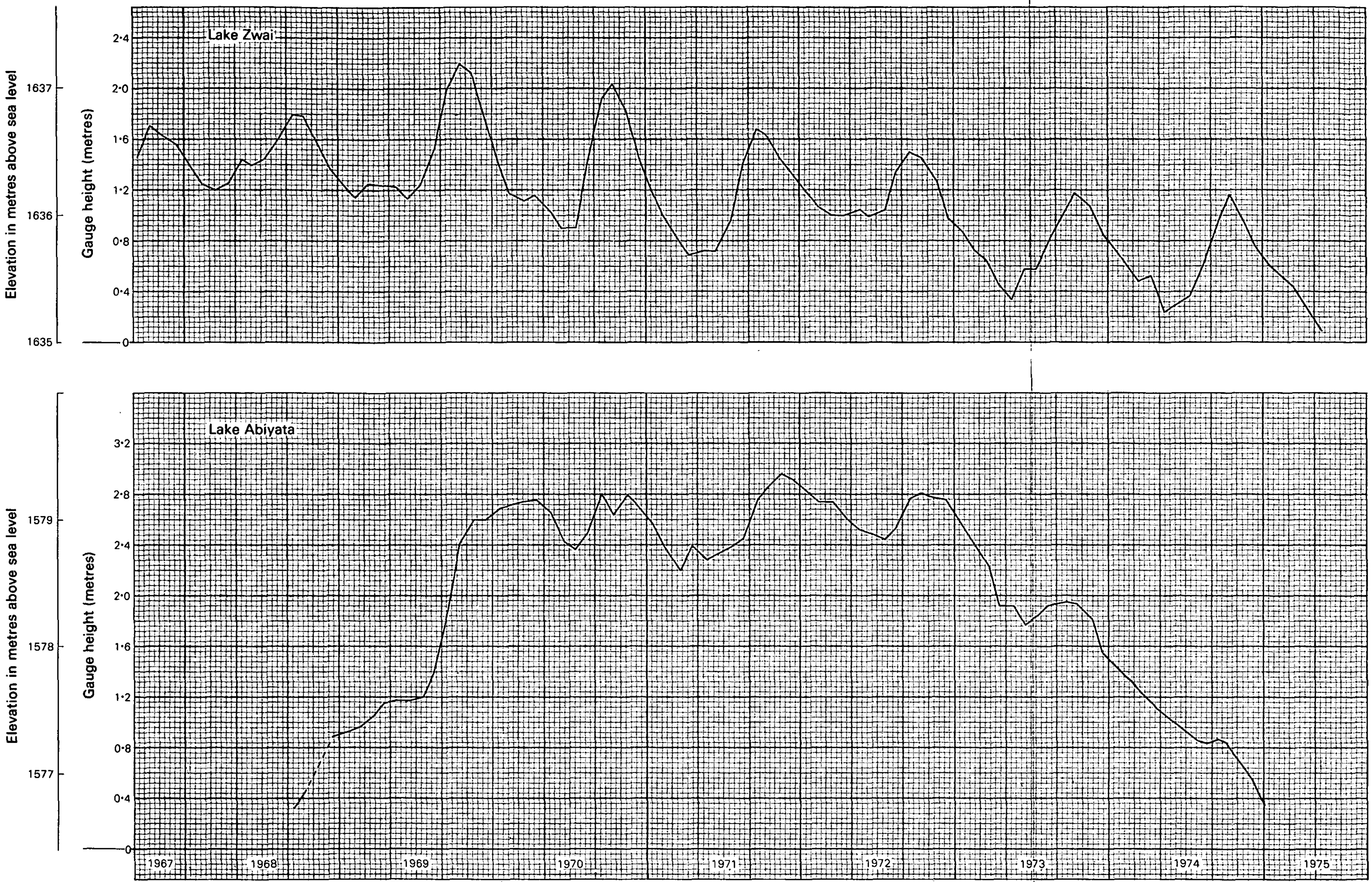

FIGURE 5 Hydrographs of Lake Zwai and Abiyata (Source: Italconsult, 1970 and AVA, 1972, 1973) and private communications.
Note: Elevation of zero on staff gauges:- Lake Zwai 1635.1 m (a.s.l.)
Lake Abiyata 1576.4 m (a.s.l.)
Gauge height data are tabulated in Appendix 3

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In an average year, the contributions to the lake from the Meki and Catar rivers and from rainfall on the lake surface amount to 1 150 million cubic metres (mcm), while the outflow through the Bulbula River to Lake Abiyata is 210 mcm. The difference between inflow and outflow, amounting on average to 940 mcm per year, is accounted for by evaporation from the lake surface. Apart from the Bulbula, the other major rivers flowing into Lake Abiyata, the Horakello and the Gogessa (Text Map 2), have also been gauged: the Horakello near the bridge on the road between Bulbula and Shashamane, and the Gogessa at a site some 5 km up-river from Abiyata. The level of Lake Abiyata has itself been recorded since 1968 at a site adjacent to the mouth of the Bulbula. The lake hydrograph (Figure 5) shows the dramatic rise in level between 1968 and 1970, a consequence of high discharges from lakes Zwai and Langano, and the decline in level after 1972. Although the high level of 1970-2 appears to be unprecedented in recent times, such marked fluctuations are characteristic of terminal lakes.

Groundwater resources

The present project did not include a systematic survey of groundwater. However, in view of the proposal by Italconsult (1970) that the development of irrigation in the Meki Valley should be based on exploitation of groundwater, a brief survey was undertaken during February 1974 to assess the depth and quality of the groundwater beneath the Meki Delta and the mid-Meki Valley. Since drilling facilities were not available, this survey was confined to measuring, in existing hand-dug wells, the depth and electrical conductivity (salinity) of the groundwater. At selected sites, samples were collected for detailed chemical analysis; the results are presented in Table 32 (Part 5) and on Figure 6. Text Maps 3 and 4 show the results of this survey which are discussed briefly below.

On the Meki Delta (Text Map 3) the watertable is highest near to the river and the lake, its depth below ground level attaining a maximum of 7 m in the north east. Villagers close to the lake reported that well water levels fluctuate approximately in accordance with variations in lake level. Much of the well water is saline (especially in central-western and north-eastern areas) and is consequently unsuitable for irrigation. Its use is confined to domestic purposes and livestock. In places, the saline groundwater approaches the surface giving rise to saline subsoils. The striking contrast in salinity levels encountered over relatively short distances suggests the existence of lenses of saline water fed by salt springs associated with recent faulting. There may also be saline seepage within the sub-deltaic deposits. Should irrigation be developed, using water from the river or lake, it will be essential to control the application of water so as to prevent the saline watertable from rising; this is a topic which is discussed more fully in Part 6.

Text Map 4 shows that the depth of the watertable beneath the mid-Meki Valley increases eastwards towards the Weja River. Immediately north of the Meki, a maximum depth of 15 m to groundwater was observed. The site of this latter observation is on rising land whereas, further south, depths do not correspond with topography. All water samples tested were moderately saline and, while the levels of dissolved salts do not render the water unfit to drink, their use for irrigation could lead to salt accumulation in the soil. The highest salinities are in the south towards Lake Tufa and also to the north of the Meki River. All well water is drawn by hand for domestic use, and also for raising red pepper seedlings many of which are sold locally. The rate at which well water is being used for these purposes is very low and there is apparently little diurnal or seasonal fluctuation in water level. Nearly every settlement in the valley has at least one well, except at riverside locations where surface water is used. Existing wells could not be used for pump irrigation, because they rarely penetrate sufficiently far into the aquifer. Moreover, it is most unlikely that the underlying materials (ash with basalt at depth) would have sufficient hydraulic conductivity to provide for the necessary rates of abstraction. Development of irrigation based on groundwater abstraction would depend on the identification and development of a deeper aquifer, possibly in the basalt. Consequently, it is suggested that it might prove worthwhile to construct and test-pump a pilot well some 2 km east of Inseno on the road to Koshe (Text Map 2). There is no geological evidence to support the choice of this site, but preliminary altimeter investigations suggest that there is a contour gradient in this area which may indicate higher transmissivity.

Water quality

Despite minor contributions from salt springs and from alkaline seepage around the lake shore, Lake Zwai, with an electrical conductivity of between 300 and 500 μmhos/cm, is the only relatively salt-free lake in the southern Rift Valley. The lake water does however contain a high level of bicarbonate relative to the calcium and magnesium contents.

Water from selected sites in the Zwai basin has been analysed to determine its suitability for irrigation. The results presented in Table 32 have been classified for alkali and salinity hazard according to the United States Department of Agriculture system (USDA, 1954) and shown graphically on Figure 6. Whereas all the surface water samples proved suitable for irrigation – with low alkali and medium salinity hazard (the Catar has only low salinity) – much of the well water tested proved to be unsuitable due to high salinity. From the point of view of domestic use, all waters appear to be generally suitable, though certain of the well waters are in excess of salinity limits normally accepted for human use. No measurement was made of the fluoride content, which may exceed maximum acceptable levels in some parts of the Rift Valley; nor were any bacteriological counts made. In view of concern that has been expressed regarding the possible spread of bilharzia, a mollusc survey was undertaken, the results of which are discussed in Part 7.

POPULATION AND SOCIAL STRUCTURE

Parts of the following *woredas* make up the project areas:- Alemtena, Meki, Meskan, Zwai and Adamitulu in Haikoch and Butajira *awraja*, and Zwai and Dugda in Chilalo *awraja*. No population statistics are available at *woreda* level, but it is estimated that the population of the project areas was approximately 70 000 in 1974. The population of Haikoch and Butajira *awraja*, the largest *awraja* in Shoa province, was 485 000 in 1968. By applying the CSO growth-rate figure of 1.8%, the population of Haikoch and Butajira was projected to be about 530 000 in 1974; this gives an overall population density in the *awraja* of 44/km². From project farm surveys conducted in 1973 and 1974, the population density per cultivated km² has been estimated and compared with population density data for the province and *awraja* (Table 7).

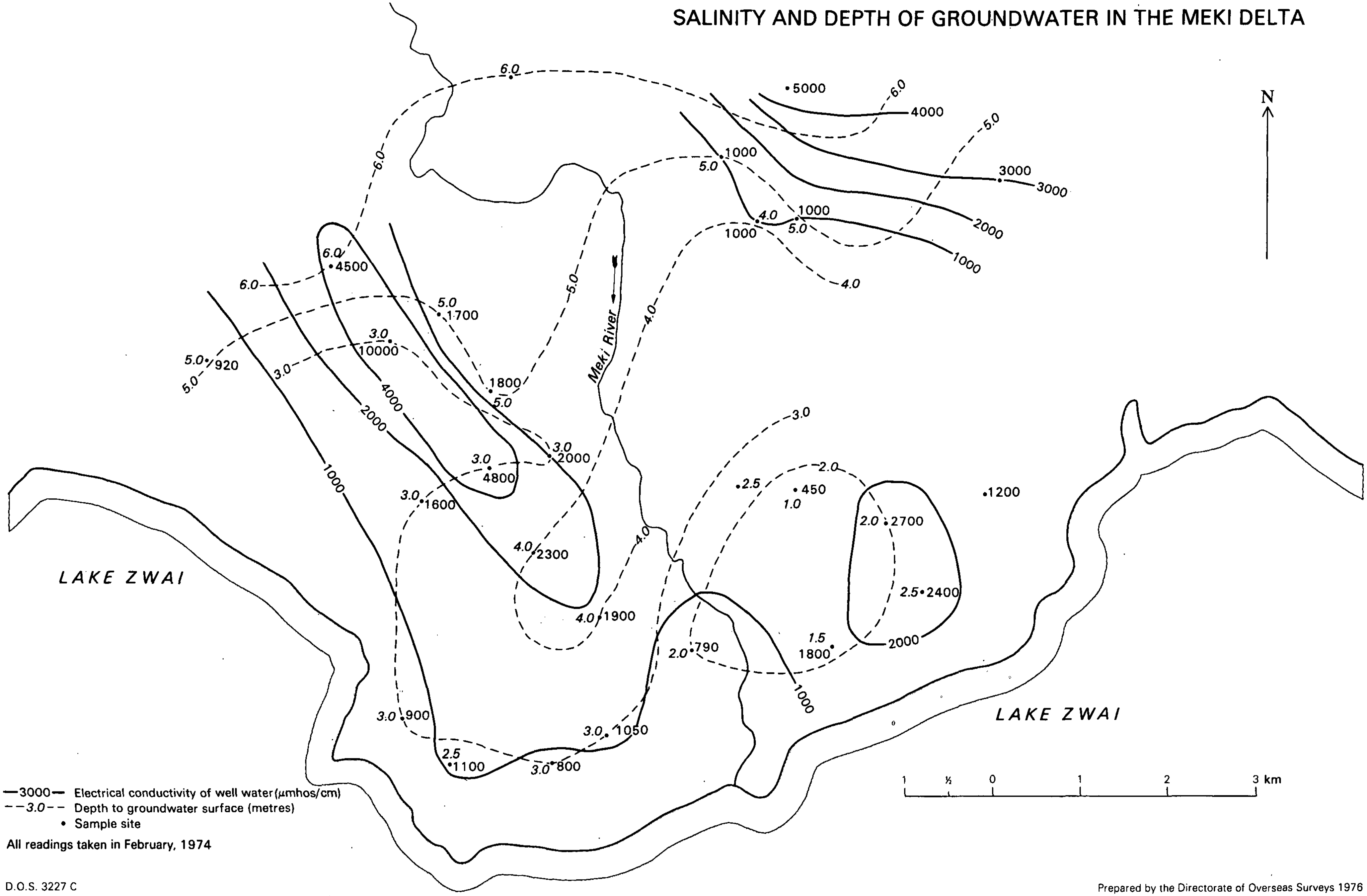
TABLE 7 Density of population in Shoa Province, Haikoch and Butajira *awraja*, and in the project area (persons/km²)

	Overall population density	Population density per cultivated km²
Shoa Province	62	–
Haikoch and Butajira	44	–
Project areas		
Meki Delta	131	226
Mid-Meki Valley		203
Zwai Terraces		275
Bulbula River (east)		240

There is no great variation in the data for population density per cultivated km² in the project area, and the differences that do occur are the result of varying farm and family size. In all these areas, over 40% of the population is under the age of 15 years. Urbanisation is barely evident, and the three main towns – Meki, Zwai and Adamitulu – have no more than 9 000 inhabitants between them. Meki is the largest town in the project area with a population of about 4 000.

The major tribal group is the Arussi Galla, who form the majority of the cultivators and herdsmen. Before the southern Rift Valley became accessible and only a small

SALINITY AND DEPTH OF GROUNDWATER IN THE MEKI DELTA



—3000— Electrical conductivity of well water (μmhos/cm)
- - 3.0 - - Depth to groundwater surface (metres)
• Sample site

All readings taken in February, 1974

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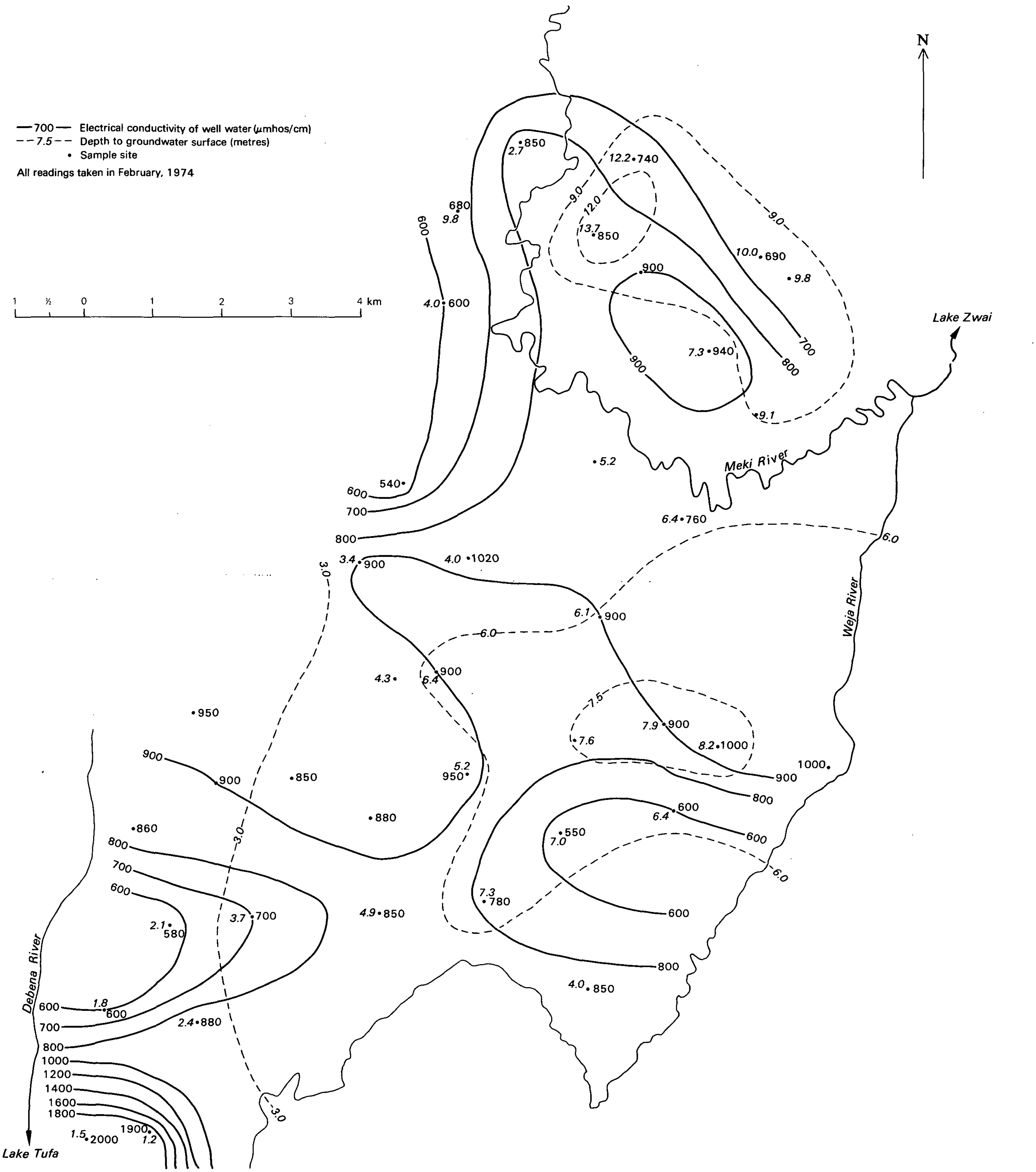
TEXT MAP 3

SALINITY AND DEPTH OF GROUNDWATER IN THE MIDDLE MEKI VALLEY



TEXT MAP 4

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FIGURE 6

Note: Refer to Table 32 for location and detailed analysis of samples

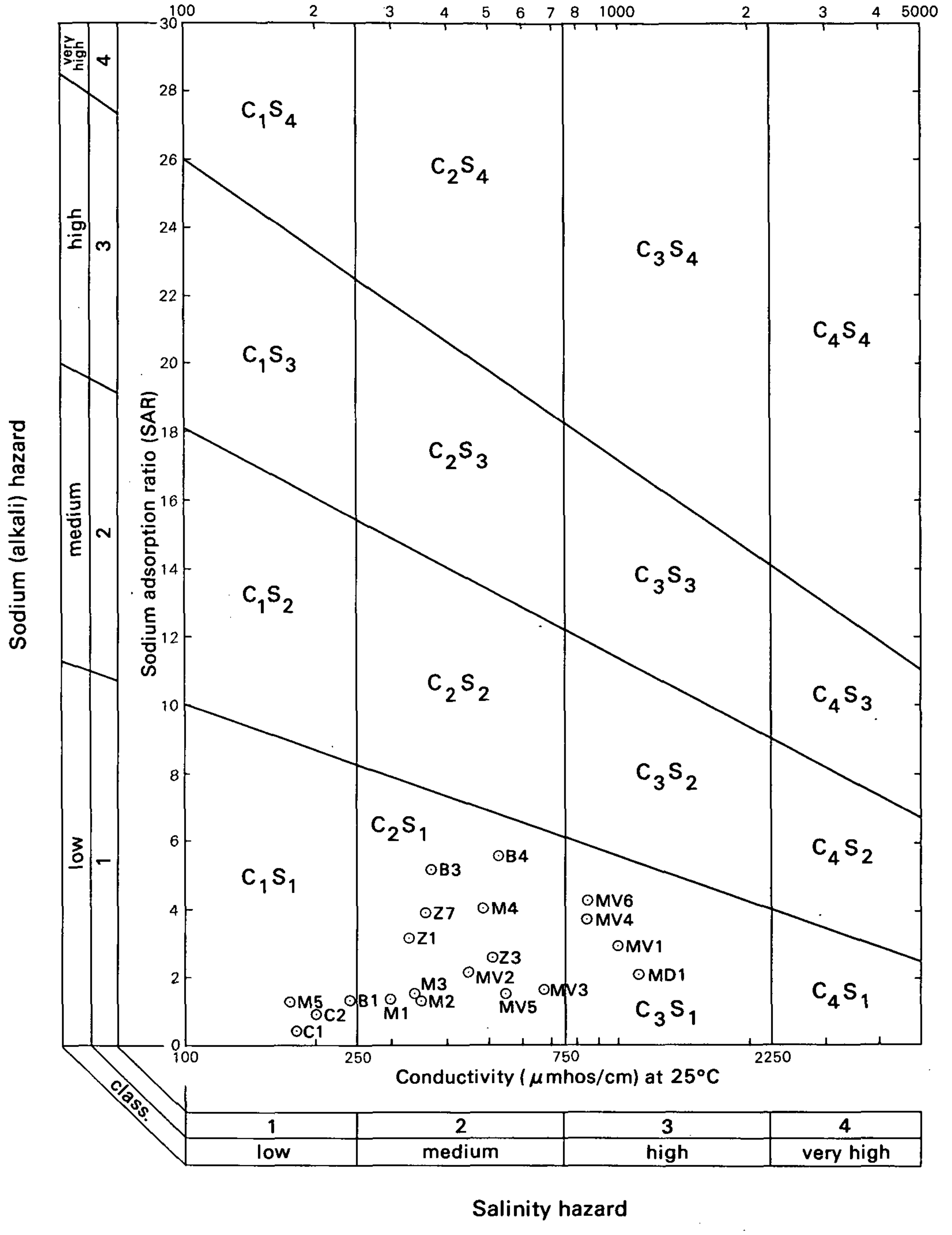

FIGURE 6 Classification of water samples with regard to sodium and salinity hazards (after USDA, 1954)

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proportion of the land area was cultivated, most Arussi were nomadic or semi-nomadic pastoralists subsisting on government-owned land. As land was distributed to people from outside the area as well as to the Arussi themselves, and as the extent of cultivation increased, the nomadic way of life all but disappeared and many became landless tenant farmers.

Butajira and the Meki Valley form the homeland of the Gurage who, unlike the Arussi, are of semitic origin. Apart from being industrious farmers, they are also active merchants who, together with a few Arabs, own the majority of shops in the project area. There has been a perceptible movement of Gurage farmers from the west to the farmlands surrounding Lake Zwai. Development of the Zwai and Meki areas has also attracted numbers of Kambatta tribesmen, who sometimes farm but are more commonly migrant labourers. The islands of Lake Zwai have traditionally been a refuge of the Orthodox church against Muslim invasions, and on two of the islands there are monasteries. In addition, there are the Amhara who held many official posts and who, having bought or received large tracts of land, also used to make up the majority of the land-owning class.

The occupational status of the rural male population of Shoa Province is indicated in Table 8; it is probable that the population in the project area is similarly employed. Of the working population, 91.5% appear to be directly engaged in agriculture and almost 95% of heads of households described themselves as self-employed (CSO, 1970) although, in the absence of industry and of formalised employer-employee relationships, this figure is hardly surprising. As a corollary, it is notable that the agricultural labourer group is very small; farm surveys confirmed that use of hired labour on small farms was comparatively rare. It is probable, moreover, that most seasonally-hired labour is drawn from the non-resident population. Unemployment data are not available but, while it is evident that the majority have work, many are under-employed for part of the year. Approximately 80% of farmers were tenants.

TABLE 8 Occupational status of the rural male population of Shoa Province

Occupation	Percentage of male population
Farmer and pastoralist	62.1
Agricultural labourer	0.4
Non-agricultural labourer	1.2
Merchant	0.3
Servant	0.4
Schoolboys	3.9
Boys of school age not attending school	27.2
Men too old to work	1.1
Unclassified	3.6

Some educational facilities exist in the larger towns, but only about 2.7% of the total population are at school; the overall literacy rate is 8.5% (CSO, 1970). There are no hospitals in the project area, although Butajira boasts a clinic. Most towns have pharmacies.

Although Amharic is the language of business, the majority speak one of several dialects of Gallinya; the Gurage however speak their own tongue. Many of the Arussi Galla are muslims.

LAND USE

The main vegetation types and forms of land use practised in the project area are shown on Separate Map 1, which is based on 1971-2 1:60 000 scale aerial photography updated by field observation in 1974 (Plate 4). The area of each dominant form of land use around Lake Zwai is listed in Table 9; these data relate to the area shown on Separate Map 1 (less the mid-Meki Valley, equivalent data for which are presented in Part 6 — Table 62).

Air photograph flown by Hunting Surveys Ltd., November 1972 Contract 133 ET 9 / print no. 117 Scale approx. 1:66,000

PLATE 4 Land use around the Bulbula River: mapping based on airphoto (1972) interpretation up-dated in the field during 1974

A Swamp
C *Cynodon* grassland
F *Acacia tortilis* woodland
G *Hyparrhenia* grassland
H Hillside bush-grassland
J *Acacia* bushland and bush-grassland
L Irrigated plots
M Large-scale cultivation with over 50% of large fields: maize, beans and peppers
N Small-scale cultivation with over 50% of small fields: maize, tef and sorghum
U Urban area (Adamitulu)

Prepared by the Directorate of Overseas Surveys 1976

TABLE 9 Land use around Lake Zwai (areas derived from Separate Map 1)

Physiognomic type	Land use class	Area (ha)	Percentage of total area
Swampland and seasonally flooded grasslands	Swamps	4 490	7.0
	Cynodon grassland	530	0.8
	Acacia/Sporobolus bush-grassland	1 340	2.0
	Total	6 360	9.8
Woodland and bushland	*Acacia/Croton* woodland	380	0.5
	Acacia tortilis woodland	4 260	6.5
	Acacia bushland and bush-grassland	9 260	14.4
	Hillside bush-grassland (undifferentiated)	8 040	12.5
	Total	21 940	33.9
Grassland	*Hyparrhenia* grassland	220	0.3
	Sporobolus spicatus grassland	510	0.8
	Total	730	1.1
Cultivation	Small-scale cultivation	31 880	49.6
	Large-scale cultivation	2 930	4.5
	Irrigated land	190	0.3
	Total	35 000	55.2
Other	Barren land	230	0.3
	Urban land	370	0.5
Total		64 630	100.0

Reduction in the area of woodland and bushland, which has been such a dramatic feature of the recent past, still continues; consequently, the area of cultivation shown in Table 9 may be an underestimate. Moreover, it is probable that the extent of large-scale farming was also underestimated, partly because of the accelerating rate at which, between 1972 and 1974, small farms were taken over and amalgamated into larger holdings, and partly because of difficulty in discerning field boundaries on the aerial photographs. Changes resulting from land nationalisation in 1975 have not been taken into account.

Around Lake Zwai the landscape is characterised by almost continuous cultivation under an open canopy of remnant acacias, principally *Acacia tortilis.* Much of this land has been cleared and put under cultivation only during the decade 1964-74, the cleared acacias yielding a valuable return in the form of charcoal. The most important crop is maize, which locally during the wet season occupies up to 80% of the land surface. On farms to the west and north of the lake, sorghum, haricot beans and red peppers are significant. On the Meki Delta most farms are devoted to maize cultivation with only minor areas of tef *(Eragrostis tef),* wheat and peppers. To the east of the lake, the areas of wheat, barley and tef are more extensive, though maize still predominates. Locally, small irrigated plots grow a variety of vegetables and fruit, with a preponderance of tomatoes. While the area under crops has been increasing, the area available for livestock has declined correspondingly. This decline has in many cases caused herdsmen to take up crop production. Nevertheless, cattle still form an important element in the farm economy, accounting, on the Meki Delta for example, for half the average smallholder's annual cash income of $200.

By contrast, much of the mid-Meki Valley had been subject to rather intensive cultivation over many years. Here maize is the dominant crop covering up to 90% of the cultivated area; there are also occasional fields of peppers, sorghum, haricot beans and barley. Around well heads and near the Meki River, hand-irrigated nurseries of red

PLATE 5

Farmer watering pepper seedlings from a shallow well in the mid-Meki Valley

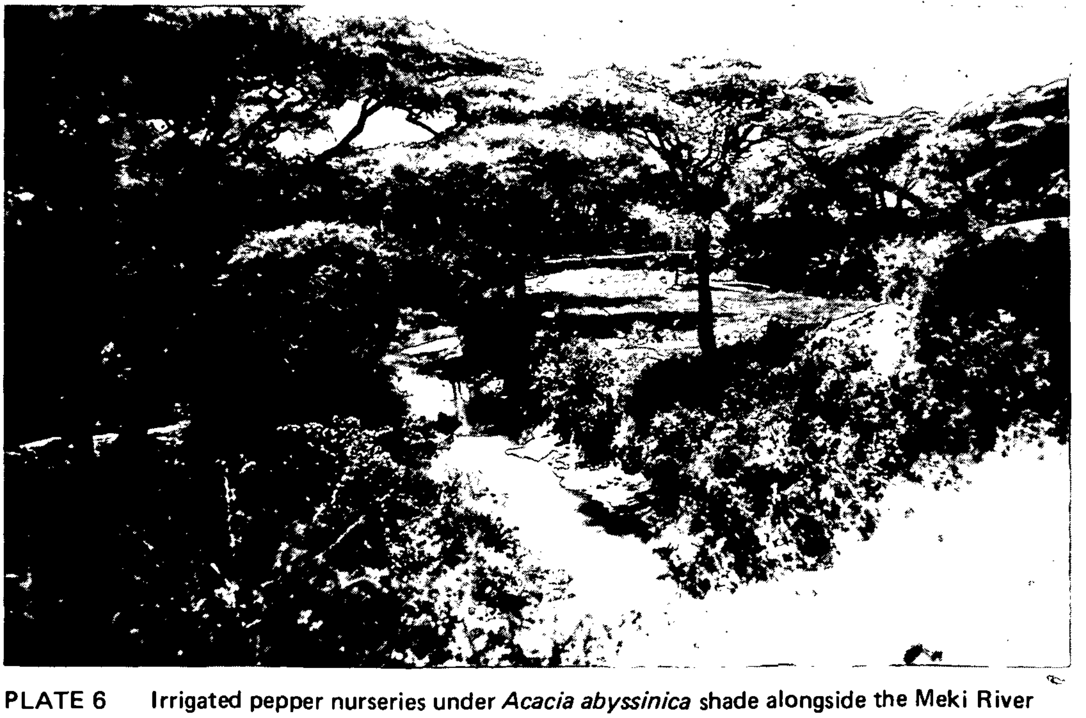

PLATE 6 Irrigated pepper nurseries under *Acacia abyssinica* shade alongside the Meki River

pepper seedlings are a characteristic feature towards the end of the dry season (Plates 5 and 6). *Acacia albida, A. seyal, Croton macrostachys, Balanites aegyptiaca, Maytenus senegalensis* and *Ficus sp.* occur as solitary remnant trees throughout the cultivated areas.

Only the heavy, poorly aerated, compact clays towards the Weja River in the east have not generally been cultivated, though the land was being opened up by mechanised farming. Here the deleterious effects of poor soil structure and aeration may be exacerbated by unreliable rainfall which appears to be significantly lower than in areas further west. The *Setaria* grassland which grows on these soils plays an important role in the local economy for thatching and grazing. Subsistence is based on sorghum as much as on maize; lentil and tef are also significant with livestock forming a major element in the local economy.

Lake Zwai area: farming systems

Prior to land nationalisation in 1975, a number of distinct farming systems could be recognised. Since the type of system adopted was governed mainly by farm size, the basic distinction between these farming systems can to an extent be expected to be carried over into the post-land reform situation; farm size was moreover the main determinant of farm income.

Large farms

These generally ranged between 40 and 800 ha, and produced a variety of crops, especially maize, haricot beans and tef, in the wet season. Basic cultivations were mechanised, although harvesting was normally performed by hand. Production was almost entirely for sale. While most specialised in the production of arable crops, one farm near Meki produced milk for the Addis Ababa market, and another on the Meki Delta produced fodder on a commercial basis. Net income per hectare ranged from $50 for tef, to $200 for haricot beans with fertiliser.

Only a few medium-sized (10-40 ha) farms occurred as discreet enterprises. Too extensive to be cultivated by family labour using traditional means, and yet too small to obtain credit easily for mechanisation, farmers in this intermediate category tended either to leave a high proportion of the holding fallow or to rent out parts to tenants. Though cropping patterns were similar to those on larger farms, these intermediate holdings often ran relatively large herds of cattle; farm incomes per hectare tended to be low except where land was rented out.

Small farms

Most agricultural employment in the project area comprises farmers cultivating small-holdings ranging in size between 0.5 and 5 ha. Farm surveys conducted in the Meki Delta and elsewhere showed that 85% of these farmers cultivated less than 3.5 ha, and that 73% were tenants of whom 77% paid rent in cash. On these farms, production is subsistence-orientated, though limited surpluses are marketed when they occur. The most important crop is maize; other crops grown include haricot beans, peppers, tef, sorghum, barley and lentils (Table 10). Table 11 indicates the gross value of production on the Meki Delta and the Zwai Terraces in 1972-3.

TABLE 10 Smallholder cropping on the Meki Delta and Zwai Terraces, 1972-3

Crop	Percentage under crop	
	Meki Delta	Zwai Terraces
Maize	81.2	55.9
Beans	12.2	33.8
Peppers	0.4	1.5
Lentils	1.0	1.9
Tef	3.6	3.1
Barley	1.1	0.4
Sorghum	0.0	1.4
Fallow	0.5	2.0

TABLE 11 Average values of production and sales from smallholdings on the Meki Delta and Zwai Terraces, 1972-3

Location	Production ($/ha)	Mean farm size (ha)	Production ($/farm)	Sales ($/farm)
Meki Delta	187.30	2.30	430.79	234.70
Lake Zwai Terraces	200.80	1.88	377.50	96.30

All small farms keep livestock, primarily for draught and the production of milk, but also as a form of capital. Sheep and goats provide the bulk of meat production, and beef is eaten only on special occasions. The ownership of cattle generated a net income of between $40 and $180 per farm holding in 1972-3.

Irrigated farms

Since 1970, a new type of enterprise, employing irrigation as a major input, has been introduced into the project area. While the irrigated area is relatively small, it is nevertheless highly significant in demonstrating development potential. In March, 1974, there were 23 farms using irrigation, with a total irrigated area of about 132 ha. Irrigation tended to be associated with larger farms (although the average irrigated plot was only 5.7 ha, overall farm size was considerably greater). Water is mostly pumped by small diesel engines, from the Bulbula and Meki rivers and from Lake Zwai, to grow vegetables for the Addis Ababa market. By far the most important vegetables grown are tomatoes, although a wide variety are cultivated including onions, leeks, carrots, celery, green beans, red and sweet peppers, lettuces, cabbages and courgettes. Papaya is also commonly grown. Many of these pioneer farmers originated from northern Ethiopia where irrigated horticulture was well known. The farms are not operating under easy conditions; crop diseases are a major problem, there is a shortage of working capital, and markets for some fresh vegetables and for tomatoes in particular have almost reached saturation. Irrigated farms tend to be labour intensive; apart from the pumps, little machinery is used. When market prices have been favourable, the gross value of production has been as high as $3 500/ha. Undoubtedly, where irrigation has been adopted, gross value of production per unit area has often been greatly increased.

Government ranches

There are two longstanding government-owned ranches — Adamitulu and Abernosa (1 520 and 4 240 ha respectively). The Adamitulu Cattle Breeding Station aims to upgrade Borana and local beef breeds through culling and selection. The Abernosa Ranch, just outside the southern boundary of the project area, is concerned with the production of cross-bred heifers for dairy farmers near Addis Ababa.

Lake Zwai area : vegetation

Before the establishment of farmland, the area was wooded. Now, scattered throughout the Lake Zwai area, and especially on rocky hillsides and on Adamitulu Ranch where cultivation has been precluded, remnant patches of *Acacia tortilis* bushland and woodland still exist, with a ground cover dominated by *Hyparrhenia* grass. *A. seyal* and *A. senegal* are the most common bush associates; *A. etbaica, A. persiciflora, Balanites aegyptiaca* and *Capparis tomentosa* also occur frequently. On seasonally poorly drained sites on the Meki Delta, a distinctive association of *Acacia/Sporobolus* bush-grassland occurs. Along the Meki River south east of Meki Town, there is a remnant area of *Acacia albida/Croton macrostachys* woodland which is rapidly being converted to farmland.

Along the lakeshore, vegetation zonation is controlled by the water level. The shoreline is itself fringed by discontinuous blocks of *Typha* (bullrush) and of *Cyperus papyrus.* Beyond this, in open water, there is an almost continuous floating belt of *Phragmites* (reed) with *Nymphaea* (water-lily). Along the lakeside edge of the periodically flooded hinterland and also along both banks of the Bulbula River, there is often a narrow thicket of the leguminous shrub, *Aeschynomene elaphroxylon.* Immediately inland, and especially along the western shoreline where slopes are gradual, there are expanses of *Cynodon plectostachyus* grassland which provide valuable grazing when the lake is low. Along shorelines subject to alkaline seepage however, the vegetation cover may be sparse and largely confined to low tussocks of the unpalatable grass *Sporobolus spicatus;* the surface accumulations of various salts are nevertheless beneficial for cattle.

LAND TENURE

On March 4, 1975, the Provisional Military Administrative Council promulgated 'A Proclamation to Provide for the Nationalisation of Rural Lands'. This proclamation marks the divide between the former freehold ownership system, characterised by a badly skewed distribution of land with a predominant pattern of absentee landlords and numerous landless sharecroppers, and the new reformed situation in which all individual ownership is abolished. Unfortunately, the project field work was largely undertaken before land reform. Nevertheless, since the former holding boundaries remain the basis for the current (post-reform) boundaries, it has been thought worthwhile to report briefly on the situation pertaining before the proclamation was issued.

Tenure prior to land reform

Nearly all land in the project area was *gebbar,* i.e. privately owned land, acquired by purchase, grant or inheritance. *Gebbar* owners could cultivate, lease, sell, or mortgage their land and were subject to land tax, a tithe known as *asrat,* and to education and health taxes, according to the size and fertility of their holding. Some 800 ha belonged to the Imperial Family under a form of tenure known as *beta rist,* which was not subject to land or other taxes. Small areas of land surrounding certain towns, such as Zwai and Adamitulu, and amounting to no more than 700 ha, have been set aside for future urban development. Around Abosa; in the mid-Meki Valley and to the east of the Bulbula River, forms of communal tenure already existed where land in parcels of 30-50 ha was cultivated by up to 20 families (usually inter-related), taxes being paid by a single owner who was clan leader. The only government-owned land in the project area comprised the margins of Lake Zwai, which are liable to periodic flooding, and the Adamitulu Cattle Station. The lake margins are variable in extent but average about 1 400 ha; the Adamitulu Station, covering some 1 520 ha, is used by the Ministry of Agriculture for beef cattle improvement.

Land measurements are in *gasha* and *karti.* Approximately 140 *karti* make up one *gasha.* A *gasha* in the Meki and Zwai *woredas* measures 35-40 ha. Land in Haikoch and Butajira *awraja* was measured during the 1950s. Measurements are unsophisticated, requiring a standard chain or rope, the specified length varying from district to district, and indeed from *woreda* to *woreda.* Measurement involves dividing a holding into triangles; then adding together the triangular areas. The system is prone to inaccuracy since reliance is placed on linear rather than angular measurement. A holding so measured was entered onto the register in the name of the owner; this formed the basis for taxation. Until 1974, the lack of large-scale maps and co-ordinates precluded accurate demarcation of holdings on the ground, which in turn resulted in frequent litigation. In many instances, errors in measurement were considerable, and in some cases falsification occurred. It was found, for example, that on the Meki Delta the total area on which land taxation was based did not coincide with the area measured from air photographs.

In the Meki and Zwai *woredas,* lists of land ownership were retained by the *balabats** who were responsible for tax collection. These lists are by no means complete, since those farmers who owned considerable tracts of land paid taxes direct to the *woreda* officials who had little information regarding land ownership. Furthermore, the lists

* A *balabat* was a locally appointed chief, formerly with responsibilities for tax collection and minor judicial matters.

having been compiled over 20 years before no longer, in many cases, reflected current ownership, taxes often being paid by new incumbents in the names of previous owners. In a sample survey on the Meki Delta, it was deduced that there were approximately three times as many landowners as had been recorded in the *balabats'* lists.

In 1974, about half the arable area was cultivated by tenant farmers. Tenancy agreements were usually contracted verbally and lasted for a year, tenants often being related to the landowner. Rents were generally paid in cash (ranging between $20-40/ha) but, in addition, landowners frequently devolved land and other taxes to their tenants. Many tenants cultivated their land on a permanent basis, although some moved from time to time. There was no security of tenure and tenants were sometimes evicted without notice, especially in cases where larger holdings were being consolidated to make way for mechanised agriculture. Particularly along the Bulbula and Meki Rivers however, some tenants had negotiated more sophisticated leases, which were written and usually formalised. Here farmers from outside the *awraja* rented up to 80 ha each, at above-average rents for specified lengths of time (up to 15 years), establishing areas of irrigated fruit and vegetables.

A detailed farm survey undertaken on the Meki Delta early in 1974 showed that, in the traditional sector (defined as subsistence-orientated, non-mechanised farms, with a low level of purchased inputs) covering approximately 79% of the delta, 82% of all farmers were tenants and 18% were owner-occupiers. The tenants cultivated some 42% of the land, while the owner-occupiers cultivated 31%. The remaining land was owned, but either lay fallow or was used as pasture. The owner-occupiers owned an average of 12.8 ha (from 2.6 to 20 ha) and the tenants cultivated an average of 1.7 ha (from 0.5 to 4.6 ha). Holding fragmentation averaged 1.9 plots per farm. The basic data are summarised in Table 12.

TABLE 12 Land tenure and farm size in the traditional sector, Meki Delta, 1974

Class	% of total farmers	% of sector cultivated	Average area cultivated (ha)	Average area owned (ha)
Tenant	82	42	1.7	–
Owner-occupier	18	31	5.3	12.8
The remaining 27% of the land in the traditional sector is owner-occupied, but under fallow or pasture				

A large majority (77%) of tenants paid rent in cash, averaging $48/ha/year; 21% paid half their total annual crop as rent; and 2% contributed labour *in lieu* of rent.

Attitudes to tenancy were found to be ambivalent. Due to uncertainty, most tenants felt that they could not optimise their resources, and therefore aspired to become landowners in their own right. Nonetheless, the generally low levels of rent paid indicate that the supply of land then available for tenancies had not been exhausted. The likely response to a major development opportunity, such as irrigation, was therefore uncertain. While welcoming schemes which could increase farm income, tenants feared that, if such schemes were successful, there would be a high risk of dispossession. In contrast, the attitudes to irrigation among landowners were more encouraging, except among those who suspected that they might be cultivating more land than they were paying for in taxes.

Tenure following land reform

Under the land reform proclamation all land is declared to be nationalised. The land is to be distributed by Peasant Associations, promoted locally by the *Zemecha* (Literacy Campaign) and based on *Chika Shum* areas with a minimum of 800 ha. Former tenants and landowners are to have highest priority in land distribution subject to an overall upper limit of 10 ha in the amount of land allocated. After them, in order of priority, land can be allocated to formerly evicted tenants, local unemployed,

unemployed and landless ex-farmers from outside the area, pensioners willing to undertake cultivation, and 'organisations needing land for their upkeep'.

Individual ownership of rural land is abolished and holdings are to be usufructuary only; rights of sale, mortgage and inheritance are abrogated. The aim in allocation is to distribute equal areas of land to each farm family, though provision is made for holdings to 'vary according to the productive potential of the land'. Actual holding sizes are to be subject to final determination by the Ministry of Land Reform (MLRA). Compensation is to be limited to moveable property and 'permanent improvements on land'. Transitional provisions, to cover the 1975 cropping season, allow tenants or hired labourers to acquire possessory rights over the land they are currently responsible for cultivating, subject to any former resident landowners retaining rights to share land with their former tenants. The tenants in turn are freed from the payment of both rents and debts. Cultivators will be responsible for managing their own allotments, though a significant degree of communalisation is anticipated in farm operations, e.g. ploughing. With but minor exceptions, the use of hired labour to cultivate allotments is prohibited.

The question of succession is unclear. As Bruce (1975) has pointed out, although the right to bequeath land is abolished, the right to use the land can by law pass to quasi-heirs: 'provided, that upon the death of the holder the wife or husband or minor children of the deceased or where all these are not present, any child of the deceased who has attained majority, shall have the right to use the land'. The problem is whether the land will pass from one single user to another single user, albeit farmed communally, or whether due to a multiplicity of successors the allotments become increasingly subdivided.

Provision has also been made for the development of state farms (managed by the Ministry of National Resources) in those cases where former large-scale farms were largely or wholly farmed by a single owner. The Peasant Associations are nevertheless the key to the success of land reform. While the Ministies of the Interior and of Land Reform are to assist in Association establishment, the current capacity of the MLRA is such that much of the local activity necessary to implement land reform must stem from the Associations themselves. Nonetheless, the Government retains the right to expropriate land for any public purpose, including 'agricultural projects'.

There are, in 1975, essentially four different types of agricultural organisation in the Zwai area:

Communal farms on which the former tenants of a single landowner cultivate on a communal basis and share the proceeds at harvest.

Communal settlements usually on land formally occupied in part by a single landowner and in part by tenants; settlement proceeding on that section farmed by the landowner, while the portion farmed by the tenants becomes a Communal Farm.

State Farms in situations where a single landowner held and farmed without tenancies an area exceeding 10 ha; or where several landowners farmed contiguous areas which when amalgamated formed a block exceeding 10 ha

Workers co-operatives on irrigated farms where single landowners or tenants farmed areas of less than 10 ha which could not physically be amalgamated; in these cases, the former employees have taken over both the management and the working capital.

Determination of the type of holding that will be created in any set of circumstances appears to be quite flexible however, and is often a result of deliberations involving the *Zemecha*, the Peasant Association, and the Ministries of Land Reform and of National Resources. The previous pattern of land ownership has nevertheless led to particular types of organisation being concentrated in particular areas, though the presence of small pockets of irrigated land along the lakeshore and the Meki River has been a complicating factor.

A majority of the holdings on the Meki Delta have been reorganised as communal farms, and local Peasant Associations have been established covering the entire Delta. Former tenants have usually been given continuing responsibility for cultivating the land which they had previously rented. Communal settlements also occur and there are cases where the local *Zemecha* has welded former tenants and incoming settlers (a majority of these settlers are evicted tenants) together into a single group which is mutually responsible for cultivation and for sharing out the harvest. The division of the land is carried out by *woreda* representatives and MLRA officials though no formal demarcation is being attempted at present. In general, oxen have been retained by the former tenants even when these were the property of the landowner. In one instance a landowner had joined the communal group working his former 2 gasha holding of which he had apparently succeeded in retaining 10 ha; his six former tenants and himself together farmed one of the gashas communally, while the other gasha which was some distance away had been taken over as a communal settlement. The land-owner had given his oxen to the group, but his tractor (on which $8 000 were still owed) had been taken over by EPID for use either on a state farm or for breaking land on new settlements. In another instance, a former landowner had joined the Peasant Association together with a number of landless people, including several previously evicted tenants. He had presented the Association with his oxen and had been allowed to retain the 2 ha which in the past he had farmed himself. Some problems had developed during communal cultivation due to the handing over of all tractors to the government which, combined with an increase in the number of potential cultivators resulting from the influx of landless (and hence oxen-less) people, had led to a shortage of draught power.

A change in tenure of particular interest is the take-over on the Meki Delta of all irrigated holdings by workers' co-operatives, comprising those former employees involved in the irrigation side of each enterprise. In general, these holdings have been partitioned, with workers' co-operatives on the irrigated areas and 'orthodox' communal farming on the non-irrigated. These co-operatives are self-managing, the former employees sharing all tasks in common, including joint responsibility for management operations such as marketing. This development evolved in response to a direct joint appeal to the Land Reform office at Meki by employees who feared that, otherwise, they might lose their means of livelihood. Moreover, since the use of hired labour is now illegal except on state farms, these irrigated farms would probably have been rendered unviable had they remained as individual holdings. The development of workers' co-operatives on the Meki Delta contrasts with the situation along the western shore of Lake Zwai where most irrigated holdings are managed as state farms by the Ministry of National Resources. Both the irrigated state farms and the workers' co-operatives are suffering from a chronic shortage of working capital.

Changes in the pattern of holdings

Other government activity in the area in 1975 included the take-over of 22 gashas of former crown land to the west of the Meki Delta for use as a state ranch, and retention by the MLRA of the area of grassland near the mouth of the Meki for communal grazing, including the grazing of cattle taken from local landlords. In this latter case the MLRA has plans for fencing blocks so as to provide rotational grazing, though some of the periphery had already been ploughed by EPID tractors preparatory to being absorbed into adjoining communal farms. An attempt by the MLRA to conserve the minor area of remaining *Acacia/Croton* woodland (see Separate Map 1) appears to be meeting with only limited success.

The pattern of holdings between Meki and Zwai (i.e. along the western lake terraces), which formerly had comprised a succession of medium-sized commercial farms and small tenancies with occasional irrigated plots along the lower terrace, has also changed radically with a predominance of newly established communal settlements and communal farms. As on the delta, the communal farms comprise groups largely composed of former tenants selected by the local Peasant Association. Often however, where commercial farms had been farmed directly by a landowner, the opportunity has been taken to settle landless and unemployed people selected by the Ministry of the Interior from as far afield as Arba Minch. Land Reform officials at Zwai indicated that the aim was to settle each family on about 4 ha. On one settlement near the fast-expanding village of Gebriel, by May 1975, 140 families had been settled on 5 gashas, i.e. about 1.5 ha per family. On another, 48 landless people from Shashamane had been settled on 4 gashas with more people to come.

Most of the irrigated plots on the western lake terraces have been taken over by the Ministry of National Resources as state farms under the control of newly appointed managers, themselves sometimes former commercial farmers most of whom lack experience of irrigation.

In general, the considerable number of diverse government departments and locally elected groups responsible for various aspects of land reform must in the long run tend to have an adverse effect on implementation. Considerable will and enthusiasm for tenure reform exists in the Zwai area; this needs to be mobilised under a unified agency operating to a carefully conceived and realistic strategy. For success, measured both in terms of maximum settlement and of the maintenance of food production and overall income levels, greater resources need to be devoted to the land reform programme.

Part 4

Evaluation of water resources

INTRODUCTION

This section evaluates in detail the water resources of the Meki Catchment and of Lake Zwai for abstraction of irrigation water.

The Meki River has been studied to determine the amount of water available for the development of run-of-river irrigation within the catchment, and to estimate the magnitude of floods from which protection would be required on the Meki Delta. Since the reliable dry season flows in the Meki were found to be extremely low, brief investigation was made of the prospects for storage in the upper catchment to enable the flow to be regulated as required for irrigation.

The Catar River was not studied in detail since the irrigation potential within its catchment is extremly limited (Makin *et al.*, 1975) and the proposals (in Part 6) concerning the Catar can be safely instituted without materially affecting the resources of Lake Zwai.

A computer study was made of the water balance of Lake Zwai to determine the effect of various irrigation abstractions on the level of the lake and on the flow in the Bulbula River. Given the condition that, over the long-term, the Bulbula flow should not deviate from the average naturally-occurring flow, it has been concluded that the Bulbula outflow from the lake should be controlled by sluices and the Bulbula channel between the lake and the sluices deepened to allow adequate outflows at lower lake levels. Four possible operating rules for control of the Bulbula flow through the sluice are considered, and the relationship between annual abstraction for irrigation and the necessary deepening of the Bulbula channel has been determined for each rule. In the Lake Zwai study, extended flow data was used from both the Meki and Catar rivers obtained by correlation with longer-term rainfall records (Appendix 4). An approximate water balance was also drawn up for Lake Abiyata (Appendix 5) and an assessment made of the possible effect of varying inflows which could result from regulation of the Bulbula.

Analyses in this study were mostly undertaken by the British Institute of Hydrology (McKerchar and Douglas, 1974). Data used are listed in Tables 13 and 14. Most of the rainfall records in Table 14 contain gaps; these have been estimated using the method explained in Appendix 4.

MEKI RIVER

Analyses were made to estimate the mean annual discharge in the Meki River and below-average flows of a given return period. The three return periods considered indicate flows that are on average exceeded once in two years, four years in five and nine years in ten (i.e. 50%, 80% and 90% probability of the calculated flow being exceeded). Monthly and ten-day discharges were also determined at these levels of probability. Initially the nine-year historical data series was analysed but, since this could have been too limited to be representative of long-term conditions, a 100-year sequence of synthetic monthly flows was derived, and the Meki flow record was extended to cover a 24-year period by correlation with rainfall records at Addis Ababa. Details of the latter exercise, the results of which suggest that rainfall correlation is unlikely to give increased precision to the analyses presented below, are contained in Appendix 4. Additionally, flood flows in the Meki were briefly investigated.

TABLE 13 Hydrological data used in the analysis of water resources

River/Lake	Station	Record type	Record used
Meki River	Meki town	Monthly discharge	May 1963 – Dec. 1972
		Daily discharge	Jan. 1964 – Dec. 1968
			Jan. 1970 – Dec. 1972*
Catar River	Ogelcho (Abura)	Monthly discharge	Aug. 1968 – Dec. 1972
Bulbula River	Bulbula	Monthly discharge	Jan. 1969 – Dec. 1972
Gogessa River	Gogessa	Monthly discharge	Jan. 1969 – Dec. 1972
Lake Zwai	Zwai Town	Monthly levels	Aug. 1967 – Dec. 1973*
Lake Abiyata	Near Bulbula	Monthly levels	Sept. 1968 – Dec. 1973*
Lake Langano	Near Bekele Mola Hotel	Monthly levels	Sept. 1968 – Dec. 1973*

*Records containing some missing values: estimates were made of these values by linear interpolation

TABLE 14 Rainfall data used in the analysis of water resources

Station	Elevation m (a.s.l.)	Catchment	Record used
Addis Ababa	2 410	Awash	1948–72
Butajira	2 100	Meki	1955–60; 1972
Egerssa	1 800	Meki	1967–72
Silte	2 100	Meki	1953–64
Adamitulu	1 650	Lake Zwai	1958–69
Meki	1 680	Lake Zwai	1965–72
Ogelcho	1 700	Lake Zwai	1967–72
Asella	2 370	Catar	1965–62; 1966–72
Bokoji	2 720	Catar	1963–72
Kersa	2 680	Catar	1967–72
Lemu	2 520	Catar	1956–61; 1965–72
Sagure	2 460	Catar	1967–72

Annual flows

The nine values of annual discharge in the Meki are plotted on Figure 7. This shows that a normal probability distribution would appear to fit the values reasonably well. Thus, assuming a normal distribution and statistical independence between successive annual totals, the following propositions can be advanced:

1. The mean annual discharge is 350 mcm. Since the distribution is assumed to be normal, this is also the estimate of the 1 in 2–year flow. The 95% confidence limits are about 257 and 443 mcm

2. The annual discharge that is exceeded four years in five is 248 mcm and the approximate 95% confidence limits are 154 and 342 mcm.

3. The estimate of the annual discharge that is exceeded nine years in ten is 195 mcm and the approximate 95% confidence limits are 86 and 304 mcm

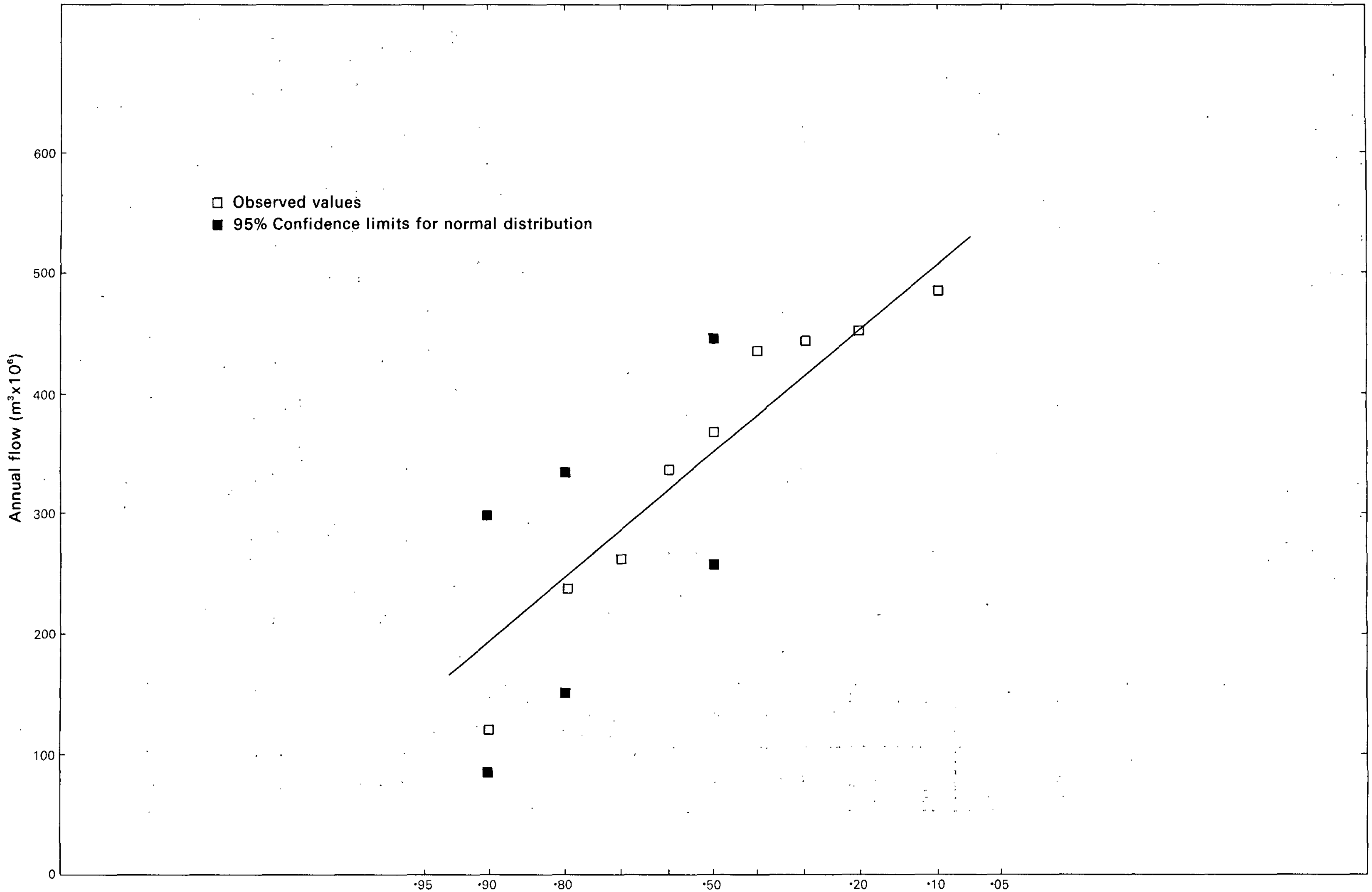

FIGURE 7

FIGURE 7 Probability plot: annual flows in the Meki River at Meki Town, 1964-72 (after McKerchar and Douglas, 1974)

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Using an autoregressive (time series) model, a 100-year sequence of synthetic monthly flows was produced and used to calculate annual flows. From a normal probability plot of the annual flows, the discharges expected to be exceeded 1 year in 2, 4 years in 5 and 9 years in 10 were computed as 338, 249 and 228 mcm respectively. Although not identical to the values estimated above from the nine full years of historic data, they fall well within the 95% confidence limits. This is verification of the estimate based on the recorded data series.

Monthly flows

The record of mean monthly flows is given in Table 15, together with monthly standard deviations, skewness, month to month correlation coefficients and the coefficients of variation.

TABLE 15 Statistics of monthly flows (May 1963 – December 1972) for the Meki River at Meki Town

Month	Mean flow (mcm)	Standard deviation (mcm)	Skewness coefficient	Month to month correlations	Coefficient of variation	No. of observations
Jan.	3.95	3.93	1.63	0.21	0.995	9
Feb.	9.66	9.92	0.85	0.27	1.027	9
Mar.	20.34	23.86	0.86	0.76	1.173	9
April	30.85	31.63	0.87	0.53	1.025	9
May	30.71	26.84	0.57	0.50	0.874	10
June	15.11	14.01	1.96	0.06	0.927	10
July	53.84	29.03	0.20	0.71	0.539	10
Aug.	91.94	36.97	0.50	0.91	0.402	10
Sept.	56.01	15.94	–0.14	0.55	0.285	10
Oct.	22.48	11.81	0.92	–0.28	0.525	10
Nov.	9.47	14.16	2.92	0.70	1.494	10
Dec.	3.87	3.22	1.23	0.82	0.832	10

Mean annual flow (5/63 – 12/72) = 350 mcm
Annual standard deviation (5/63 – 12/72) = 121 mcm

All the statistics show a large seasonal variation, from which it can be deduced that monthly flows (a) follow a skewed frequency distribution, and (b) are serially correlated. The coefficient of variation is least between July and October when the most reliable flows can be expected. The mean monthly flows (in Table 15) have been plotted on Figure 8, together with estimates of low flows at the three levels of probability selected. Although the data series is too short to determine the type of probability distribution best suited to represented the flows, the fact that all but one of the skewness coefficients are positive suggests the use of a skewed distribution. Hence the log-normal distribution has been used and the low flows of given return periods calculated for each month. Care is needed in interpretation however, since flows have been calculated from nine (or 10) years of record and no account has been taken of the flows in the preceding or following months. Since, however, it has been shown (Table 15) that there is generally a strong correlation between successive monthly flows, the probability of experiencing successive low flows must in practice be significantly greater than would appear from Figure 8. For example, there is a chance that once in 10 years the flow in January will be zero. Likewise, there is the same chance (once in 10 years) that the flow will be zero in February. However, the probability that the flow in any one year will be zero in both January and February is not the product of the two chances, i.e. once in 100 years (which would be the case if month to month flows were not correlated), but is a rather more likely event.

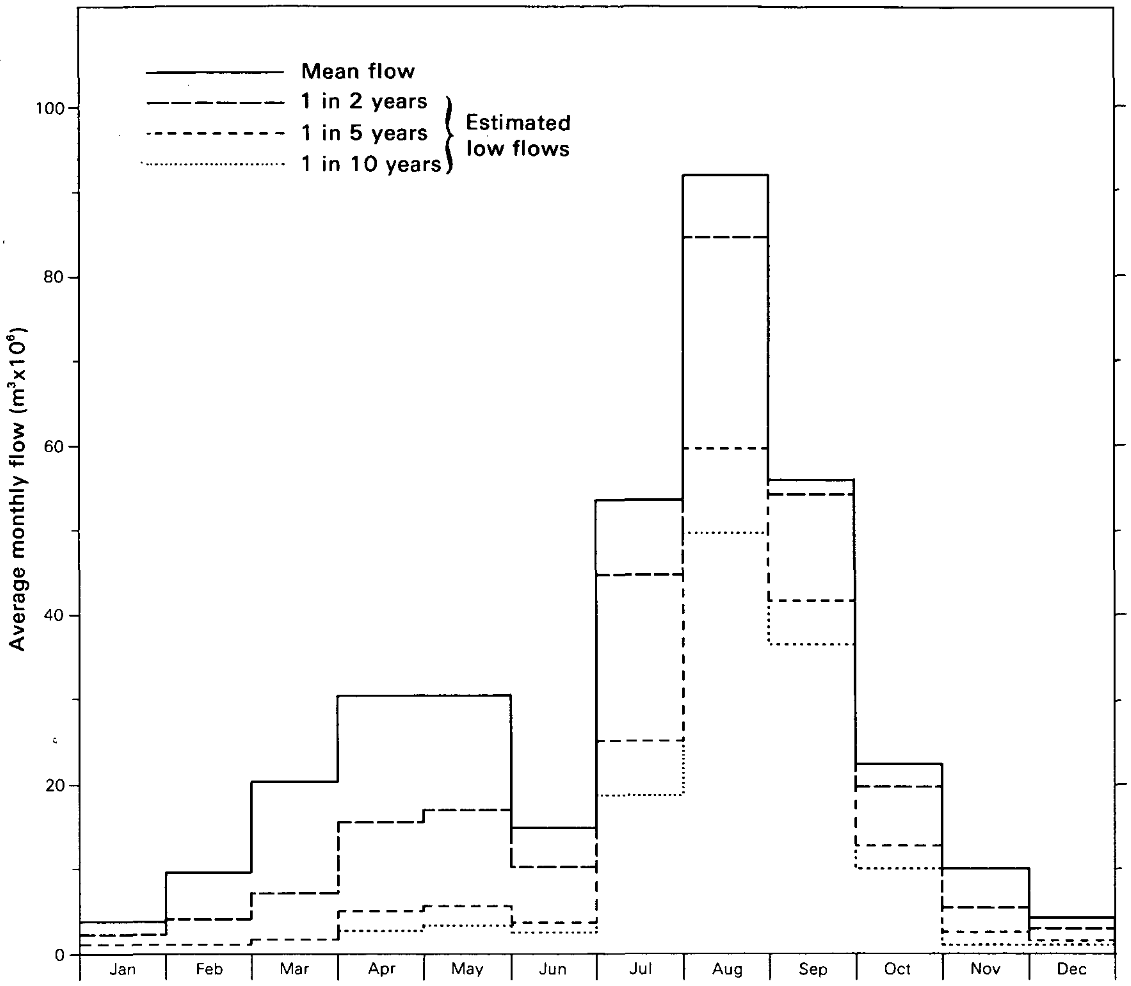

FIGURE 8 Monthly flows in the Meki River at Meki Town (May 1963-Dec 1972) (after McKerchar and Douglas, 1974)

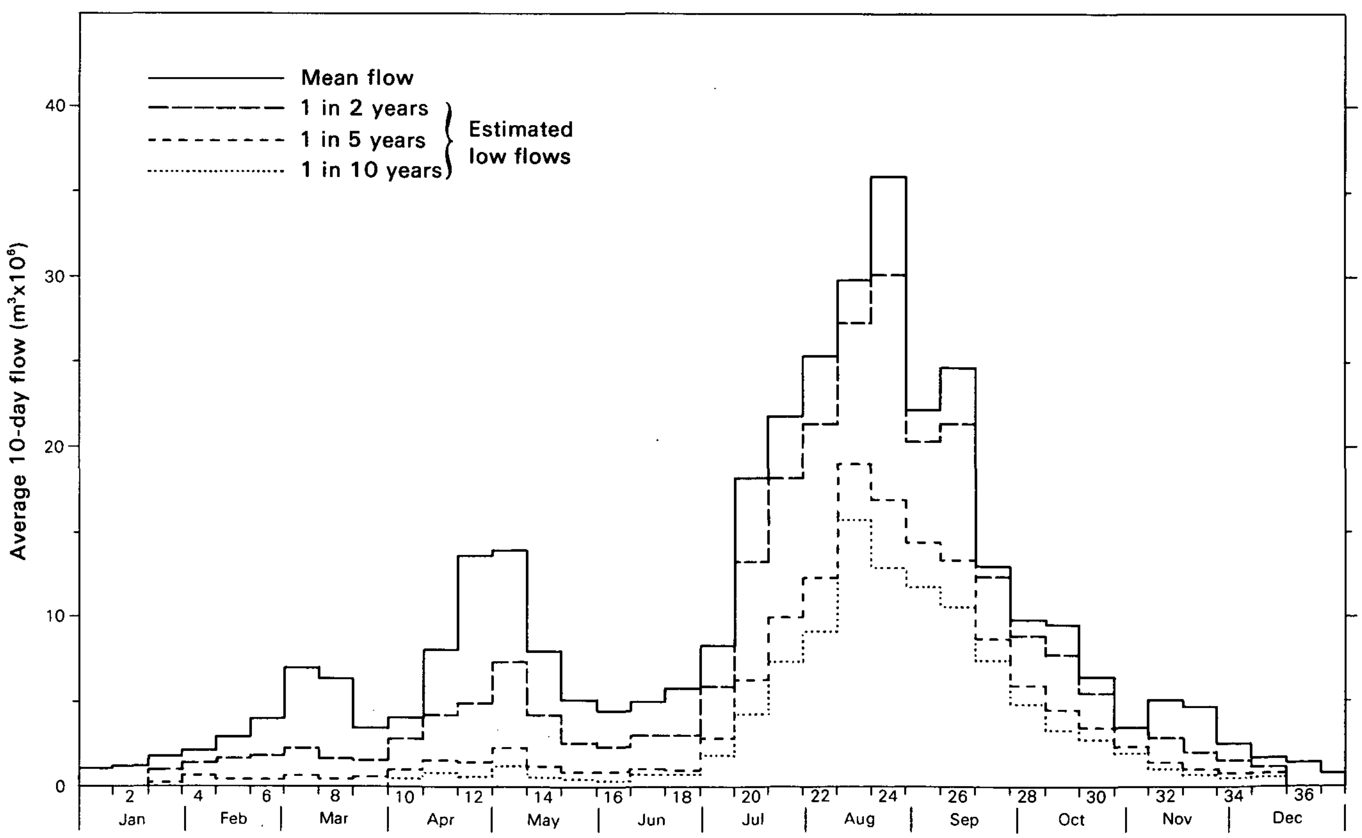

FIGURE 9 Ten-day flows in the Meki River at Meki Town (1965-68, 1970-72) (after McKerchar and Douglas, 1974)

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Ten-day flows

The mean flow for each 10-day period of the year (10-day flows) was calculated from the daily discharge data for 1965–8 and 1970–2. Daily records could not be traced for 1969. Each year has been divided into 36 10-day periods, with a five-day period at the end of the year. Statistics for these 10-day periods are given in Table 16, which shows the seasonal nature of the flow regime. The coefficients of variation are lowest between July and the end of October (periods 20–31) because the flow in the rainy season is the most reliable. A log-normal distribution has again been used for each 10-day period (justified by the generally positive skewness coefficients) to determine the flows which may be exceeded 1 year in 2, 4 years in 5 and 9 years in 10. The results are plotted on Figure 9.

TABLE 16 Statistics of 10-day flows (1965–8; 1970–2) for the Meki River at Meki Town

Ten-day period	Mean discharge (mcm)	Standard deviation (mcm)	Skewness coefficient	Inter-period correlation	Coefficient of variation	No. of observations
1	1.09	1.14	2.17	0.99	1.055	7
2	1.25	1.18	1.16	0.46	0.944	7
3	1.87	2.80	2.36	0.90	1.500	7
4	2.16	1.65	0.35	0.37	0.761	7
5	2.95	3.20	1.18	0.74	1.085	7
6	3.81	3.67	0.66	0.93	0.964	7
7	6.97	8.72	1.27	0.58	1.252	7
8	6.34	8.57	1.21	0.96	1.351	7
9	3.45	3.69	0.71	0.93	1.068	7
10	4.04	4.05	1.15	0.65	1.001	7
11	8.05	8.72	1.10	0.91	1.083	7
12	13.53	18.44	1.63	0.97	1.363	7
13	13.84	15.40	1.85	0.94	1.112	7
14	7.81	7.57	1.10	0.58	0.969	7
15	5.20	4.63	0.14	0.81	0.890	7
16	4.54	3.88	0.16	0.73	0.854	7
17	4.92	6.11	2.34	0.78	1.243	7
18	5.61	6.27	1.61	0.93	1.117	7
19	8.15	6.24	0.67	0.94	0.766	7
20	18.03	12.90	0.15	0.84	0.715	7
21	21.65	13.59	0.74	0.93	0.628	7
22	25.16	14.27	0.65	0.61	0.567	7
23	29.66	15.07	2.02	0.77	0.508	7
24	35.83	23.63	1.14	0.41	0.660	7
25	22.05	9.81	1.14	0.88	0.445	7
26	24.44	13.17	0.56	0.30	0.539	7
27	12.89	4.12	–1.06	0.19	0.319	7
28	9.64	3.68	–0.76	0.73	0.381	7
29	9.38	6.92	1.32	0.12	0.738	7
30	6.28	3.90	1.31	0.14	0.620	7
31	3.37	1.34	–0.23	0.82	0.397	7
32	4.97	7.43	2.57	0.59	1.496	7
33	4.42	7.04	2.46	0.99	1.592	7
34	2.41	3.00	2.23	0.99	1.247	7
35	1.63	1.32	1.25	0.96	0.814	7
36	1.13	0.77	0.34	0.72	0.679	7
37 (5 days)	0.63	0.65	1.98	0.89	1.019	7

Mean annual flow (1965–8; 1970–2) = 339 mcm
Annual standard deviation (1965–8; 1970–2) = 115 mcm

The 10-day flow data give a better indication of the seasonal distribution of flow than the monthly analysis, but individual statistics are less reliable since they are estimated from seven as opposed to nine or 10 years of data. However, the annual mean flow and its standard deviation for the seven years (339 and 115 mcm respectively) are not very different from the values of 350 and 121 mcm which were obtained from the longer sequence used in the monthly analysis.

The correlation between successive 10-day flow totals is even greater than the correlation between monthly flows. Consequently, the precaution (discussed above) concerning the joint probability of two or more successive low flows applies to even greater effect.

Flood flows

The shortest period for which discharge data are available on the Meki River is 24 hours; the annual values of the maximum daily discharge during the 11 years since records started is given in Table 17.

TABLE 17 Annual maxima of average discharge during 24 hours (May 1963—December 1973) for the Meki River at Meki Town

Year	Discharge (m^3/s)
1963	141.0
1964	93.3
1965	75.0
1966	97.9
1967	70.2
1968	118.8
1969	112.3
1970	114.6
1971	122.4
1972	104.3
1973	117.4
Mean	106.1
Standard deviation	19.9

There is some doubt about the accuracy of these values which lie along an extrapolated section of the rating curve, since in recent years discharge measurements do not appear to have been made during floods. The highest measurement is recorded as 101.6 m^3/s on 8 August 1964 (AVA, 1973), but there are known to have been shifts in the control of the gauging section. A second gauging station (Meki 1 – see Text Map 2) was installed 5 km upstream of Meki in 1968; the published flood discharges for this station are about 42% lower than those recorded at Meki. This suggests that the maximum Meki discharges in Table 17 could be overstated. They are, however, the best available series of unrelated flood events and these have been used to estimate flood flows of a given return period. By applying Gumbel's method, the following equation for floods in the Meki has been derived:

> Flood discharge (m^3/s) = $15.5\,y + 97.2$, where y is the reduced variable which has the values set out in Table 18, depending on the return period under investigation.

TABLE 18 Estimated flood discharges in the Meki River for given return periods

Return period (years)	Reduced variable (y)	Flood discharges (m^3/s)
50	3.9	157.6
100	4.6	168.5
250	5.5	182.4
500	6.2	193.3
1 000	6.8	202.6

Caution should be exercised in interpretation of the data in Table 18, in view of the doubts about the accuracy of the published data and the short period they span. Determination of maximum (instantaneous) discharge from maximum daily discharge is difficult since there are no continuous hydrograph records of discharge at Meki. It has been suggested (Italconsult, 1970) that the ratio of average daily to maximum discharge for the Meki could be 1:1.5 but, since the published daily discharges may be too high during floods, estimated maximum daily discharges of given return periods can also be considered as maximum instantaneous discharges at a given level of probability. While there is no recent evidence to contradict the assumptions made by Italconsult, in view of the element of doubt relating to these assumptions it would be safer to base designs on maximum daily discharges having a very low chance of occurrence. Accordingly, a conservative figure of 200 m^3/s has been selected for the design of flood control works on the Meki Delta (described in Part 6).

Prospects for storage in the Meki catchment

Figures 8 and 9 show that only very low discharges can be expected in the Meki River with any degree of reliability between mid-November and the end of March. Consequently there can be no prospect for year-round, large-scale irrigation either in the mid-Meki Valley or on the Meki Delta based on run-of-river flows.

Although part of the Delta can be irrigated economically using water pumped from Lake Zwai, the alternative of river regulation by construction of storage reservoirs has also been briefly investigated. Prospects for storage are limited to the upper reaches of the catchment west of the main Addis Ababa to Butajira Road (Text Map 2). Here the flow is almost equally divided between three perennial rivers, the Meki, the Lebu and the Akomoja. Possible sites for storage on the three rivers (Text Map 5) have been located using aerial photographs and provisional maps at 1:50 000 prepared by the SMD, followed by a brief visit to each site. There are no measurements of flow on any of the three rivers but, from knowledge of the catchment areas upstream and the total flow in the Meki River, combined with consideration of the topography as shown on the SMD sheets and plotted on Text Map 5, the possible yields of storage reservoirs constructed on each of the rivers have been estimated (Table 19).

TABLE 19 Estimated annual yields of possible storage reservoirs on the Upper Meki, estimated areas that could be irrigated downstream, and cost per cubic metre of water stored

Storage site	River	Estimated yield (mcm)	Irrigable area (ha)	Estimated cost of stored water ($/$m^3$)
1	Meki	30	2 500	0.19
2	Lebu	10	850	no estimate
3	Akomoja	15	1 250	0.50
Costs of dam construction are estimated from data used by Jovanovic (1972) updated to 1974 price levels				

None of the reservoirs alone would be sufficient to water all the potentially irrigable land on the Meki Delta, let alone in the mid-Meki Valley. Site 1 offers the greatest yield, requiring a simple rockfill dam about 30 m high. The foundation would be on rock and only a limited amount of grouting should be required to make an adequate cut-off. A reinforced concrete apron on the upstream face is envisaged. The spillway could conveniently be located to the west of the sam where a low col limits the maximum level to which water can be stored. The estimated cost of a reservoir at Site 1 is about $5.75 million (at 1974 prices). Construction of a storage reservoir at this site would not eliminate flooding on the Meki Delta, although it would reduce the extent and cost of flood control works (see Part 6).

Storage site number	River	Height of dam m	Top water level m (a.s.l.)	Area at T.W.L. ha	1:50,000 Series SMD 4 Sheet number and title
1	Meki	20	1980	130	0838 D1 BUI
		30	1990	300	
2	Lebu	15	1915	100	0838 C4 BUTAJIRA
3	Akomoja	30	2040	95	0838 C4 BUTAJIRA

The maximum water level of a reservoir at Site 2 would be governed by the land elevation to the north. The reservoir would be contained within a former crater now partially filled with river sediment, and would require construction of a dam at a point where the river breaches the crater wall close to the main road. The geology of this site does not look promising and the cost of construction is likely to be high in relation to the small volume of storage. In view of the uncertainties governing the dam site, river flow and choice of structure, no cost estimate has been made.

Site 3, on the Akomoja River, would require a wide (500 m at crest) and moderately high (30 m) dam to store a reasonable volume of water. It should be possible to found the dam on rock and a rockfill construction similar to that proposed at Site 1 could be used. However, due to the greater volume of rock-fill required for the dam, the cost would be higher and is estimated at about $7.5 million to give a storage volume only half that at Site 1.

On the basis of this initial investigation, it is recommended that a detailed topographic survey be undertaken of the area of the reservoir at Site 1, to determine more accurately the size of dam required, its construction cost and the annual yield that could be achieved. The survey should map the reservoir site at 1:5 000 and the dam site cross-section at 1: 1 000. A contour interval of 2 m would be used in both cases. It is further recommended that measurements of river discharge are initiated at an early stage, at a site close to the bridge where the main Addis Ababa road crosses the Meki about 7 km south of Bui. The nature of the river in this reach, with its rocky bed and moderately steep gradients would, however, make accurate current metering difficult during low flows. Should it prove impracticable to use this method (though trials could first be made with a pygmy meter), it will be necessary to measure the flow over a fixed weir constructed on the river bed. In any event, twice-daily observations of river stage should be started as soon as possible. No further surveys are recommended at this time at Sites 2 or 3 in view of the relatively high estimates of capital cost.

Analysis of the natural flows in the Meki River has shown that, during a substantial portion of the year, reliable discharges are extremely low. Consequently, development of run-of-river irrigation in the Meki catchment must be limited to only a few hundred hectares. Analysis of a longer sequence of flows derived from rainfall correlations did not increase the precision of calculations made on the basis of the 10 years of recorded data. Since it would be necessary to increase the flows during periods of maximum irrigation demand if a significant proportion of the irrigable land in the catchment were to be developed, consideration has been given to the possibility of flow regulation by means of storage dams upstream. However, it is concluded, in the light of the limited information relating to the possible storage sites, that river regulation for irrigation could prove uneconomic, especially since the cost of regulation in the upper catchment would have to be augmented by the cost of complementary works downstream, e.g. a diversion weir, main feeder canals and associated structures.

LAKE ZWAI

An estimate is presented in this section of the amount of water that can be abstracted from Lake Zwai without significantly affecting total flows in the Bulbula River. The hydro-meteorological data used in the analyses are contained in Appendixes 1, 3 and 4. Reliable evaporation data for Zwai were lacking however. Hence mean monthly Penman Estimates of evaporation at Wonji (30 km north-east of Meki Town in the Awash catchment) were reduced to allow for the small difference in altitude between Zwai and Wonji (evaporation varies by about 20 mm per 100 m change in elevation in the Awash catchment) to give estimates of monthly evaporation from Lake Zwai (Table 20).

TABLE 20 Estimates of monthly evaporation (mm) from Lake Zwai

J	F	M	A	M	J	J	A	S	O	N	D	Total
163	154	194	179	201	179	154	154	142	175	159	158	2 012

Webb (1966) has presented a simple method for determining evaporation from lake surfaces using the results of evaporation measured from a pan on the shore. The method derives a pan factor based on the relative temperatures of the lake and the pan, and the vapour pressure of the air at a fixed height (4 m suggested) above the pan. Consideration should be given to applying this method at Zwai in future.

The storage-capacity curve of Lake Zwai (Figure 4) was computed from contours of the lake bed (Separate Map 4); storage variations resulting from changes in lake level and area were obtained from lake level data (published by AVA) and from the level/storage relationship derived by Italconsult (1970).

Water can be made available for irrigation around Zwai without decreasing the outflow in the Bulbula River by the expedient of reducing evaporation from the lake surface. This can be achieved by decreasing the surface area of the lake, but any such reduction is inevitably accompanied by a lowering of the lake level (Figure 4), which is incompatible with maintenance of the Bulbula flow unless the relationship between lake level and outflow can be altered. This in turn can only be achieved by lowering the lava rock sill across the Bulbula River (6 km downstream from Lake Zwai) and by adequate deepening of the upper section of the Bulbula channel including part of the lake bed near the outlet.

Estimates of the available water from Lake Zwai were determined in two stages. First the four years of flow records from 1969–72 were used to determine the amount of water that could be abstracted from the lake under a variety of conditions: with the Bulbula channel unchanged, with the Bulbula channel deepened, but without outlet control sluices and with the Bulbula channel deepened and the outflow controlled by sluices. The results of the third condition were further investigated using reconstructed 20-year records of flows and rainfall.

The water balance of Lake Zwai can be summarised thus:

> Meki flow + Catar flow + rain on lake = evaporation + Bulbula flow + change in storage (volume); (inflow = outflow + change of storage).

It is evident that, in order to provide water for abstraction, there must be a reduction in evaporation; since in the long term overall flows should remain the same and the storage change term will tend to zero.

The water balance equation was used to predict abstraction volumes for irrigation. By arranging the equation to give evaporation in terms of the other variables (and assuming no abstraction), the reduction in evaporation losses resulting from lower levels of Lake Zwai was computed and is shown in Figure 10. During the four-year period January 1969 to December 1972, the mean annual evaporation was 970 mcm (2 016 mm). If, however, the lake level had been 2.4 m lower (as suggested by (Italconsult), the loss of water would have been reduced to 649 mcm (a difference of 321 mcm). This is not the amount of water that would have been available for abstraction, since it would have been physically impossible to maintain the Bulbula flow at the lower lake levels. Consideration of irrigation potential must therefore take account of the outflow characteristic of Lake Zwai and its relationship to flow in the Bulbula.

Estimation of irrigation potential

Bulbula channel unchanged

Figure 11 (the outflow characteristic curve) shows that, unless the rock bar is removed, thereby changing the relationship between lake level and outflow, a reduction in lake level due to abstraction will inevitably lead to reduced Bulbula flows. Table 21 shows the effect various rates of abstraction would have had on the Bulbula flow in 1972, assuming that the demand for irrigation water were spread evenly over the year (1972 has been chosen as the year nearest to steady-state conditions). All lake levels refer to the AVA staff gauge at Zwai.

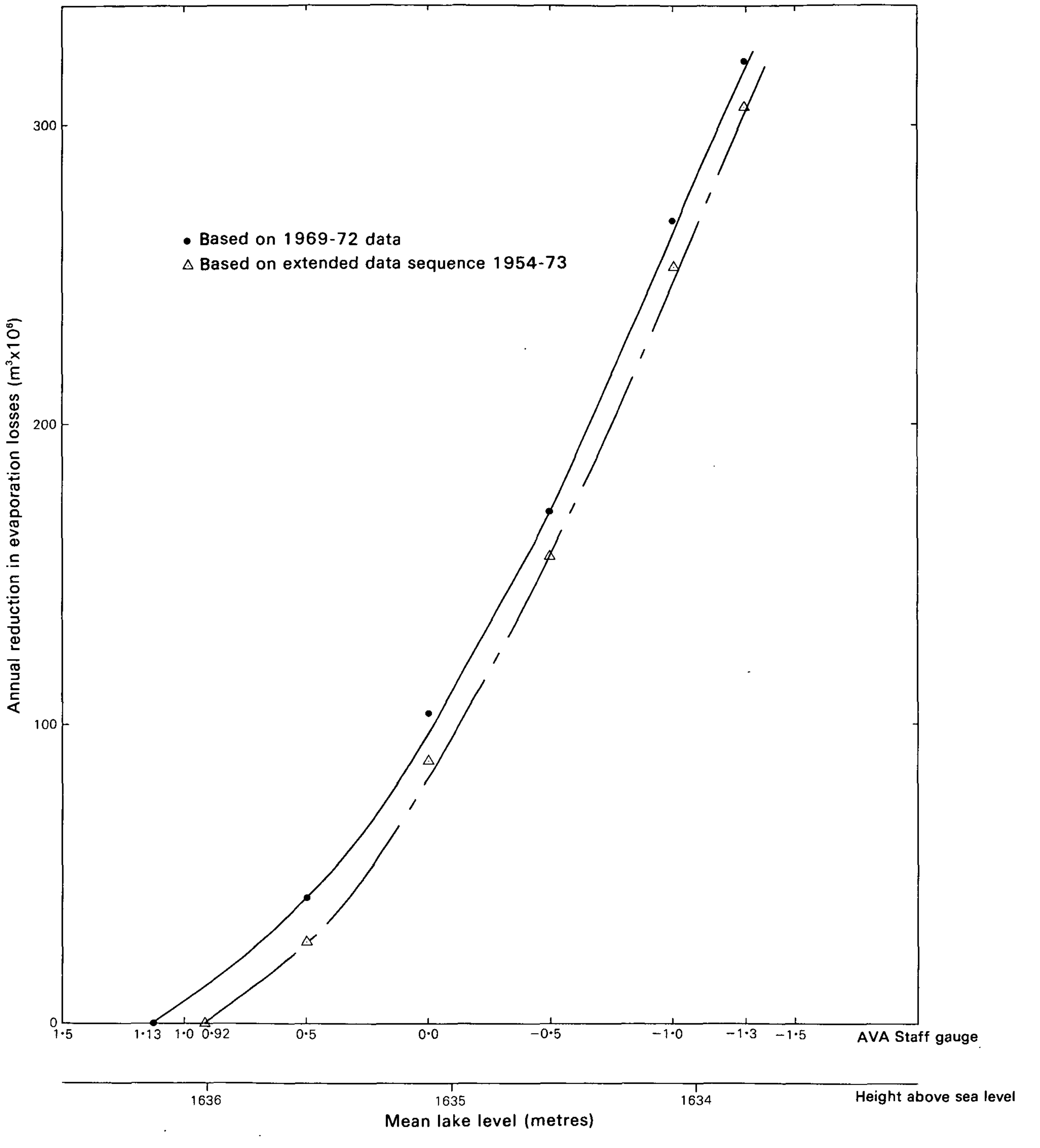

FIGURE 10 Reduction in evaporation losses resulting from a lowering of the mean level of Lake Zwai (after McKerchar and Douglas, 1974)

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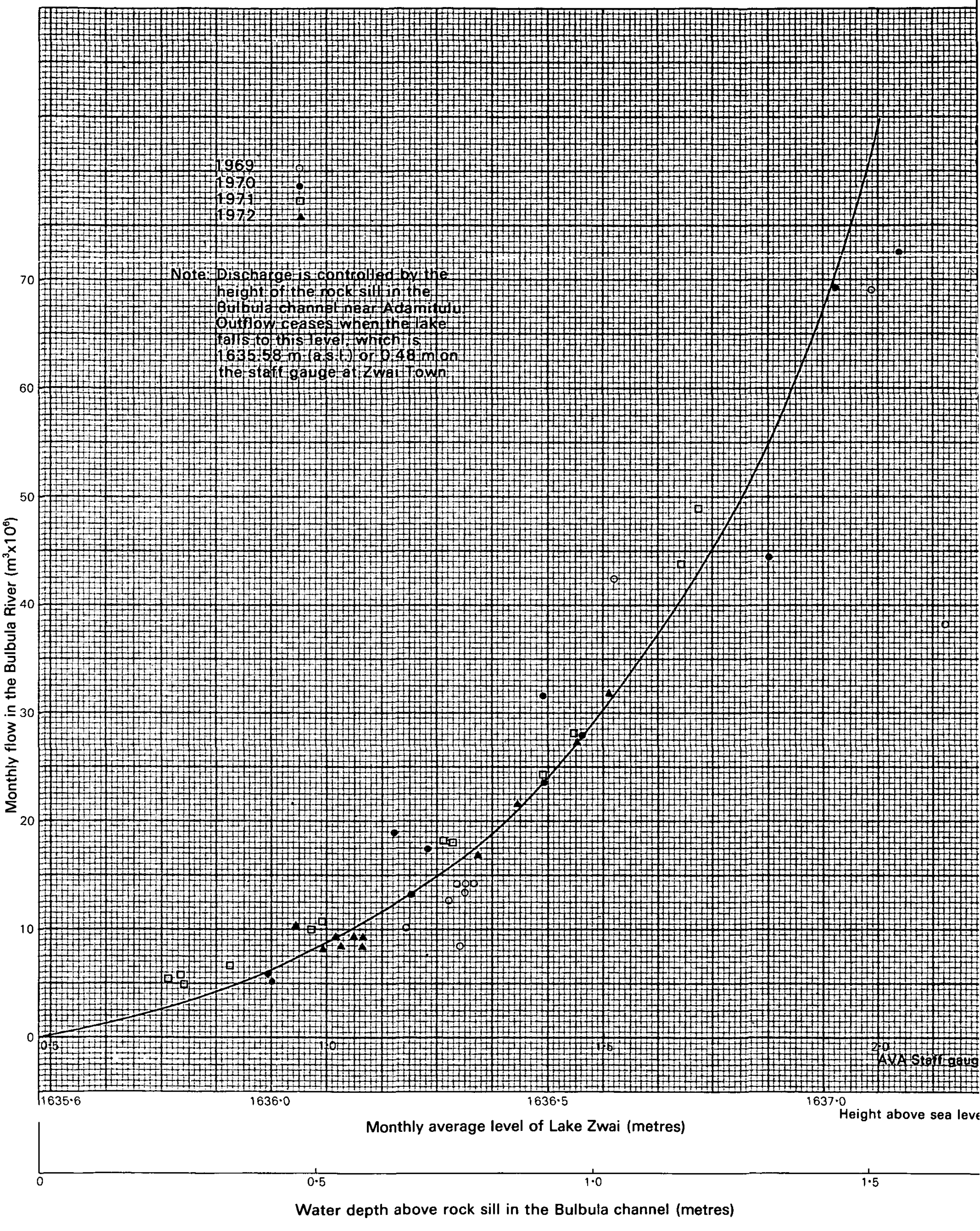

FIGURE 11 Relationship between the level of Lake Zwai and monthly outflows in the Bulbula River (after McKerchar and Douglas, 1974)

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TABLE 21 Projections of the effect of various hypothetical rates of abstraction from Lake Zwai for 1972

Abstraction for irrigation (mcm)	Reduction of Bulbula flow (mcm)	Reduction in lake evaporation (mcm)	Average lake level (m)
0	0	0	1.14
48	34	6	*
96	65	14	*
144	92	25	*
192	114	39	*
240	131	57	0.37 decreasing

*not calculated
1972 Bulbula flow = 176 mcm; lake evaporation = 960 mcm.

Table 21 shows that if 240 mcm had been abstracted for irrigation in 1972, as much as 131 mcm would have been at the expense of the Bulbula, with only 57 mcm derived from a reduction in evaporation; the remaining 52 mcm would have been obtained by depletion of lake storage. A similar pattern would hold for other abstraction rates, because outflow is more sensitive to lake level than is lake area and hence evaporation loss. The greater part of any abstraction is inevitably supplied at the expense of Bulbula flow. The extent to which Bulbula flow can be depleted depends on the social impact this would have along the course of the river as well as the effect on Lake Abiyata; these factors are discussed below and in Part 7.

Bulbula channel deepened

Table 22 lists the mean annual quantity of water that would have been available for irrigation in the 1969–72 period for six different levels of the lake provided that the Bulbula channel had been deepened sufficiently to maintain the monthly flows actually recorded in the Bulbula during the period. It has been assumed that the Bulbula flow is directly related to the difference in level between lake surface and the bed of the river, and that a relationship similar to that shown in Figure 11 would apply once the bed had been lowered (in practice the relationship would vary depending on the profile of the control. Figure 11 is based on the lava rock sill acting as control; whereas, following removal of the sill, flow in the Bulbula would be controlled by the level of the lake bed at the Bulbula outlet).

By combining the relationship of lake level to Bulbula outflow (Figure 11) with the relationship between lake level and the volume of storage in the lake (Figure 4) the relationship between lake volume and Bulbula outflow was obtained. Then for each month in the period January 1969 to December 1972, the changes in Lake Zwai storage necessary to maintain flows in the Bulbula River at lower average lake levels of 0.5, 0.0, – 0.5, – 1.0 and – 1.3 m (on the AVA gauge at Zwai) were determined from the monthly average recorded values of lake level. By applying the Zwai water balance equation, the surplus water available for irrigation each month at the lower lake levels was determined; these data enabled mean annual abstraction values to be computed (Table 22).

TABLE 22 Mean annual potential abstraction at various lake levels for the period 1969–72

Mean lake level (m)	Potential abstraction (mcm)
1.13	0.0
0.50	24.7
0.00	64.9
–0.50	103.0
–1.00	154.6
–1.30	191.3

Having established the annual total quantity of water that would have been available for abstraction, two different seasonal patterns of abstraction were tested to determine their effect on the Bulbula flow. Firstly it was assumed that abstraction would be at a constant rate throughout the year. Secondly it was assumed that the same annual quantity of water would be abstracted in the four months October to January only, in proportions 15%, 30%, 35% and 20% respectively of the annual total, this being the seasonal demand pattern for vegetables in the upper part of the Awash Valley. The effects of these regular and seasonal abstractions are given in Table 23.

TABLE 23 **The effect of various annual abstraction quantities on Lake Zwai level and Bulbula River flow based on data for 1969–72, assuming deepening of the Bulbula Channel without flow control sluices (a) with constant monthly abstraction and (b) with seasonal abstraction (October-January only)**

Annual total abstraction (mcm)	Change in annual Bulbula flow (mcm)	Change in dry-season flow (mcm)	Change in wet-season flow (mcm)	Predicted mean lake level (m)	Change in river-bed level (m)
Constant monthly abstraction					
0	0	0	0	1.13	0
25	+88	+25	+63	0.55	–0.6
65	+106	+13	+93	0.04	–1.1
103	+78	–26	+103	–0.39	–1.5
155	+42	–61	+103	–0.84	–1.9
191	+51	– 76	+128	–1.15	–2.2
Seasonal abstraction					
0	0	0	0	1.13	0
25	+100	+21	+78	0.55	–0.6
65	+136	+1	+134	0.03	–1.1
103	+128	–44	+172	–0.40	–1.5
155	+126	–90	+215	–0.86	–1.9
191	+158	–108	+266	–1.18	–2.2
Mean annual Bulbula flow (1969–72) = 265 mcm					

For the purpose of this calculation, the dry season has been considered to be from December to July and the wet season from August to November

Table 23 suggests two things:

1. That regardless of the pattern of abstraction, channel deepening alone would cause a net increase in flows in the Bulbula of up to 15%. This increase would almost entirely occur during the months August to November (the increase during these four months being as high as 39%) and would be only partially compensated by a decrease of up to 25% in dry season flows. Such a situation would be unacceptable since the total Bulbula flow into Lake Abiyata would be increased over and above its present level. Moreover, the rates of flow would be excessive for part of the year and too low at other times; such a flow pattern might cause flooding in September or October, whilst reduced low flows could cause the Bulbula to dry up regularly during the early part of the year. These undesirable consequences of lowering the Bulbula channel could be rectified by controlling the lake level and outflow with sluices.

2. That seasonal abstraction (October to January only) would cause a greater depletion of dry season Bulbula flows and increased wet season flows than in the case of constant monthly abstraction.

Bulbula channel deepened and flow controlled by sluices

Initially for the purpose of analysis the assumption was made that sluices would regulate the outflow at a constant rate each month. The mean monthly flow in the Bulbula for the four-year period 1969–72 was about 22.1 mcm, representing an instantaneous discharge rate of about 9 m^3/s; this figure was used in the calculations. Irrigation abstraction was assumed to be confined to the months October–January as in the previous section. The effect, under these conditions, of controlling the outflow of the lake is shown in Table 24.

TABLE 24 Deepening of the Bulbula river channel required to maintain flow at various levels of abstraction, when uncontrolled or when controlled by sluices

Annual abstraction (mcm)	Flow uncontrolled		Flow controlled by sluices	
	Mean lake level (m)	Deepening of river bed (m)	Mean lake level (m)	Deepening of river bed (m)
25	0.55	–0.6	0.74	–1.1
65	0.03	–1.1	0.26	–1.6
103	–0.40	–1.5	–0.21	–2.1
155	–0.86	–1.9	–0.67	–2.6
191	–1.18	–2.2	–0.96	–2.9
250	-	-	–1.16	–3.2

Table 24 shows that a controlled outflow, as compared to an uncontrolled flow through a deepened channel, would result in higher lake levels whatever the rate of abstraction. However, to maintain desired flows through the dry season (when the lake would be at its lowest level) it would be necessary to lower the Bulbula bed by rather more than if flows were uncontrolled. Figure 11 shows that a minimum lake level on the AVA staff gauge of 1.37 m (relating to a minimum water depth above the control in the Bulbula of 0.9 m) is required to produce an outflow rate of 22.1 mcm per month. To achieve this constant outflow, the bed level in the Bulbula would therefore have to be 0.9 m lower than the minimum predicted lake level.

Having established that the only feasible method by which significant quantities of water can be made available for abstraction is by deepening the Bulbula channel and controlling the outflow with sluices, further calculations were made (a) to determine whether the data series available (1969–72) was representative of longer–term conditions and (b) to test various operating rules for discharges into the Bulbula.

Extended data series

A derived sequence of lake levels has been projected for the 20-year period 1965–73 (Appendix 4). Figure 12 shows the projected lake levels over this period and compares them with actual observations on the staff gauge. The following conclusions have been drawn:

1. The long-term (20-year average) flow in the Bulbula River is 4.6 mcm (21%) per month less than the 1969–72 data would suggest. The projected mean annual flow is 210 mcm (17.5 mcm/month).

2. The projected mean lake level during the 20 years (referred to the AVA staff gauge) was 0.92 m compared with 1.13 m over the 1969–72 period.

3. There is some suggestion of long-term periodicity in the variation in lake level, though the series is too short to predict cycles with any confidence. The possible existence of cycles however renders short-term regulation of flows in the Bulbula difficult. The seasonal variation superimposed on the longer-term variations identified in the 20-year series suggests a total natural variation in lake level of about 2.2 m.

4. The extended data sequence suggests that the amount of water available for abstraction will be less than that calculated from the 1969–72 data and Figure 10 has been revised to indicate the reduction in evaporation losses based on the longer sequence. The graph shows the ultimate amount of water available for abstraction and should not be confused with the amount of water which can actually be abstracted, since in practice several constraints serve to limit outflow in the Bulbula, e.g.:

   i. Inability to predict future lake inflows

   ii. The expense of lowering the Bulbula river channel sufficiently to give complete control over flows at all times

   iii. A desire to reduce the variability of monthly flows in the Bulbula River.

Given these constraints, it is apparent that selection of a suitable operating rule is critical for maximising the amount of water available for abstraction.

Operating rules

Four possible rules have been investigated. For each rule the effect was determined of abstractions in the range 25 to 250 mcm/annum, with Bulbula channel deepenings of 0.5, 1.0, 1.5, 2.0 and 2.5 m, on flows in the Bulbula River and on the level of Lake Zwai. A condition applicable to all the rules is that the long-term total flow in the Bulbula should not vary from the naturally occurring long-term average flow (210 mcm/annum). Owing, however, to considerable variations in flows into the lake from year to year, annual outflows will also have to be allowed to vary. Consequently, dredging the Bulbula Channel and the lake outflow could be less than if outflows were regulated to pass 210 mcm every year.

The operating rules considered were:

1. Release of 17.5 mcm/month (6.75 m^3/s), the derived 20-year average monthly flow in the Bulbula River, provided there is sufficient head, i.e. a minimum water depth in the Bulbula channel of about 0.8 m. At times when the depth is less than this, the release flow is computed in accordance with the outflow characteristic curve (Figure 11) for the head available.

2. If on 1 January the lake level is above average (0.92 m on the AVA staff gauge), release of 25 mcm/month (9.65 m^3/s) throughout the year provided there is sufficient head. On the other hand, if the lake level is below average on 1 January, release of 17.5 mcm/month (6.75 m^3/s) throughout the year provided there is sufficient head. In either case, if the head is insufficient at any time during the year to permit the desired discharge, release of the maximum flow possible with the head available.

3. Similar to Rule 2 except that if on 1 January the lake level is above average, release of 30 mcm/month (11.57 m^3/s) throughout the year if sufficient head is available. Alternatively, if the lake level is below average on 1 January, release of 12.5 mcm/month (4.82 m^3/s) throughout the year if sufficient head is available. In either case, if the head is insufficient at any time during the year to permit the desired discharge, release of the maximum flow possible with the head available.

4. Release of flows in accordance with the naturally occurring pattern of average monthly flows, as shown in Table 25, but exceeding the average flows by up to 50% depending on the head available. In this way, releases are increased in years of high lake level. The long-term average release would however be similar to that under natural conditions.

FIGURE 12

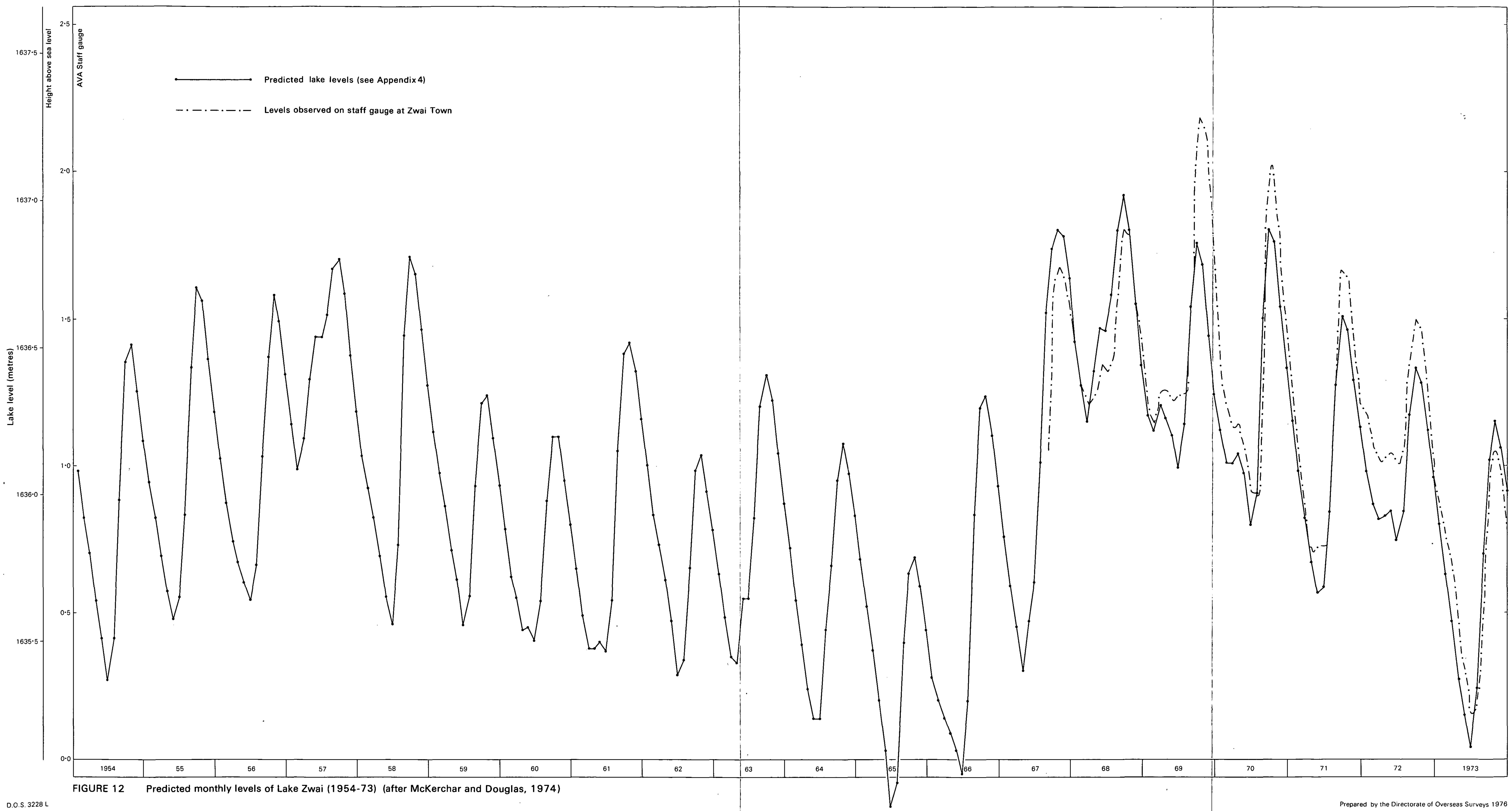

FIGURE 12 Predicted monthly levels of Lake Zwai (1954-73) (after McKerchar and Douglas, 1974)

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FIGURE 13

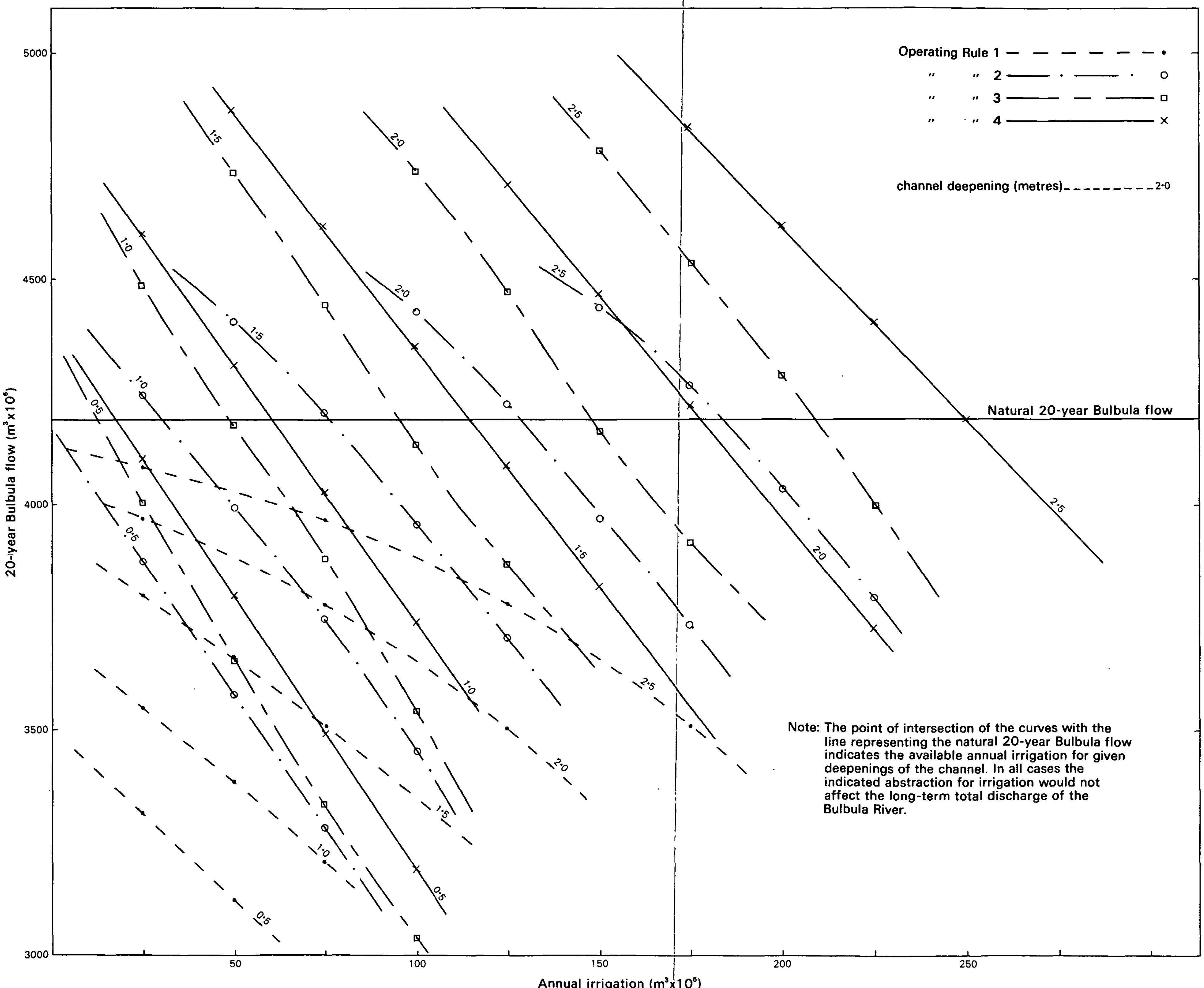

FIGURE 13 Flows in the Bulbula River resulting from various operating rules and river channel deepenings (after McKerchar and Douglas, 1974)

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TABLE 25 Projected 20-year average monthly flows (mcm) in the Bulbula River

J	F	M	A	M	J	J	A	S	O	N	D	Total
13.0	9.3	7.8	7.9	8.3	7.9	10.4	22.9	36.8	37.8	28.5	18.9	209.5

Figure 13 shows, for each rule and for five levels of channel deepening, the annual quantity of water that would be available for abstraction, in relation to the long-term (20 years) flows that would be released into the Bulbula. By considering that part of the graph above the line representing the natural 20-year Bulbula flow, the amount of water available for abstraction can be determined.

This information is presented in Figure 14 for each operating rule. Whilst Rule 4 would allow maximum abstraction for any given deepening of the Bulbula channel and would limit maximum flows to about 20 m^3/s, there is the possibility, should the channel be deepened by more than 2 m, that low flows might be reduced to zero for short periods. Since however, the developments proposed in Part 6 do not envisage abstraction of all the water available, the maximum deepening of the channel is unlikely to exceed 1.5 m so ensuring that some flow can be maintained in the Bulbula River throughout the year. Table 26 projects levels of Lake Zwai (based on 20 years data) when the outflow is controlled in accordance with Rule 4.

TABLE 26 Predicted mean levels of Lake Zwai (m) under Operating Rule 4

Channel deepening (m)	Annual abstraction (mcm)										
	25	50	75	100	125	150	175	200	225	250	300
0.5	0.60*	0.50*	0.40*	0.29*							
1.0	0.25	0.15	0.04*	-0.05*							
1.5		-0.18	-0.28	-0.38	-0.48*	-0.57*					
2.0				-0.67	-0.78	-0.88	-0.98*	-1.07*	-1.16*		
2.5						-1.15	-1.25*	-1.35*	-1.45	-1.54*	-1.72*

*Abstraction rates too high for the channel deepening shown, rendering them incompatible with maintenance of long-term average flows in the Bulbula River. These values are provided to allow interpolation of intermediate values of abstraction and channel deepening.

Table 26 can be used to predict the changes in lake level resulting from various combinations of abstraction and channel deepening. For any given level of abstraction, reference should first be made to Figure 14 (Rule 4) to determine the minimum effective Bulbula channel deepening compatible with maintenance of long-term average Bulbula flows. The derived value of the necessary channel deepening can then be referred to Table 26, with the value of annual abstraction, to determine the projected lake level.

Whilst Rule 4 gives the highest levels of abstraction for minimum deepening of the Bulbula channel compared with the other rules tested, it may not be ideal. It is merely presented as an initial framework for the authority responsible for lake level regulation and abstraction but might need to be revised in the light of experience relating to the seasonal pattern and magnitude of irrigation demand. Optimisation would however also be dependent on ability to forecast climatic cycles, so that above-average releases could be discharged on the rising limb and peak of a cycle and below-average releases on the falling limb and trough.

Accuracy of water availability estimates in Figure 14 depends on:

1. The accuracy of river-flow data, some of which are based on a very small number of current meter gaugings (particularly for the Catar River) and/or old rating curves (Meki and Bulbula rivers).

2. Adequacy of rainfall and evaporation estimates, both in developing relationships between rainfall and streamflow and in estimating evaporation losses from the lake.

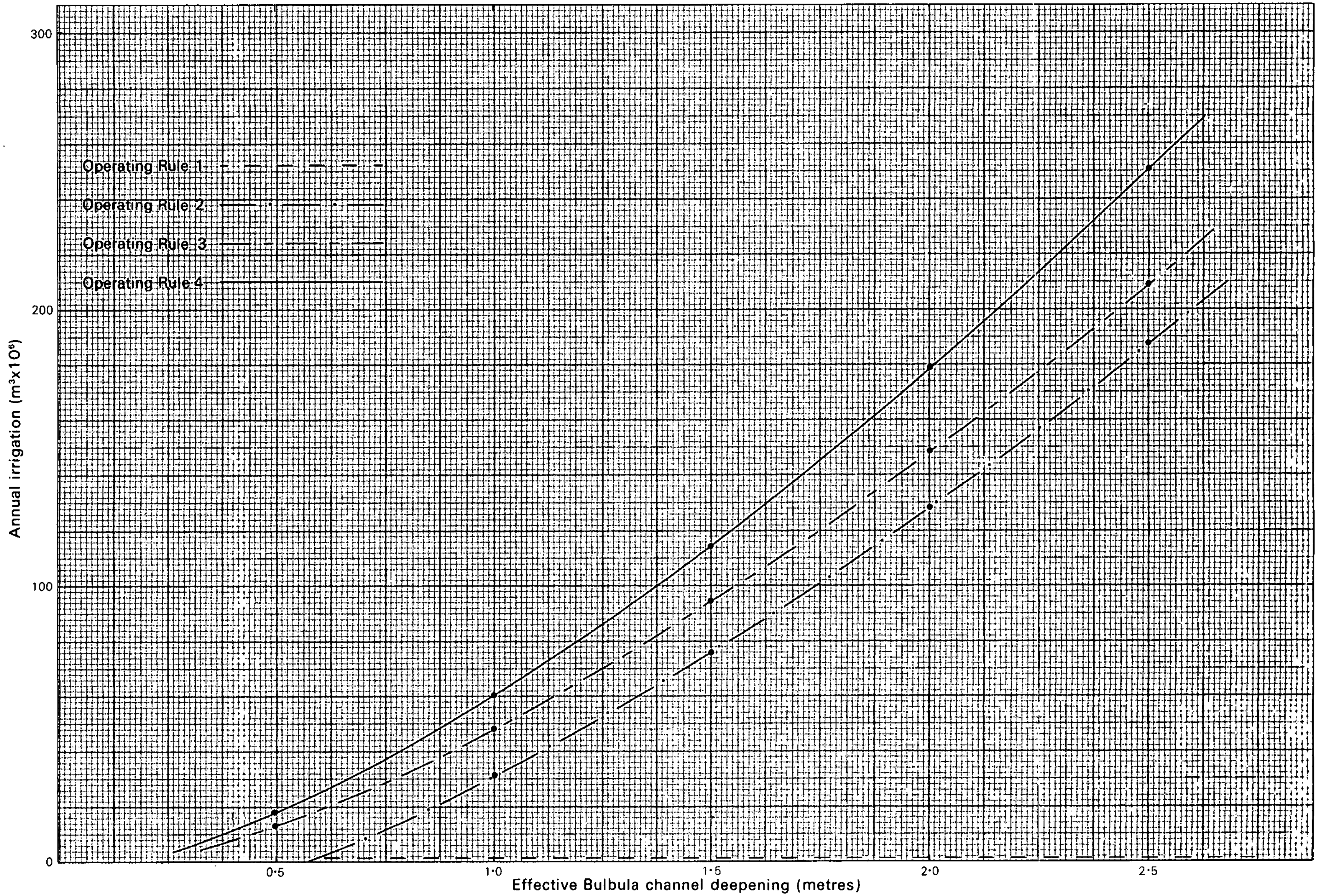

FIGURE 14 Water available for irrigation with Bulbula flow maintained at its natural level (after McKerchar and Douglas, 1974)

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3. The accuracy of the Italconsult lake area/stage/volume curves. These have had to be modified after additional soundings. The revised curve (Figure 4) indicates that the reduction in surface area resulting from a lowering in lake level from say 1 635 to 1 634 m (a.s.l.) would be significantly less than had been suggested by Italconsult. This discrepancy implies the possibility or rather lower average lake levels than those calculated in the above analyses. Since, however, the overall water requirement for irrigation is considerably less than the total available water resource, this need only be investigated further if future additional demands for water arise (e.g. for additional reclamation and irrigation of the lake bed or for pumping into the Awash Valley).

In this computation no account has been taken of possible changes in transpiration from lakeshore vegetation resulting from lower lake levels. The associated lowering of the watertable could be expected to result in an overall reduction in transpiration from plants which formerly drew on groundwater. Some plants however, through root elongation, will be able to keep pace with the falling watertable and so continue to transpire at maximum rates. Additionally, the zones of marginal vegetation will tend to follow the receding lake so that the area of vegetation drawing on groundwater will increase, despite a decrease in the circumference of the lake. The effects of these various possibilities are not easy to foresee, though it is possible that the net result may be a slight increase in transpiration loss from the lake margins.

This evaluation of the water resources of Lake Zwai has shown that a considerable volume of water can be abstracted annually from the lake without disturbing the long-term average outflow to Lake Abiyata, provided the average level of Lake Zwai is lowered. In order to maintain flow in the Bulbula River and control the lake level, it will be necessary to construct sluices in the upper reaches of the Bulbula. It will also be necessary to deepen the Bulbula channel between the sluice and the lake, the amount of dredging being dependent on the desired level of abstraction. Without modification to the Bulbula channel and the construction of sluices, abstraction of water must inevitably deplete the flow in the Bulbula River.

LAKE ABIYATA

In this section, consideration is given to the water balance of Lake Abiyata, the terminal lake which receives the outflow from Lake Zwai via the Bulbula River (Text Map 2). Abiyata also receives water from the Horakello River derived from Lake Langano and from the intermittent Gogessa River. Consideration of the effect on Lake Abiyata of any change in the flow regime of the Bulbula is important since this lake forms part of the Rift Valley Lakes National Park, a major feature of which is the abundant birdlife dependent on the habitat provided by Abiyata.

Being a terminal lake with no outflow of water (and assuming that ground-water flow away from the lake is negligible), the inflow and the surface evaporation must in the long term balance. The water balance may be presented as the equation: Bulbula flow + Horakello flow + Gogessa flow + rainfall on lake = evaporation + change in lake storage (volume). Since the rate of evaporation from the lake remains fairly uniform from year to year (though with some seasonal variation), it can be seen that following a succession of years with above-average flows, the amount of water in the lake will increase, causing a rise in level. This leads to an increased surface area from which the volume of water lost by evaporation will be greater than previously. The converse applies following a series of drier years. In both instances new equilibrium levels are established. In the absence of long-term observations of Lake Abiyata, an indication of the levels has been obtained from aerial photographs flown in 1956 and 1972 and from field observation in 1974. Table 27 gives the approximate areas and levels of the Lake derived from these sources; a graph of lake level versus area is plotted on Text Map 6.

TABLE 27 **Areas and levels of Lake Abiyata**

Date	Source	Approximate area (km^2)	AVA gauge height (m)
1956	Aerial photos	142	No record (−2.0 derived from Text Map 6)
Nov. 1972	Aerial phots	181	2.8
April 1974	Field observation	168	1.2

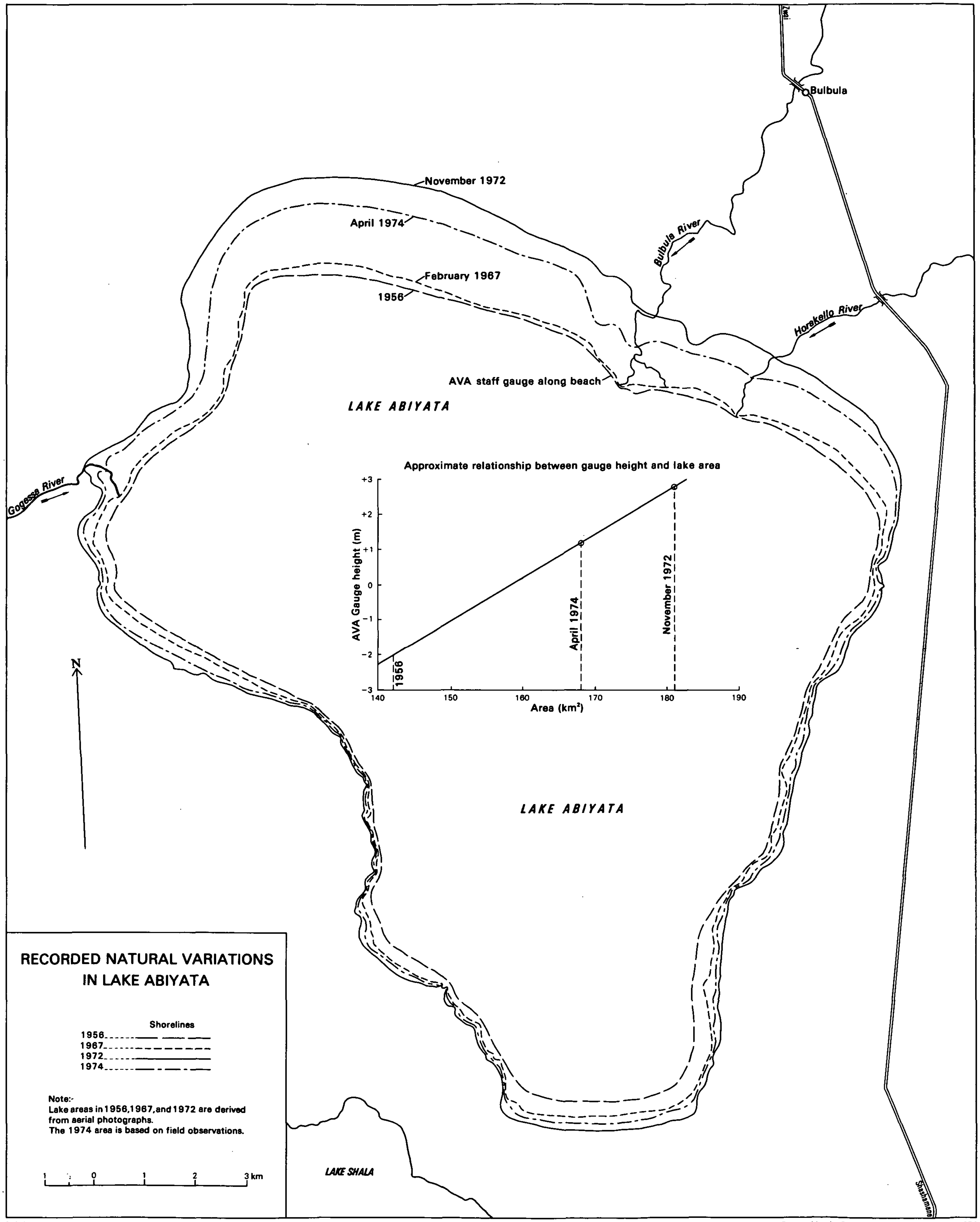
It can be deduced from Table 27, which may virtually cover the natural range of lake fluctuation, that the area of the lake may alter by as much as 40 km^2; this is equivalent to a variation in storage volume of 820 mcm and a change in level of about 5 m.

The lake level/area relationshio has been used in conjunction with river flow data to draw up a month by month water balance for the lake over the five years 1969–73 (Appendix 5). The computed lake levels for each month are plotted together with the observed values in Figure 15 and, accepting the validity of the assumptions made, a reasonable comparison has been achieved. In order to make use of the water balance as a means for confidently predicting the effects of regulating the Bulbula River inflow (once control works exist on the Lake Zwai outlet), it would be necessary to extend the input records statistically so as to remove the effects of short-term variation, since it is clear that the existing record of lake levels is not typical of long-term average conditions. Flows so derived could then be compared with the projected Lake Zwai release flows. However it would be rash to attempt to extend the data series at this stage, in view of the short record, the poor quality of many of the observations and the lack of evaporation data (although an evaporation pan is installed at Langano, the record is fragmentary, the results differ greatly from those at Zwai and no confidence can be placed in either set of data without further investigation).

At this stage, therefore, only tentative estimates can be given of the possible influence of varied Bulbula flows on Lake Abiyata.

Two further factors need to be considered: 1. The point at which reduced Bulbula flows resulting from irrigation development around Lake Zwai significantly affect the level of Lake Abiyata, and 2. The possibility of releasing above-average flows, thereby lowering the average level of Lake Zwai and enabling additional land on the lake bed to be reclaimed. In either case, it has been assumed that Lake Abiyata can be allowed to fluctuate within the range known to occur naturally:

1. It has already been determined that any abstraction from the lake will deplete the Bulbula flow, and that the major portion of the water abstracted will be at the expense of the Bulbula rather than Lake Zwai. It is evident then that even the existing irrigation must, however slightly, be depleting the Bulbula flow and whereas the current rate of depletion is clearly inconsequential, it will inevitably become more pronounced as irrigation development continues. Assuming, for example, that irrigation abstraction were allowed to build up to 20 mcm per year (as discussed in Part 6), then by interpolation in Table 21, the reduction in Bulbula flow in an average year would be 15 mcm. Comparing this with the maximum natural variation in volume of Lake Abiyata of 820 mcm, it is clear that this low level of abstraction would have a barely significant effect and that, in the long term, the average lake level would be only slightly lowered (by about 10 mm) with equivalent lower maximum and minimum levels. A more serious considera-tion would be the possible reduction in river flow during the dry season with consequent effect on users along the river, especially at Bulbula village; It is therefore strongly recommended that irrigation development around Lake Zwai should be carefully controlled, even prior to the construction of control sluices on the Bulbula.



RECORDED NATURAL VARIATIONS IN LAKE ABIYATA

TEXT MAP 6

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FIGURE 15

FIGURE 15 Lake Abiyata levels 1969-73

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2. Before flushing water out of Lake Zwai to enable additional land to be reclaimed, it would be necessary to construct outlet sluices and deepen the Bulbula channel. Following this, abnormally high release flows down the Bulbula would presumably be acceptable during a particularly dry run of years, even though continuing above-average releases would inevitably raise the level of Abiyata. In view of the large natural variation in the volume of water stored in Abiyata however, there is considerable scope for inter-annual variation in releases. This natural variation is in excess of 800 mcm; in the long term a total flush of water from Lake Zwai greater than this amount might be accepted, in view of the markedly increased evaporation at high lake levels. The effect on Abiyata of phased developments around Lake Zwai is discussed further in Parts 6 and 7.

Under natural conditions, the variations in level and area of Lake Abiyata are considerable. Although the hydrological data available are inadequate to predict accurately the effect of varied Bulbula inflow rates following the regulation of Lake Zwai for irrigation, it should nevertheless be possible to maintain the level of Abiyata within the range recorded over the past 20 years.

Part 5

Evaluation of agricultural potential

Agricultural development possibilities within the project area and the prospects for profitable irrigation in the Lake Zwai area are now considered. Agricultural potential is discussed in relation to climate and soils, market opportunities and socio-economic limitations. In Part 6 consideration is given to the need for agricultural research, extention and credit.

CLIMATIC FACTORS

The climate has been described in Part 3; data for the Lake Zwai area are summarised in Table 28.

TABLE 28 Means of climatic data: Lake Zwai area

	Unit	J	F	M	A	M	J	J	A	S	O	N	D	Mean year
Temperature at Zwai[1]	°C	18.8	19.8	19.5	19.8	19.5	20.1	19.7	19.2	18.9	18.9	18.9	18.2	19.3
Daily max. at Zwai[1]	°C	26.4	27.2	27.9	28.1	28.4	28.3	26.1	25.0	26.0	26.8	26.3	26.5	26.9
Daily min. at Zwai[1]	°C	11.2	12.4	11.2	11.6	10.7	11.9	13.3	13.4	11.9	11.1	11.6	10.0	11.7
Rainfall at Adamitulu[2]	mm	11.3	29.5	37.7	65.0	61.4	53.3	113.5	99.3	89.1	22.0	10.6	9.2	602.1
Rainfall at Meki[3]	mm	21.5	38.2	35.3	57.4	49.4	74.4	147.2	160.7	123.6	36.6	19.9	1.3	765.7
Rainfall at Ogelcho[4]	mm	11.9	46.7	43.5	85.0	39.2	71.6	131.6	117.5	89.2	32.1	11.3	5.8	685.4
Wind speed at Zwai[5]	m/s	1.66	1.15	1.13	0.90	0.94	1.59	1.06	1.06	0.79	1.13	1.55	1.31	1.19
Estimated evaporation[6]	mm	163	154	194	179	201	179	154	154	142	175	159	158	2 012
Daily solar radiation[7]	cal/cm^2	475	450	500	490	510	480	440	450	460	510	450	460	5 675

1. Aug. 1968 – Dec. 1973. 2. For 39 years from 1914-1940 and 1956-1969. 3. Sept. 1965 – Dec. 1973. 4. Sept. 1967 – Dec. 1973. 5. Aug. 1968 – Dec. 1972. 6. Extrapolated Penman estimates from HVA Sugar Estates, Wonji, Awash Valley, adjusted for altitude. 7. See Table 5 (Part 3).

Temperature

The mild temperatures prevailing throughout the year are suitable for a wide range of subtropical and tropical crops including wheat, maize and sugar cane, but not for cotton which requires warmer conditions. The mean annual temperature at Zwai is 19.3°C and varies little throughout the year. The annual means of daily maximum and minimum temperature are 26.9°C and 11.7°C respectively. The mean daily maximum is between 25°C and 27°C from July to February rising to about 28°C between March and June.

Although frost has not been recorded at Stevenson screen level (1.5 m above ground) minimum temperatures below 10°C are common between November and June. Between November 1969 and February 1974 the extreme minimum was 4°C implying a temperature at ground level close to 0°C, but no evidence of crop damage due to freezing has been found. In 1971, there were 47 occasions between March and June with a minimum of 4°–5°C, compared with five occasions in 1972, one in 1973 and none in 1969. Specific temperature effects are more fully discussed in later sections.

Radiation

The incoming daily solar radiation is high, varying from about 440 to 510 cal/cm^2 (Table 28). Maximum advantage from such a primary energy source would be obtained by growing leafy crops such as sugar cane or lucerne which cover the ground for most of the year, or by growing a succession of arable crops throughout the year with irrigation.

Rainfall

The mean annual rainfall is 766 mm at Meki and 602 mm at Adamitulu. In the mid-Meki Valley rainfall increases in a north-westerly direction to about 850 mm (Text Map 2). Rainfall over Lake Zwai may well be less than 500 mm. The year is broadly divisible into wet, dry and intermediate seasons, the wettest months being from July to September and the driest from October to January inclusive. The season February to June has variable rainfall, monthly amounts ranging from nil to over 100 mm. Rain fed crops are not usually planted until the end of June or early July owing to the unreliability of rainfall in the preceding period. The effective duration of the average growing season for rainfed crops (including the period in October when growth is dependent on residual soil moisture) is about 110 days. At the end of the growing season dry weather can be relied on for ripening and drying grain and pulse crops.

Tables 29 and 30 list the occurrence of dry periods in the wet season (July-September) over eight years at Meki and a different 10-year sequence at Adamitulu (a dry period was arbitrarily defined as one of three or more days with less than 4 mm of rain in any day). The number of dry periods in any one wet season at Adamitulu varied between 6 and 12. Figure 16 shows the cumulative frequency distribution of dry periods by length; 12% and 14% of the dry periods exceeded 10 days at Meki and Adamitulu respectively. Two of the dry periods at Adamitulu even lasted for 22 consecutive days. In some years, therefore, dry periods must impose severe limitations on rainfed crop yields and a response to irrigation can confidently be expected in the wet seasons, as well as at other times of the year.

TABLE 29 Distribution of dry periods during the wet season (July-September) at Meki, 1966-73

Length of dry period (days)	1966	1967	1968	1969	1970	1971	1972	1973	No. of dry periods	Cumulative percentage of total of periods
3	1	2	2	2	3	2	1	2	15	100.0
4	4	2		3	1	3	4	5	22	80.0
5	1	1	2	3	1	2	3	1	14	50.6
6	2	1	2	1	1				7	32.0
7						1	1		2	22.7
8	1	1	2				1		5	20.0
9		1							1	13.3
10				1	1		1	1	4	12.0
11	1			1					2	6.7
12					1				1	4.0
13			1			1			2	2.8
Total	10	8	9	11	8	9	11	9	75	

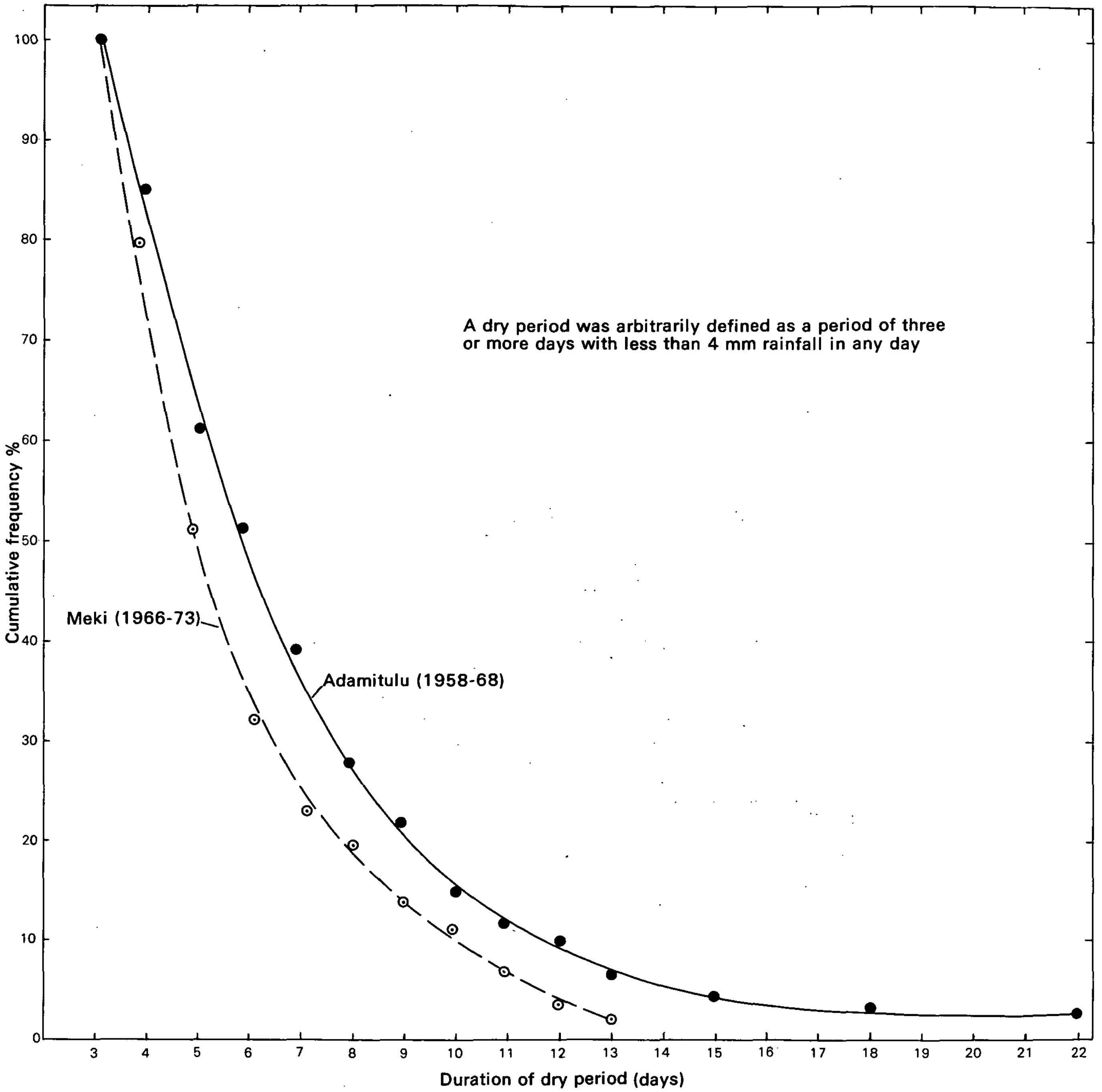

FIGURE 16 Cumulative frequency distribution of dry periods by length during the wet season (July-September)

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TABLE 30 Distribution of dry periods during the wet season (July-September) at Adamitulu, 1958-68 (1964 excluded)

Length of dry period (days)	1958	1959	1960	1961	1962	1963	1965	1966	1967	1968	No. of dry periods	Cumulative percentage of total of periods
3		1	5	3	1			3	1		14	100.0
4	1		2	4	1	3	1	4	2	4	21	84.5
5	1		1		1	1	2		1	2	9	61.1
6	1		1	2	1		2	1	1	2	11	51.1
7	1	1	1		2		1	1	3		10	39.0
8			2		1		2				5	27.8
9	1				2	1	1	1		1	7	22.2
10												14.5
11												
12												
13												
15												
16												
17												
18												
22												
Total	6	7	12	11	8	8	9	10	9	10	90	

Rainfall intensity is not considered to be a special hazard. Over a recent nine-year sequence the daily rainfall at Meki exceeded 75 mm on only one occasion and exceeded 50 mm on only eight occasions. Table 31 gives the average rainfall intensities experienced during the worst storms at Zwai between September 1968 and July 1969 and between January 1972 and October 1973. The risk of damage to crops is within acceptable limits for the developments to be proposed in this report. Although sheet erosion is evident in some cultivated fields on the lake terraces, this could be controlled by appropriate methods of land preparation.

TABLE 31 Average rainfall intensities during storms at Zwai

Date	Rainfall (mm)	Duration (min)	Intensity (mm/hour)
16.8.68	15.4	5	185.5
15.8.68	10.4	15	41.6
13.1.72	6.5	10	39.2
15.4.72	10.6	25	25.5
28.9.68	14.2	40	21.3
1.6.73	24.1	70	20.7
30.8.73	6.8	20	20.4
9.6.73	13.4	40	20.1
11.3.69	6.2	20	18.6
23.7.73	8.8	30	17.8
6.7.69	10.2	35	17.5

Wind

October to March is the windiest half of the year, monthly mean wind speeds varying from 1.13 to 1.66 m/s (Table 28). The prevailing direction during this period is from the north east. At other times of the year, wind speed and direction are more variable. Wind erosion which occurs on dry, exposed land, may be controlled by planting windbreaks. The risk of damage to crops by wind is within acceptable limits, except for bananas.

Evaporation

Mean annual evaporation around Lake Zwai is about 2 000 to 2 200 mm compared with a rainfall of 500-750 mm. Evaporation exceeds rainfall in every month of the year. Monthly evaporation data were estimated both from a lake water balance equation and by making altitude adjustments to Penman Estimates which had been determined for Wonji in the Awash Valley (at 30 km distance). The latter method is probably the more reliable and has been used in calculations of evapotranspiration and crop irrigation requirements (Appendix 2). Open-water evaporation varies little during the year, but is greatest between March and June (180-200 mm per month) and least (140-160 mm per month) during the wet season (Table 28).

Climatically therefore the project area can be regarded as having considerable potential for irrigated agriculture. The main favourable features are temperatures suited for a wide range of crops throughout the year, high solar radiation, excellent conditions for ripening and drying crops during much of the year, and minimal risk from storms. Pest, disease and weed incidence, though expected to be of major concern, will pose less of a problem at Zwai than in more humid climates.

SOIL AND LAND SUITABILITY

In this section the project area is considered according to its physical suitability for irrigation. The land classification has been based on United States Bureau of Reclamation guidelines (US Department of the Interior, 1953) as summarised in Table 38. The division of the project area into irrigation suitability classes is shown on Separate Map 3. Although incorporating major physical factors of consequence for irrigation (e.g. topography, drainage and soil type), no account could be taken of two of the most critical factors for pump irrigation, the height above and distance from a source of irrigation water, since these are continuous variables. Both factors have nevertheless been paramount in specifying the planned capacity of the pumps and the lengths of pipes and feeder canals, all variables of crucial importance in determining economic viability. The land has been classified therefore on the basis of its potential productivity under irrigation, i.e. the capacity of the land, in terms of soil and topography to produce crops. The economics of production, including the costs of land development, are not embodied in this classification, though representing key considerations in the actual formulation of proposals for irrigation development.

The specific features of each part of the project area, in terms of topography and soils, are described in the early sections of Part 6; descriptions and analyses of characteristic soil profiles are presented in Appendix 6. The soil survey showed that, over much of the project area, and especially on the lake terraces, a major potential constraint to irrigation development is the occurrence of severe subsoil alkalinity (due to excessive sodium). Consequently, much effort was devoted to elucidating the possible effects of this alkalinity and predicting the long-term impact of irrigation on these soils. Because of its special significance, the problem of subsoil alkalinity is discussed at some length below.

Irrigation water quality

In considering the suitability of land for irrigation, the quality of the proposed irrigation water and the chemical effect that this may have on the soils must be taken into account. Water samples were analysed to determine their irrigation suitability in terms of the USDA classification (1954). The results are listed in Table 32. Since, in all cases, there was a delay of at least several days between sample collection and analysis, little reliability can be placed on the pH values quoted, due to changes during storage.

All irrigation water contains salt and the water of the Lake Zwai catchment is no exception. While the salt contents indicated in Table 32 are relatively low for all surface water samples, there will still be a need to use a certain proportion of the irrigation water to leach the soil so as to prevent salt accumulation in the profile. The leaching requirement for Lake Zwai water has been calculated (method in USDA, 1954) at about 9% of the total quantity of water applied for irrigation, and for Meki River water about 10%, these are maximum values since they take no account of the leaching effect of rainfall, nor of salt precipitation in and uptake from the soil. Nevertheless, it should be emphasised that irrigation applications have to be computed (Appendix 2) with this requirement in mind.

TABLE 32 Zwai Basin water sample analyses

Sample notation	Location	Date	pH	Cations (meq/1)				Anions (meq/1)			Boron (ppm)	SAR*	Electrical conductivity µmhos/cm at 25°C	USDA classification (see Figure 6)	Residual sodium carbonate
				Ca	Mg	Na	K	C1	SO_4	CO_3 + HCO_3					
M1	Meki R. in mid-Meki Valley	9. 1.74	7.6	1.5	1.0	1.40	0.41	0.08	0.30	3.00	n.a.	1.3	300	C_2S_1	+0.5
M2	Meki R. at Meki Town	22. 2.74	7.5	2.0	1.2	1.72	0.18	0	1.30	2.18	n.a.	1.4	350	C_2S_1	−1.0
M3	Meki R. in mid-Meki Valley	15. 4.74	7.3	1.2	0.7	1.50	0.10	0.25	1.05	2.17	n.a.	1.5	340	C_2S_1	+0.3
M4	Meki R at Meki Town	21. 4.74	8.1	1.3	0.7	4.00	0.18	1.00	0.75	3.69	n.a.	4.0	490	C_2S_1	+1.7
M5	Meki R. at Meki Town	15. 5.74	7.3	0.8	0.4	0.95	0.36	0	0	2.28	n.a.	1.2	175	C_1S_1	+1.1
M6	Meki R. 4 km downstream from Meki Town	25.10.74	8.1	1.0	0.5	3.90	0.19	n.a.	n.a.	4.65	0.28	4.5	490	C_2S_1	+3.1
M7	Meki R. at Meki Town	28.10.74	7.8	1.0	0.6	3.45	0.19	n.a.	n.a.	4.45	0.20	3.9	460	C_2S_1	+2.8
C1	Catar R. at Ogelcho	25. 6.73	7.9	1.1	0.8	0.39	0.12	0	1.55	0.74	n.a.	0.4	180	C_1S_1	−1.2
C2	Catar R. near Catar Delta	11. 4.74	6.7	0.7	0.6	0.80	0.10	0.25	0.75	1.74	n.a.	1.0	200	C_1S_1	+0.4
Z1	Lake Zwai near Zwai Town	6.72	7.4	0.6	0.6	2.44	0.18	n.a.	n.a.	n.a.	n.a.	3.2	330	C_2S_1	n.a.
Z2	Lake Zwai near Zwai Town	3.74	8.1	0.6	0.7	2.43	0.13	n.a.	n.a.	n.a.	n.a.	3.0	410	C_2S_1	n.a.
Z3	Lake Zwai near Zwai Town	24. 4.74	7.4	0.8	0.7	2.20	0.60	0.50	0.30	3.72	n.a.	2.5	510	C_2S_1	+2.2
Z4	Lake Zwai near Zwai Town	6.74	8.0	0.5	0.8	2.39	0.38	n.a.	n.a.	n.a.	n.a.	2.9	365	C_2S_1	n.a.
Z5	Lake Zwai near Zwai Town	8.74	8.9	0.5	0.7	2.78	0.36	n.a.	n.a.	n.a.	n.a.	3.5	350	C_2S_1	n.a.
Z6	Lake Zwai near Meki Delta	3.74	7.7	0.6	0.9	2.26	0.31	n.a.	n.a.	n.a.	n.a.	2.6	383	C_2S_1	n.a.
Z7	Lake Zwai near Meki Delta	1. 5.74	7.9	0.7	0.4	2.95	0.37	0	0	4.59	n.a.	3.9	360	C_2S_1	+3.5
Z8	Lake Zwai near Chefe Gila	3.74	7.5	0.2	1.5	3.17	0.28	n.a.	n.a.	n.a.	n.a.	2.4	360	C_2S_1	n.a.
Z9	Lake Zwai near Galila Island	23.10.74	8.2	0.5	0.5	2.55	0.27	n.a.	n.a.	3.26	0.14	3.6	350	C_2S_1	+2.2
Z10	Lake Zwai near Zwai Town	28.10.74	7.7	0.7	0.6	2.62	0.30	n.a.	n.a.	3.53	0.14	3.3	380	C_2S_1	+2.2
B1	Bulbula R. near Adamitulu	26. 6.73	7.7	1.0	0.2	1.00	0.32	0.02	0.35	2.10	n.a.	1.3	240	C_1S_1	+0.9
B2	Bulbula R. near Adamitulu	3.74	7.5	0.7	1.1	2.23	0.31	n.a.	n.a.	n.a.	n.a.	2.4	400	C_1S_1	n.a.
B3	Bulbula R. near Adamitulu	30. 3.74	7.8	0.4	0.3	3.08	0.30	0.50	0	3.63	n.a.	5.2	370	C_2S_1	+2.9
B4	Bulbula R. near Adamitulu	9. 4.74	7.3	0.6	0.7	4.50	0.18	1.00	0.25	3.75	n.a.	5.6	530	C_2S_1	+2.4
B5	Bulbula R. 2.5 km from Lake Zwai	22.10.74	8.0	0.5	0.5	2.74	0.27	n.a.	n.a.	3.25	0.16	3.8	360	C_2S_1	+2.2
B6	Bulbula R. at Bulbula Town	28.10.74	7.6	0.7	0.6	2.56	0.29	n.a.	n.a.	3.51	0.16	3.2	270	C_2S_1	+2.2
MV1	Well in mid-Meki Valley (depth 20m)	8. 1.74	7.5	3.2	1.8	4.68	0.33	0.32	0.70	8.30	n.a.	2.9	1 000	C_3S_1	+3.3
MV2	Well in mid-Meki Valley	2.74	7.4	2.0	1.0	2.60	0.43	1.00	1.30	2.80	n.a.	2.1	450	C_2S_1	−0.2
MV3	Well in mid-Meki Valley	2.74	7.6	4.6	1.8	2.90	0.37	1.50	0.90	3.75	n.a.	1.6	675	C_2S_1	−2.6
MV4	Well in mid-Meki Valley	2.74	7.6	2.6	2.0	5.72	0.47	2.50	0.90	4.35	n.a.	3.8	850	C_3S_1	−0.2
MV5	Well in mid-Meki Valley	2.74	7.6	3.4	1.4	2.32	0.31	0.60	0.40	3.45	n.a.	1.5	550	C_2S_1	−1.3
MV6	Well in mid-Meki Valley	2.74	7.9	2.4	2.0	6.40	0.48	2.50	0.70	4.95	n.a.	4.3	860	C_3S_1	+0.5
MD1	Well on Meki Delta (depth 6 m)	24. 4.74	8.1	6.0	0.6	3.80	0.80	1.00	0.80	7.88	n.a.	2.1	1 100	C_3S_1	+1.3

*Sodium adsorption ratio
n.a. = not available

Soil physical constraints

Table 33 summarises the chief morphological, physical and chemical properties of the main soil types, the distribution of which has already been outlined in Part 3. So far as land utilisation for irrigation is concerned, the prime constraints are physical. Leaving aside topography (slopes as well as topographic position), the most crucial individual constraints may be listed as follows:

1. Flooding by Lake Zwai around the lake margins and especially along the fringes of the Meki Delta, and seasonal flooding by the Meki River across parts of the delta leading to periodic inundation and local gully formation.

2. Seasonally high groundwater levels beneath the Meki Delta causing drainage impedence and salt deposition in the subsoil horizons.

3. Locally around Adamitulu, the occurrence of consolidated volcanic rock materials close to the surface or of abundant pumiceous boulders and gravel.

4. The general occurrence (except on the Meki Delta) of termite mounds at a density of up to 50/ha.

5. Poor subsurface structure and partial induration impeding both drainage and rooting on the lake terraces, usually associated with abnormally high levels of alkalinity.

6. Except in the coarsest-textured pumiceous lacustrine sand, high levels of silt (commonly 30-60% silt content) such that soil surfaces are prone to capping and soil profiles to significantly reduced infiltration rates following cultivation.

Constraints 1-4 above are self-evident and require no further discussion. The soil structural problems, however, are more complex and have important implications. Constraints 5 and 6 are to an extent related, and any increase in soil alkalinity can be expected to exacerbate the degradation of soil structure and reduction in profile permeability. The problems specifically associated with concentrations of alkali are discussed later. At this stage it is sufficient to point out that the degree of soil degeneration to be anticipated over time will be a function of the original texture and structure.

Most of the soils on the lacustrine terraces which are affected by these particular physical constraints fall into one of two broad soil categories:

1. Soil H (together with Hb, a total of 7 060ha or 38.6% of the lacustrine terrace surface). This comprises deep, well drained though weakly structured, coarse sandy loam or loamy sand overlying coarse pumiceous alkaline sand. At depth, alkalinity can be severe and the mean subsoil ESP is 28. The permeability of Soil H is remarkably low for such coarse-textured material (around 40mm/hour); this can be ascribed to the significant silt and very fine sand content (see Appendix 6) and to the alkalinity of the subsoil. In this case, a degree of impedence in the profile hydraulic conductivity can be regarded as advantageous, in that the very rapid permeability rates normally associated with coarse-textured soils could have been expected to have caused high percolation losses with irrigation. A particularly advantageous feature noted during the survey was the way irrigation canals constructed without artificial lining across areas of Soil H rapidly became self-sealing (silt particles blocking the soil pores) and consequently allowed little loss through seepage. Moreover, even if the entire clay content became dispersed as a result of total structural breakdown, the amounts involved are so low (clay rarely exceeds 15% of the soil) that soil aeration and drainage would remain adequate for sustained plant growth.

TABLE 33 Soil properties

Soil Group and Unit	Locality	Morphology	Munsell colour of subsoil	Texture topsoil / subsoil	Subsoil drainage	Final infiltr-ation rate (mm/h)	Accum-ulated intake after 9 hours (mm)	Available moisture % (volume basis) Top-soil	Sub-soil	Top-soil organic matter %	pH in water (1:5) Mean topsoil / subsoil	Range topsoil / subsoil	Top-soil CEC meq %	Conductivity in water (1:5) µmhos/cm Mean topsoil / subsoil	Range topsoil / subsoil	Exchangeable Sodium % Mean topsoil / subsoil	Range topsoil / subsoil	Total P in topsoil ppm Mean	Range	Special features
1 A	Gentle levee slopes adjacent to the Meki River	Brownish clay loam, silty and rather weakly structured in the subsoil	10YR 4/3	CL / CL-ZCL	Free	25	402	11.3		4.9	7.3 / 7.4	6.9-7.7 / 6.7-8.0	39	185 / 158	70-440 / 85-425	2 / 2	1-3 / 1-9	705	378-1 278	Uniform profile
B	Gently undulating old levee ridges along former river channels on Meki Delta, in association with C	Brownish clay loam with a variable subsoil. Sand layers below 30 cm	10YR 4/2 –5/3	CL / ZCL,S,C	Impeded in heavy textured layers	43	740	9.0	14.8	3.4	7.2 / 7.2	6.6-7.9 / 5.9-9.1	34.2	130 / 413	90-245 / 65-2 130	2 / 6	1-5 / 1-15	767	300-2 110	Subsoil markedly layered and locally slightly saline
Ba	As B, in areas of high water table	As B with alkaline subsoil								3.5	7.7 / 9.2	7.4-8.1 / 9.1-9.4	39	213 / 823	120-305 / 365-1 280	9 / 37	4-14 / 20-53	772	470-1 074	Scattered termitaria
C	Flat land adjacent to old river channels on Meki Delta *	Brownish clay loam with a variable subsoil. Sand layers below 75 cm	10YR 4/2 – 5/3	CL / ZCL,S,C	Impeded in heavy textured layers			8.0	7.7	4.4	7.2 / 7.5	6.7-7.7 / 7.1-8.0	41.2	142 / 225	80-290 / 45-800	2 / 9	1-3 / 2-24	648	320-1 396	Marked layering in subsoil
Ca	As C, in areas of high water table	As C, with alkaline subsoil				32	291			4.5	7.1 / 8.8	6.6-7.7 / 8.2-9.3	39.8	160 / 876	110-190 / 290-1 220	9 / 52	2-18 / 32-75	832	300-1 830	Scattered termitaria
D	Flat land along the upper margins of the Meki Delta	Greyish and brownish Clay	10YR 4/2	C / C-ZC	Slightly impeded	5 48*	151 856*			4.4	6.6 / 6.9	6.1-7.1 / 6.5-7.9	42.1	93 / 101	65-170 / 50-160	1 / 3	1-3 / 1-13	496	406-590	Dry season cracking gives rise to variable infiltration
E	Flat land along sandy flood channels of the Meki River	Variable topsoil; heavy-textured subsoil	10YR 3/1 – 5/3	ZCL-S / C-ZC	Periodically impeded					4.3	6.9 / 7.8	7.6-8.1	37.2	68 / 96	65-70	5 / 9	4-5 / 5-12	318	257-378	Periodic flooding from Meki River
F	Flat grassy plains on lower Meki Delta	Mottled clay	10YR 3/2 – 4/1	C / C-ZC	Seasonally impeded	21*	834*		7.0	4.8	6.5 / 7.2	6.1-7.1 / 6.6-8.1	46.4	162 / 322	65-300 / 155-520	4 / 9	2-6 / 4-14	402	290-570	Seasonal flooding both from Meki River and Lake Zwai
Fa	Limited to Central Meki Delta and north-eastern swamp margins	As F, with a higher silt content and subsoil alkali		C-ZC / C-ZC	Seasonally impeded					3.8	7.9 / 9.1		32.5	268 / 665		12 / 28		398		

* In association with B

Key to table on p.88

TABLE 33 Soil properties (Continued)

Soil Group and Unit	Locality	Morphology	Munsell colour of subsoil	Texture topsoil / subsoil	Subsoil drainage	Final infiltration rate (mm/h)	Accumulated intake after 9 hours (mm)	Available moisture % (volume basis) Topsoil	Available moisture % (volume basis) Subsoil	Topsoil organic matter %	pH in water (1:5) Mean topsoil / subsoil	pH in water (1:5) Range topsoil / subsoil	Topsoil CEC meq %	Conductivity in water (1:5) µmhos/cm Mean topsoil / subsoil	Conductivity in water (1:5) µmhos/cm Range topsoil / subsoil	Exchangeable Sodium % Mean topsoil / subsoil	Exchangeable Sodium % Range topsoil / subsoil	Total P in topsoil ppm Mean	Total P in topsoil ppm Range	Special features
G	Flat land adjacent to the Catar River	Brownish loam with variable subsoil often with sand and gravel layers	10YR 3/3 – 4/3	L-CL / Variable	Slightly impeded					2.4	7.0 / 8.0			80 / 70		1 / 30		490		Locally affected by alkali
2 H	Lacustrine terraces around Lake Zwai, in association with J	Pale sandy loam becoming coarser textured with depth	10YR 7/2	SL-LS / LS-LCS	Free	44 25*	1 079 329*	14.6	11.3	2.3	8.0 / 8.9	6.5-8.3 / 6.9-10.4	21.3	229 / 424	40-775 / 32-960	4 / 28	1-18 / 2-95	276	80-560	Weak structure compact alkaline subsoil, Termitaria common in places
J	Lacustrine terraces around Lake Zwai, in association with H	Pale loam over silty ash	10YR 6/3	FSL-L / L-ZL	Slightly impeded	25	229	13.8	15.5	3.1	7.5 / 9.2	7.0-8.5 / 8.0-10.4	28.6	169 / 465	50-610 / 130-900	3 / 42	1-19 / 1-100	263	180-360	Alkaline and often slightly indurated in subsoil. Termitaria common in places
Jz	As J, adjacent to the Meki Delta	Brownish silt loam over silty or fine sandy ash	10YR 6/3	ZL / LFS-ZL	Slightly impeded					2.6	6.6 / 8.1	6.5-6.8 / 6.9-8.9	25.8	70 / 428	60-80 / 80-1 260	1 / 22	1-2 / 1-70	255		Scattered termitaria
L	North-east and north-west shores of Lake Zwai, occasionally in association with J	Brownish clay loam with variable subsoil	10YR 4/3	CL-SCL / CL-C	Slightly impeded					2.6	7.9 / 9.2	7.3-8.5 / 8.1-10.4	34.8	139 / 615	70-240 / 100-1 740	6 / 42	1-17 / 1-100	310	220-490	Locally alkaline and slightly saline in subsoil Scattered termitaria
M	Lakeshore at foot of terraces	Well structured clay over compact sandy pumice	10YR 7/2	C / LS-S	Free	34*	607*			4.5	7.5 / 7.9	7.6-8.1	45.5	150 / 73	70-80	4 / 6	4-8	220		Seasonal flooding from Lake Zwai

TABLE 33 Soil properties (Continued)

Soil Group and Unit	Locality	Morphology	Munsell colour of subsoil	Texture topsoil / subsoil	Subsoil drainage	Final infiltration rate (mm/h)	Accumulated intake after 9 hours (mm)	Available moisture % (volume basis)		Topsoil organic matter %	pH in water (1:5)		Topsoil CEC meq %	Conductivity in water (1:5) umhos/cm		Exchangeable Sodium %		Total P in topsoil ppm		Special features
								Topsoil	Subsoil		Mean topsoil / subsoil	Range topsoil / subsoil		Mean topsoil / subsoil	Range topsoil / subsoil	Mean topsoil / subsoil	Range topsoil / subsoil	Mean	Range	
N	North-east, north-west and southern shores of Lake Zwai	Saline and/or alkaline soils of variable morphology	10YR 5/4		Impeded					2.4	9.4 / 10.6	8.3-10.5 / 8.7-10.4	33.2	1 957 / 1 157	610-6550 / 530-2 000	50 / 60	6-100 / 11-95	370	190-650	Saline and/or alkaline to surface, weak structure. Ground often bare
P	Mainly south of Zwai Town	Lacustrine rock sheets and lava outcrops at or above 50 cm		L / Rock																
3 R	Western side of the mid-Meki Valley	Well structured heavy clay or silty clay	10YR 4/4	C-ZC / C	Slightly impeded	45	1 498			2.6	6.8 / 7.6	6.2-7.6 / 6.5-8.2	37.9	50 / 150	13-90 / 13-320	1 / 2	1-2 / 1-4	263	100-696	
S	Eastern side of the mid-Meki Valley	Highly silty ash overlying heavy clay: tendency to surface capping	10YR 3/2	ZL-ZCL / C	Impeded	21	305			2.5	6.6 / 7.7	6.0-7.3 / 7.1-8.2	29.1	64 / 95	40-90 / 20-150	1 / 7	1-3 / 1-16	221	55-796	
4 T	Papyrus and Typha swamp fringing Meki and Catar Deltas	Mottled silty clay	10YR 3/1	ZC / ZC	Water-logged					5.8	5.1 / 7.4		56.8	120 / 70		2 / 21		210		Subsoils affected by alkalinity adjacent to seepage or saline areas
U	Swamps fringing Lake Zwai on all sides but the north	Organic loam over coarse pumice sand	5YR 5/1	L / S	Water-logged					13.0	7.7 / 8.0	6.7-8.9 / 7.4-8.4	28.5	330 / 160	80-490 / 130-210	24 / 8	16-41 / 2-13	250		Tends to be alkaline in topsoil due to inundation by lake

meq % = milliequivalents per 100 g air-dry soil
CEC = Cation Exchange Capacity
P = phosphorous
ppm = parts per million

L = Loam
Z = Silt
C = Clay
S = Sand
CS = Coarse sand
FS = Fine sand

*Infiltration test on uncultivated land

Blanks are left where no information is available

2. Soil J (together with Jz, a total of 7 070ha or 38.7% of the terrace surface). This comprises fine sandy or silty loam overlying an alkaline subsurface layer of consolidated and poorly structured ash often partially indurated. Subsoil alkalinity may be severe with pH levels of 8.0 to 10.5 and ESP values ranging up to 100 (mean around 40). The combination of fine silty texture, pre-existing structural impedence, and high levels of alkalinity at a shallow depth in the profile, must render irrigation development on these heavier-textured soils a questionable proposition. Compared with Soil H, levels of exchangeable sodium are up to twice as high, clay contents are three to five times as great, and intake rates are already lower by as much as 50%. The high risk of developing drainage impedence with irrigation was confirmed by laboratory leaching studies in which, even using 0.01 molar calcium chloride solution, the rate of leaching through loosely packed, medium-textured, alkaline subsoil was extremely slow. During this process there appeared to be some gel formation, such that the slurry of soil with calcium chloride would filter normally but a slightly viscous solution was obtained. It was concluded that this soil may contain amorphous (opaline) silica derived from volcanic ash. If these soils behaved in the field as in the leaching tests, they could become so impermeable that the leaching requirement could not be met and surface drainage would be essential to remove excess salts.

Soil fertility constraints

As mentioned above, these are less critical than the physical constraints, though certainly already implicated in limiting yields under both rainfed and irrigated conditions. Apart from the most obvious constraint, that of excessive levels of salt and/or alkali in the root zone, which fortunately affects only 1 340ha within the project area, there are two other significant factors, nutrient deficiencies and deficiencies induced by high pH levels. The soils are already low in phosphate, copper and to a lesser extent manganese. Although rainfed crops grow well on these soils and no deficiency symptoms were observed, the availability of some nutrients could already be a yield-limiting factor even in soils with a surface pH of only 8; any increase in pH could reduce the availability of certain nutrients, notably phosphate, iron, zinc and manganese, possibly inducing chemical imbalance. Under irrigation, the soil moisture content will be closer to that of a saturated paste than to a soil/water suspension in the ratio of 1 to 5. Soil pH has been measured under both these conditions and some results are presented in Table 34. When the pH is below 9, the saturated paste is up to 1.0 pH units lower than in the 1:5 suspension. However, when the pH is above 9, the difference is less than 0.5 of a pH unit. It is anticipated, therefore, that if the sodium levels are very high, the pH under irrigation would also be high and induced nutrient deficiencies would probably occur.

TABLE 34 Soil pH in the saturated paste and in the 1:5 soil-water extract, derived from representative soils

Soil type	Depth (cm)	pH (saturated paste)	pH (1:5 extract)
H	0-20	6.5	7.2
	20-60	6.3	6.9
	60-110	8.9	9.7
	110+	10.3	10.4
H	0-50	6.7	7.8
	50+	9.0	9.4
J	0-35	7.0	7.7
	35-110+	8.4	9.2
J	0-45	7.4	8.0
	95-125	9.3	9.8

Subsoil alkalinity

Around Lake Zwai, and especially on the Western Terraces, the subsoil exchangeable sodium percentage is frequently above the maximum laid down (ESP of 15) for irrigation suitability (USDA, 1954); although the surface soil is generally free of alkali. It is evident that such a degree of alkalinity would have built up gradually over a long time period, as a consequence of:

1. The weathering of sodium-rich (volcanic) parent material, as demonstrated by the significant excess of total sodium over exchangeable sodium shown in Table 35.

2. The relative concentration of sodium on the soil exchange complex caused by the precipitation of calcium carbonate due to high levels of bicarbonate present during lake terrace formation.

TABLE 35 Total and exchangeable sodium (Na) in selected soils

Soil type	Depth (cm)	Exch. Na (ppm)	Total Na (ppm)	Difference in Na (ppm)
L	0-30	400	2 250	1 850
	65-90	7 050	9 000	1 950
	135-160	6 100	9 000	2 900
H	0-20	150	4 425	4 275
	20-60	100	4 350	4 250
	60-110	2 100	6 675	4 575
	110+	5 700	9 000	3 300
J	0-35	50	3 825	3 775
	35-140+	1 400	6 300	4 900

The detrimental effects of alkalinity (exchangeable sodium) in the soil are essentially two-fold, physical and chemical. The presence of high levels of sodium, associated with a relatively low concentration of electrolyte in the soil solution (as during irrigation), can cause the deflocculation and dispersal of soil clays and organic material; this in turn may lead to structural degeneration, worsening aeration and drainage, reduced rooting capacity and, eventually, near-total impermeability. The point at which physical degradation sets in and the extent of this deterioration are primarily dependent on the soil mineralogical composition, especially the clay mineralogy, the effects of various cementing materials on aggregate stability and the cultivation practice to which the soil is subjected; there is no clear permissable limit with which to evaluate the sodicity (alkali) hazard either of an irrigation water or of a soil sample (Rhoades, 1972). Moreover, failure in the soil physical condition is progressive and may not be evident in the early stages, though it tends to accelerate with time as decreasing permeability hinders the removal (leaching) of salts and alkali in the drainage water. This state is matched by worsening chemical imbalances as pH levels increase and ions critical for plant nutrition either attain toxic proportions or else become unavailable to roots. This combination of poor physical structure with unbalanced fertility can have a devastating effect on crop yields. Since some years may elapse before symptons of alkalinity become apparent, it is essential for long-term preliminary soil and crop experiments to be undertaken in areas where alkali accumulation can be anticipated prior to the initiation of large-scale irrigation.

The question of whether or not salt or alkali will accumulate as irrigation develops is crucial in assessing the suitability of the land for irrigation. On the Meki Delta there must be a real risk of salt accumulation resulting from shallow saline groundwater. Here it will be necessary to install adequate drainage and ensure that the Meki River is prevented from flooding; constant monitoring of groundwater levels and of soil conductivity would be an essential adjunct to irrigation development.

In the case of the lake terraces, the land is sufficiently high lying for a rise of groundwater to rooting depth to be unlikely. There, however, the problem is one of implementing the prescribed leaching requirement through maintenance of pre-irrigation infiltration and permeability levels. Under current climatic conditions, the alkaline subsoils around Zwai are almost permanently dry. The subsoil clays do moreover contain significant quantities of allophane (estimated at around 50% of the clay fraction) and hence the structure is difficult to disperse despite high levels of subsoil exchangeable sodium (20-100%). Introduction of year-round irrigation however provides radically changed conditions; the continuous exposure of the clay minerals to near-saturated conditions will alter the entire physico-chemical state and could induce clay dispersal, so gradually reducing profile permeability until the necessary leaching rate can no longer be achieved. Resolution of this problem is likely to depend on the relative level of soil sodium and the dispersability potential of the allophanic soil material.

So far as sodium levels are concerned, there are a number of conflicting trends which in the case of the initially permeable soils (e.g. Soil H) could result in a long-term reduction, though for the heavier soils (e.g. Soil J) the outcome must be highly problematical. The release of sodium from weathering minerals is likely to be counteracted by release of calcium. The effect of high bicarbonate in the irrigation water, in causing calcium precipitation and hence an increase in the proportion of sodium in the soil solution (Bower and Wilcox, 1965), is likely to be mitigated by the desirably low SAR (ranging from less than 1 to 6). The relatively high levels of exchangeable calcium and low values for ESP in a large majority of topsoils is another favourable feature.

This generally optimistic view is supported by semi-quantitative theoretical models (Rhoades, 1972; Oster and Rhoades, 1975) employed to predict soil water composition at steady-state resulting from the long-term use for irrigation of a water of given composition (Table 36); it should be emphasised however that these predictive models are entirely independent of the initial conditions and have never been tested on soils initially sodic.

TABLE 36 **Projections of electrical conductivity (EC) and sodium adsorption ratio (SAR) for the lower root zone of an intially non-saline non-alkaline soil material following prolonged irrigation with Lake Zwai water: (A) According to Rhoades (1972): (B) According to Oster and Rhoades (1975)**

	Leaching fraction					
	0.1		0.2		0.3	
	A	B	A	B	A	B
EC (mmhos/cm)	4.0	3.1-3.6	2.0	1.6-1.9	1.2	1.1-1.2
SAR	11	12-15	7	6.5-10	5	3.7-6.7

Equivalent projections of EC/SAR in the upper root zone are about 0.5/4 according to Rhoades (1972) and 0.6/2 according to Oster and Rhoades (1975).

Some rather more definite evidence is available regarding the dispersability potential of these volcanic materials. Comparison of mechanical analysis results with and without the use of a dispersion agent (Table 37) demonstrates the fairly high degree of structural stability.

On balance it would appear that the coarser-textured alkaline terrace soils can be recommended for irrigation; their physical characteristics are such that, in the event of a significant increase in topsoil sodium, structural deterioration can only be minimal. An additional consideration is that crops on these soils are currently yielding well under irrigation. In the case of the heavier-textured land however, the levels of subsoil alkalinity are such that a decision on suitability for irrigation must be deferred pending a successful conclusion to long-term field trials. It should further be emphasised that, even in the case of land classified as being suitable for irrigation despite subsoil alkalinity, the irrigated soil should be subject to periodic monitoring at several depths down to 2 m, so that any accumulation of alkali can be detected at an early stage.

TABLE 37 **Mechanical analysis results with and without a dispersion agent (calgon)**

Soil type	Depth (cm)	% Fraction >50 μ		% Fraction 50-20 μ		% Fraction 20-2 μ		% Fraction <2 μ	
		Water dispersion	Calgon dispersion	Water dispersion	Calgon dispersion	Water dispersion	Calgon dispersion	Water dispersion	Calgon dispersion
H	0-50 50+	48 67	47 64	16 12	13 12	26 19	25 20	10 2	15 4
H	0-20 20-60 60-100 100+	63 66 72 48	60 64 72 47	11 11 12 15	12 12 11 16	15 14 10 25	14 13 10 23	11 9 6 12	14 11 7 14
J	0-35 35-140	29 36	28 33	16 18	14 18	40 31	36 31	15 15	22 18
J	0-45	38	26	14	20	38	40	10	14

Because of the complex and intimate association of the coarser-textured and the finer-textured soils (more complex than could be portrayed on Separate Map 2) and, moreover, the highly variable occurrence of both topsoil and subsoil alkalinity, it is essential for irrigation development in the Zwai area to be preceded by a detailed soil survey, with mapping at a scale of not less than 1:10 000 and a minimum sampling density of one site per 4 ha sampled at regular depths down to 2 m. In areas on the Western Terraces with above-average soil variation, sampling may even be required at an intensity of up to one site for every 2 ha.

Land classification

Six classes of irrigation suitability have been defined (Table 38). The distribution of land physically suitable for irrigation is shown on Separate Map 3.

Class 1

This land comprises about 500 ha of Soil A (see Table 33 for a summary of the soil properties) on levees close to the Meki River, in addition to minor areas in the mid-Meki Valley. Soil and topographic conditions are such that there are no serious constraints on the use of this land for irrigation. The soils are deep and friable with no visible indication of poor drainage. Infiltration rates are moderately slow (average final rate averaged about 25 mm/hour), and available moisture,although lower than anticipated in soils with up to 50% clay content, is adequate for the range of crops anticipated. The soils have a high capacity for holding plant nutrients (average topsoil CEC is 39 meq%) and nutrient levels are generally adequate. However, while both total and exchangeable potassium are at a high concentration, there is evidence of a deficiency in both total and available phosphate. There are no harmful accumulations of salt or alkali. The topography is favourable; on the Meki Delta the land falls gently away from the Meki River at less than 1% slope. There is, exceptionally, a slight risk of river flooding, although this is unlikely to occur more often than once in 50 years.

Class 2

Most of the land on the Meki Delta not subject to seasonal flooding nor affected by subsoil alkalinity is included in this class, a total of 2 660 ha; it also occurs on the Catar Delta and in the mid-Meki Valley. This Class 2 land has been downgraded due to slow subsoil permeability in heavy-textured layers, and local subsoil salinity associated with a high saline watertable.

TABLE 38 Irrigation suitability classes (see Separate Map 3)

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Irrigation suitability	high suitability; no special land management required	Moderate suitability; provided adequate subsoil drainage can be maintained	Marginal suitability; use contingent on surface levelling and maintenance of profile structure and permeability	Unsuitable at present; suitability dependent on river and lake level regulation	Unsuitable at present; use contingent on favourable long-term field trials	Unsuitable
Limiting factors	Slight risk of flooding from the Meki River in some areas	Presence of subsoil layers of varying composition which inhibit percolation with a risk of seasonal waterlogging. Some subsoils may be slightly saline	Subsoil alkalinity and/or uneven topography. Poor soil structure and deficiency in some plant nutrients	High risk of flooding	Subsoil alkalinity in soils with moderate to high silt plus clay content	High level of salinity and/or alkalinity throughout the soil profile (ESP > 20, EC in the saturated paste > 4 000 µmhos/cm); or bedrock within 50 cm of the ground surface; or slopes over 5%
Soil Series or Phase	A	B, C, D, G, R	H, Hb, S	E, F, M, T, U	Ba, Ca, Fa, J, Jz, L	N, P and Terrace Scarps
Area (ha)	560	3 730	8 530	5 600	9 130	3 600
% of project area	1.8	12.0	27.4	18.0	29.3	11.6

Subsoil mottling is most intense in lower-lying clay soils on ancient levees; there are even indications that some silty soils are seasonally poorly drained to within a few centimetres of the ground surface (e.g. Soil Type C in Appendix 6). In contrast, the higher-lying levee ridges are less mottled and have topsoils that are well drained throughout the year with a moderately rapid intake (average final rate: 43 mm/hour). Such soils have nevertheless been placed in Class 2 because they coincide with areas of saline groundwater within one metre of the ground surface (Text Map 3). Basin Clays (Soil Type D), although free of mottling throughout the profile, are also grouped in Class 2 because they occur on level sites which, with irrigation, are likely to require drainage. Although under natural vegetation the water intake of this soil is rapid (average final rate: 48 mm/hour), with cultivation and inevitable deterioration in surface structure, intake declines sharply. Topographically, Class 2 land is generally less favourable than Class 1.

Soils in Class 2, although generally fertile, are low in both total and available phosphate (e.g. Soil Type B in Appendix 6). Nutrient levels tend to be lower in sandy layers than in the heavier-textured layers which comprise the bulk of the soil profile. Available moisture is lower than predicted from the texture but adequate for the range of crops anticipated.

Class 3

Class 3 land occurs widely in all parts of the project area other than the Meki Delta. The freer draining coarse-tectured terrace soils have been placed in this class due to the prevalence of subsoil alkalinity (see above). Although sodium accumulation in the topsoil should not decrease the water intake rate, the high proportion of silt present (up to 40%) suggests a risk from surface capping which could both reduce intake and impede crop germination. There is little current evidence for ridge capping on existing irrigated farms, but clearly precautions will need to be taken to ensure that surface capping does not become a serious hazard. The available moisture capacities of these soils are adequate, in the range 10-13%.

Class 3 soils appear to have a higher capacity for retaining plant nutrients than might be predicted from the measured clay content (e.g. Soil Type H in Appendix 6), though this may merely be due to inadequate clay dispersal during mechanical analysis. Although total and exchangeable potassium levels are high, these soils are low in organic matter and have poor reserves of phosphate and copper. The need to prevent the high pH of these soils from rising during irrigation has already been stressed. Orthodox methods of reducing soil alkalinity, such as the application of gypsum, are unlikely to be an economic proposition in the foreseeable future. Clearly, careful monitoring of topsoil sodium levels should be an essential element in the development of the lake terraces.

Although the topography on the terraces is not ideal for surface irrigation, the Class 3 coarser-textured soils generally occur on the lower-lying terraces involving only a limited pump lift from the lake. Because of the risk of exposing alkaline subsoil through removal of relatively shallow topsoil, land levelling would have to be kept to a minimum; this may be a serious problem where the terraces are undulating or where there is a high density of termitaria. Although termite mound constituents were not analysed, the removal of 50 termitaria/ha, quite apart from the cost involved, could add about 1 cm of highly alkaline material to the soil surface.

Class 4

This includes all land affected by seasonal flooding, both on the Meki Delta and around the lake margins. Use is conditional on river and/or lake level regulation to eliminate flooding. The means for reclamation are discussed in Part 6. On Separate Map 3, the potentiality of the land, following flood protection and adequate drainage, is shown by a suffix (e.g. Class 4_2: in this example Class 4 land would, following improvement, be reclassified as Class 2). Thus the clays bordering the Meki and Catar deltas and the North-Eastern Terraces (Types E, F and T), given their inherent fertility and provided they were not adversely affected by alkaline seepage, could ultimately be developed as Class 2 land, whereas soils formed on pumiceous sand along the western lake margins (Types M and U), being inherently less fertile, would, on drainage, only attain the status of Class 3 land.

Class 5

This comprises all land with alkaline subsoil exceeding 20% ESP, other than the coarser-textured soils placed in Class 3. It includes the following soils:

1. Medium-textured loams on the higher Western Terraces (Type J)
2. A silty phase occurring along the North-Eastern Terraces (Type Jz)
3. Lacustrine clay loams flanking the Meki and Catar deltas (Type L)
4. Alkaline phases of alluvial soils on the north-west of the Meki Delta (Types Ba, Ca and Fa)

Average subsoil ESP ranges from about 25 on the North-Eastern Terraces to 50 on the Meki Delta; depth to the alkaline horizons varies from 30 cm to over 100 cm respectively on loam and clay loam terrace soils. Over 75% of the medium-textured terrace soils sampled were found to have a degree of alkalinity exceeding the maximum laid down by the USDA. On the Meki Delta, alkalinity occurs in conjunction with a high saline watertable and a degree of salt accumulation has taken place in the subsoil. Intake rates vary from 25 to over 30 mm/hour.

On all these soils, the widespread occurrence of serious subsoil alkalinity, combined with silt and clay contents sometimes exceeding 85% of the mineral constituents, preclude early development for irrigation. However, since the topsoils are free of alkalinity, in some cases even to below 1 m, and moreover currently growing adequate crops are apparently unaffected by soil alkalinity, the land has been classed as non-irrigable under existing conditions, though possibly warranting tentative segregation for special study before a final decision is reached regarding suitability for irrigation. It is therefore suggested that irrigated soil monitoring be initiated at the earliest opportunity on representative Class 5 land. These investigations would have to be long-term to supply meaningful data regarding the effect of irrigation on structure and fertility. Consequently, once adequate base-line data have been obtained, regular monitoring of selected irrigated farms is recommended, to obtain essential data without the need for formal trials.

Class 6

Four categories of land comprise this class, all being unsuitable for irrigation:

1. Areas affected by salinity and/or alkalinity throughout the soil profile (EC over 4 000 μmhos/cm and generally exceeding 10 000 μmhos/cm, and/or ESP exceeding 20)

2. Areas with shallow soil and bedrock within 50 cm of the ground surface

3. Areas with slopes exceeding 5%, and

4. Urban areas

CROP SELECTION

In the following sections attention is focussed on crops which are expected to produce economic yields under irrigation, whether grown singly or in combination with other crops. The choice of crops is based on their adaptability to local environmental conditions, potential response to irrigation, probable profitability and market prospects, thus excluding those crops for which markets currently appear to be severely restricted or non-existent. Existing land use and farm structure have also been taken into consideration.

Each crop is discussed initially in isolation from the overall farming system. Feasible crop rotations are discussed in a later section taking account of the potential hazards presented by various pests and diseases, timing of the rains, availability of irrigation, and for production inputs (e.g. labour) at the farm level. Proposals for specific inputs (e.g. fertiliser) are tentative and are advanced without regard to immediate feasibility in terms of supply, credit, etc. All commodities are expressed in metric tons and Ethiopian dollars unless otherwise stated.

Cereals

Market prospects

National cereal production in 1972 was estimated to be 7 549 200 metric tons (CSO, 1972), maize accounting for 882 100 tons (14.6%) and tef for 1 382 000 tons (22.8%). Exports of cereals and cereal products in 1972 amounted to 4 586 tons, of which sorghum grain was by far the most important component (Table 39). Imports amounted to 11 664 tons, with wheat, malt and barley grain predominating (Ministry of Finance, 1972). Since 1972, parts of Ethiopia have been affected by drought which has caused severe, though localised shortfalls in supply. It has been estimated by the United Nations that additional import requirements in 1973-4 were about 150 000 tons.

Whether Ethiopia will be able to regain self-sufficiency in cereal production in the near future is open to doubt. With population expanding at 1.8-2.2% each year and cereal production increasing in normal years by only 1.3% annually, the internal market for cereals should remain strong for the foreseeable future. Of all the cereals, maize appears on both economic and agronomic grounds to be the most suitable and is the most widely grown at present. Prices have ranged from $10 to $20/q, but the market prospects seem secure. Construction of a maize-processing plant at Awassa would create an additional outlet. The prospects for maize exports are negligible while internal demand and prices remain high. Moreover, problems of quality and high transport costs would have to be overcome before significant quantities could be exported.

TABLE 39 Imports and exports of cereals and cereal products, 1972 (t)

Commodity	Imports	Exports
Wheat	5 054.9	29.0
Rice	1 093.7	–
Barley	2 000.0	35.7
Malt	2 332.7	–
Maize	114.6	92.0
Sorghum	695.6	4 333.8
Millet	114.1	–
Other cereal grains	33.0	80.0
Flour	67.1	10.0
Other cereal products	138.8	5.2
Totals	11 664.5	4 585.8

Both wheat and sorghum can be grown with success in the project area: wheat to boost local food supplies and substitute for imports, sorghum for transport to food-deficit areas or even for export to neighbouring countries. Wheat prices vary between $15 and $30/q according to quality. In March 1975, grain sorghum was making $20/q at Nazereth.

Agronomy

Of the cereals discussed above, maize, wheat and sorghum can all be grown in the wet season in normal years without irrigation. Rainfed maise production is however a risky proposition and can be expected to fail about one year in six; dry periods at critical times in the growth cycle can have a dramatically adverse impact on yield. Consequently, a very considerable increase in food production could be obtained from the more widespread use of irrigation. Meanwhile, in those areas where only rainfed farming is possible, it should prove worthwhile to promote the production of appropriate higher-altitude varieties of sorghum, a crop which is drought resistant and which regularly out-yields maize in many of the drier parts of East Africa. The major disadvantages of sorghum, apart from the limited local market, are its susceptibility to heavy attacks from the substantial bird population and, compared with maize, the high labour requirement for harvesting, threshing and cleaning. So far as wheat is concerned, conditions are far from ideal and rainfed yields must inevitably be below those at higher altitudes (e.g. in the Chilalo Highlands). Nevertheless, in view of the low humidity in the Zwai area, the disease incidence should not be high and respectable yields should be attainable under irrigation.

Maize yields in the project area ranged from 5 to 15 q/ha in subsistence agriculture and from 10 to 40 q/ha on commercial farms. The wide range of local and introduced cultivars being tested by the IAR throughout Ethiopia should ensure that a progression of improved cultivars becomes available. Their relative suitability for rainfed and irrigated conditions may differ however, and it will be important to establish experiments locally to assess the combined effects of fertiliser and irrigation treatments on different cultivars. It is likely that large responses will be obtained from both nitrogenous and phosphatic fertilizers, especially with irrigation. Under good management with irrigation, yields of 80 q/ha are possible if long-cycle maize varieties are grown. Nevertheless, it could well be advantageous to intercrop maize with either red pepers or groundnuts. Irrigated maize intercropped with peppers or groundnuts would use about 540 mm of water between planting and harvesting the maize; one pre-plant irrigation and three post-plant irrigations would normally be required, i.e. a total allocation of 2 250 m^3/ha for surface application (Appendix 2).

Haricot beans

Market prospects

Production and export of haricot beans showed an upward trend between 1958, when exports amounted to only 6 170 tons, and 1974. After 1970, exports increased rapidly (Table 40), with pulses contributing up to 9% of Ethiopia's annual export earnings.

TABLE 40 Exports of haricot beans

Year	Exports (t)	Average f.o.b. price ($/t)
1970	17 144	396
1971	22 568	443
1972	25 653	402
1973	60 709	513
Source: EGB, market reports		

The dramatic upsurge in exports between 1972 and 1973 was due to shortfalls in North American production, and increasing demand and shortages in Europe, the main centre of consumption. Prices had exceeded $1 000/ton f.o.b. Assab by the end of 1973, but the increasing acceptability of Ethiopian haricot beans should ensure an enlarged share of the European market in the long term.

International prices for haricot beans have fluctuated considerably over the past few years. The major determinant of price levels is the American crop. Thus high production in the USA in 1974 seriously weakened prices, while the prospects of a poor crop in 1975 have had the effect of strengthening them. Between July and August 1975, for example, prices for American Michigan pea beans rose from Eth. $963 to $1 134 per ton c.i.f. London, though poorer quality Ethiopian beans commanded somewhat lower price levels. It is anticipated that prices in the long term should even out at around $750/ton f.o.b. Assab.

Due to local factors, and especially the failure of the marketing system, internal prices for haricot beans fell to unprecedentedly low levels in the first half of 1975 ($120/ton at Zwai; and $190/ton in Nazereth). Nevertheless, once these temporary problems have been overcome, it is anticipated that internal prices will regain normal levels and the prospects for future expansion look promising.

Agronomy

Beans (*Phaseolus vulgaris)* grow well in areas where the mean temperature is between 18°C and 23°C; lower temperatures reduce vegetative growth and germination, and higher temperatures affect pod set (Ohlander, 1974). Too much rainfall and high humidity lead to increased incidence of bacterial and fungal leaf diseases, while drought reduces yield, especially if it occurs in the flowering or pod-filling stages. Haricot beans are well suited to the climate and soils of the project area and are now grown mostly without irrigation from June, July and August sowings. Dry weather is required to ripen and dry the crop and, although much of the harvesting is at present undertaken during dry periods in the wet season, it would be safer to plant so that harvesting takes place in October when the weather is reliably dry. With irrigation, beans could be grown throughout the dry season, though it is advisable to have a closed season after the main rainfed crop is harvested to prevent the transfer of pests and diseases to the new crop. This could be achieved by sowing the dry season crop in January and harvesting it in April or May, with the wet season crop sown in the July-August period.

The white pea bean type of haricot fetches the highest price in export markets, the three cultivars currently recommended by the IAR being Ethiopia 10, Tengeru 16 and Mexican 142. At present the area planted is limited because insufficient seed is saved from the previous crop. Seed, at a rate of 45-55 kg/ha to give 250 000 plants/ha, is best sown for furrow irrigation in rows on flat-topped ridges, rather than broadcast as at present. Current fertiliser recommendations (Ohlander, 1974) are for 100-150 kg/ha of diammonium phosphate at planting, plus extra nitrogen such as urea at flowering if required.

Given adequate water, evapotranspiration from a 90-100 day bean crop in the Lake Zwai area (Appendix 2) is expected to be about 390 mm in the wet season and 450 mm in the dry season. Yields would be increased in most years by irrigating during dry periods in the wet season; with furrow irrigation an average of about

2 000 m^3/ha are required. January-planted crops would respond to about 10 irrigations depending on rainfall, equivalent to field applications of about 5 000 m^3/ha for furrow irrigation.

An expanded area under beans could lead to an increased incidence of pests and diseases; preventative measures such as the 'closed season' mentioned above, rotations and the use of clean seed would be important. Rotations assist in the control of soil pathogens (e.g. *Rhizoctonia, Fusarium* and *Sclerotium* spp) which cause foot rots, and in preventing anthracnose and bacterial leaf blights. Since common blight, halo blight and anthracnose are also seed-borne, seed should be obtained where possible from disease-free sources. Spraying for the prevention of bacterial and fungal leaf diseases and for insect control may be worthwhile in high yielding, high value crops and particularly in seed crops.

Yields of between 5 and 10 q/ha are now obtained, but given improved husbandry it should be possible to produce up to 35 q/ha with irrigation although yields may be somewhat lower because of the relatively low tolerance of beans to salinity.

Peppers

Market prospects

The total annual production of peppers in Ethiopia, including capsicum *(C. annuum)*, red pepper *(C. frutescens)* and bird's eye chilli *(C. minimum)*, is estimated at about 105 500 tons/year (Table 41). Much of this is consumed on-farm or sold locally. In 1972, exports amounted to about 4 600 tons; 952 tons of fresh capsicum were flown from Eritrea to Europe, and the remaining exports were in the form of dried or ground pepper. In addition, approximately 120 tons of oleoresin pigment extracted from red peppers were exported, principally to the United States (Table 42).

TABLE 41 **Ethiopian production and export of peppers, 1968-72 (t)**

Year	Production	Exports
1968-9	97 300	1 565
1969-70	99 500	4 579
1970-1	102 200	1 300
1971-2	105 500	4 579

Sources: CSO, Annual External Trade Statistics, 1972
CSO, 1972

World trade in dried red pepper amounts to about 35 000 tons/year. There are great variations in price depending on pungency, colour and quality. The Ethiopian Spice Extraction Company in Addis Ababa buys dried red peppers both for oleoresin extraction and for ground pepper. After five years of operation, the factory was still not working to its full annual intake capacity of 10 000 tons, due to inadequate and low quality supplies. About 40% of the supply originates from the Butajira area which, in the company's view, produces the best quality peppers. Market prices for peppers are high, ranging from $60 to $100/q at the farm gate. The internal market is firm and export prospects for dried peppers, extracts and fresh capsicum flown to Europe are all good, provided the stringent quality requirements of the terminal markets can be met.

Agronomy

In the more humid areas near Butajira, red peppers already constitue up to 15% of the cropped area. Seed saved from the preceding crop is sown in nurseries in February and March and transplanted at the start of the wet season. The mature crop dries off during October and November. The fruit is dried on the plant and picked in a single terminal operation.

TABLE 42 Breakdown of pepper exports, 1972 (t)

Product	Exports
Capsicums	952
Whole dried peppers	3 589
Ground pepper	38
Total	4 579
Oleoresin pigment (derived from red peppers)	121

Source: CSO Annual External Trade Statistics, 1972

Yield and quality could be much improved by using new cultivars selected at Awassa (IRAT, 1971), by applications of nitrogenous and phosphatic fertiliser, and by keeping the fruit clean after harvest. The crop is currently grown as a pure stand; with irrigation it could be intercropped using maize as a nurse crop until the bushes have established. A maize/red pepper intercrop is already successfully grown in Kenya. After harvesting the maize in October, the peppers given regular irrigation could be picked from October to March. Since the fruit would be harvested fresh instead of dry, a system of slow drying under cover would need to be developed.

Peppers are prone to many pests and diseases, which are largely responsible for the low yields of 4-10 q/ha now obtained. Rotations should be used to reduce problems from root-knot nematodes and bacterial wilt, and to control the parsitic weed, *Orobanche ramosa,* which is already present in the area. The local red pepper cultivars will have evolved a relatively high degree of natural resistance to pests and diseases; this resistance may not however have been passed on to the new improved varieties. Serious problems have developed at the Awassa Research Station where a 7-year break between solanaceous crops is now being advocated. There, the incidence of nematodes is of particular concern. In the future, breeding for nematode resistance in peppers and other solanaceous crops can be anticipated, but meanwhile the nematocide carbofuran is recommended, applied as 10% granules at a rate of 3.5 kg/ha to the pepper nurseries. Carbofuran has the advantages of being reasonably priced and simply applied, as well as acting as an effective soil insecticide. Bacterial leaf spot and anthracnose should be controlled by protective sprays of copper and dithiocarbamate, and by the use of clean seed. Mosaic viruses which currently reduce the vigour of the crop throughout the project area can be rendered less virulent through the use of resistant cultivars. With good pest and disease control it should prove possible to increase rainfed yields in the wetter areas to 20 q/ha. With irrigation and a six-month harvest period, yields of 35 q/ha could be obtained; even 60 q/ha should be attainable.

Irrigated pepper plants would require about 17 applications totalling some 475 mm of water during the picking period between October and March; a total of 8 500 m^3 water/ha should therefore be allocated for surface application (Appendix 2).

Groundnuts

Market prospects

Production and export of groundnuts and groundnut cake since 1968 is shown in Table 43. Most of the groundnuts produced in Ethiopia are consumed locally and exports are relatively insignificant.Indeed, exports, principally comprising unshelled nuts, have declined from 7 130 tons in 1964 to only about 1 000 tons in recent years. Oilcake exports have been rising however and in 1972 amounted to almost 4 000 tons.

TABLE 43 **Production and export of groundnuts, 1968-72 (t)**

Year	Production	Exported nuts	Exported cake
1968-9	20 900	1 866	2 013
1969-70	22 400	651	2 021
1970-1	24 200	1 327	2 407
1971-2	26 400	1 133	3 895

Source: EGB, 1973

Groundnut oil is not widely used in Ethiopia but the consumer will readily substitute one oil for another, the preference being for bland cooking oils. Sunflower oil, for example, was almost unknown in Ethiopia before 1968 but is now widely used, and there is no reason why groundnut oil should not become popular if it is competitively priced; the oil can moreover easily be produced locally using small village presses. Indeed, the overall demand for vegetable oils is increasing at about 3% a year. The export market for groundnuts is also attractive and the world market price is expected to continue at its current high level due both to increased demand and declining supplies.

Agronomy

Although groundnuts are not grown in the project area at present, the climate and soils are generally suitable. The duration of the growing season would be between 100 and 140 days depending on the cultivar grown, the shorter-cycle varieties possibly being adapted to cultivation without irrigation; this possibility should be tested in field experiments.

Groundnuts could be grown either in a pure stand or intercropped with maize under irrigation. Maize/groundnuts is a traditional intercrop in some parts of Asia, where a favourable ecological balance develops resulting in less pest damage. The two crops can be planted in alternate rows after ridging for furrow irrigation. Cultivars should be chosen so that both crops can be planted at the same time, the maize being harvested first. About 80 kg/ha of groundnut seed is required, spacing in the row depending on whether bunch or runner types are used. No additional fertiliser is required for the interplanted groundnuts over and above that applied to the maize and, though some crop protection measures will be required, these should be relatively few and inexpensive. If the crop is planted in early July, harvesting should take place under dry conditions in October or November. After windrowing and drying, the nuts are picked from the haulm and stored at 8-10% moisture content. It is important for the crop to be lifted when the greatest percentage of nuts are mature, as timing markedly influences yield. Since most of the Zwai soils are easily worked, loss of nuts due to breakage during lifting should not be a major problem.

Yields of 15 to 20 q/ha could readily be achieved; the potential yield with good management and irrigation is 40 to 60 q/ha. The irrigated crop planted in early July would require about 520 mm of water if interplanted with maize (Appendix 2). A pre-plant irrigation of 75 mm to bring the soil to field capacity and three subsequent surface irrigations of 50 mm each should suffice in most years (i.e. a total field allocation of 2 250 m^3/ha).

Sugar

Production of refined sugar in Ethopia is controlled by a single nationalised company operating two estates in the Awash Valley. Small quantities of cane are grown elsewhere but such production is negligible.

Market prospects

In 1972-3, total sugar production amounted to 135 000 tons of which 36 000 tons were exported, the remainder being consumed within Ethiopia. Per capita consumption, at about 4 kg/year is low, and lower than that in neighbouring countries (average per capita comsumption overall in developing countries is about 13 kg). Income elasticity of demand in Ethiopia is approaching 1.0; demand has been growing rapidly and will continue to do so as living standards improve. Between 1968 and 1973, the average annual increase in demand was 6% and, if this is sustained, Ethiopia will need to import sugar by 1980 unless production is expanded beyond the current capacity of 150 000 tons a year.

If these projections hold, a decision to establish a new estate should be taken before 1977, since at least five years must elapse between that decision and production of the first sugar. A new modern factory with a capacity of up to 150 000 tons could cater for Ethiopia's requirements until the middle 1990's, when it is estimated that per capita consumption will be just under 10 kg. In the meantime there should be opportunities to export significant quantities of surplus sugar to neighbouring sugar-deficit countries, such as Yemen, TFAI (Djibouti), Saudi Arabia and Kenya. With sugar prices on the world market reaching an all-time high in 1974 this is currently an attractive prospect, although world prices in the past have been notoriously variable. The capital costs of such a project would be enormous, probably approaching US$120 million. The problems in raising the finance and the risk involved in an enterprise of the size suggested are considerable.

An alternative prospect would be for a smaller project catering for the more immediate domestic needs of Ethiopia, e.g. one producing 50 000 tons of sugar annually from about 5 000 ha. Some economies of scale would inevitably be lost, but viable projects based on outgrowers' production have recently been established with success in Kenya and elsewhere, and the cane area and factory size have been less than that required for a fully developed estate. A ratio of land cultivated by nucleus estate and by outgrowers of about 1:3 has been found to be feasible; indeed a ratio of this order ensures reasonable farm incomes for a maximum number of producers, though with concomitant organisational problems, especially where irrigation is involved. The difficulties in establishing such a system at Zwai would include: (a) location of 5 000 ha of irrigable land which is not uneconomically dispersed (see Separate Map 3), (b) acquisition of a block of at least 1 400 ha for a nucleus estate, and (c) ensuring that sufficient land is committed to a cane rotation.

Garg (1974) has described very small sugar-producing units in India capable of processing only 100 tons of cane a day; such units produce a lower grade of sugar, and recovery rates are not as high as for conventional mills. The estimated cost of a plant of this size, which would require annually only between 300 and 500 ha of cane, is approximately US $100 000. Technical and economic feasibility have reputedly been established, and it is suggested that the possible performance of such a plant operating in conjunction with a high dependence on outgrowers' production be further investigated. More sophisticated forms of mini-mill are also feasible, employing special techniques to raise sugar extraction rates and with as little as 60 ha under cane (Tainsh, 1975).

In the outgrowers system of cane production the investing company buys cane under contract from the farmers and installs and operates a central factory and nucleus estate. The company provides the necessary expertise and discipline to ensure an adequate supply of cane to the factory and high standards of management in irrigation and cultivation. The individual farmers maintain their independence and can continue to produce other crops in rotation with cane.

There are possible alternative uses for sugar cane; the Canadian Comfith process, in which the pith is used for livestock feed leaving the rind for use as a building material, could have relevance in future developments at Zwai.

Agronomy

Most of the world's sugar cane is grown in the lowland tropics as a series of 12-month ratooning crops. At cooler, higher altitudes the growth rate is slower and the growing period is extended accordingly to 15-24 months. Nevertheless, average sugar yields equal to those at lower altitudes can be obtained, since there are fewer harvest breaks, an increased duration of leaf cover and higher sucrose contents. Annual yields of 12-14 t/ha of raw sugar are obtained at Wonji in the Awash Valley, at an elevation of 1 550 m and only 30 km from the project area. A 22-month plant cane crop is followed by four or five ratoons of 15-18 month duration. The mean daily maximum temperature at Zwai is 26.9°C compared with 28.8°C at Wonji, but the mean minimum at Zwai is significantly higher than that at Wonji (11.7°C compared with 7.5°C). The warmer nights at Zwai during the dry season would be advantageous for the germination and growth of newly planted setts. The finer-textured clays and clay loams of the Meki Delta are well suited for cane. Good growth could also be obtained on the coarser soils to the west and south of Lake Zwai given frequent irrigation, but the utilisation of surface irrigation would be less efficient.

Although sugar cane is agronomically well suited to the project area and would give a better return on investment per unit area than almost any other crop, a crucial problem would be finding sufficient land around the lake to sustain an economically-viable conventional factory.

Grapes

Market prospects

Ethiopian wine production amounted to approximately 5.5 million litres in 1970-1 (Table 44). As there are insufficient grapes in Ethiopia to supply the industry, the three main manufacturers (who produce 90% of total production) imported about 350 tons of dried grapes and 50-100 tons of grape liquor (must) from Greece, Turkey, Israel and Italy (Table 45). The total cost in foreign exchange amounted to $380 000-$424 000. Local producers supplied for wine production no more than 175 tons of fresh grapes. Overall, wine consumption has been increasing gradually, and is expected to expand further with increasing population and incomes. There is therefore a significant market for locally produced grapes and any proposal to increase the area under vines should intially be considered as a means of import substitution.

TABLE 44 Production of wine in Ethiopia, 1968-71 (litres)

Year	Production
1968-9	5 023 700
1969-70	5 095 000
1970-1	5 545 400
Source: CSO, 1972	

TABLE 45 Raw material utilisation by the three main wine producers in Ethiopia, 1971-2

Company	Fresh grapes (t)	Dried grapes (t)	Grape must (t)	Estimated production (l)
Makanissa	60	6	-	360 000
Sarris	65	240	50 - 100	4 100 000
Altavilla	48	100	-	450 000
Total	173	346	50 - 100	4 910 000

Current prices (c.i.f. Ethiopia, 1974) for dried grapes are $0.65-$0.75/kg. Even with an import tariff of 50% *ad valorem* and allowing for commission and transport charges, the wholesale price of Ethiopian-grown fresh grapes varies between $0.60 and $0.90/kg which, at a fresh to dried ratio of 3:1, is equivalent to a dried grape price of $1.80-2.70/kg. It is uncertain which commodity acts as price leader but, for fresh grapes to acquire a larger share of the wine market, both the price and the costs of production will have to be substantially reduced. In 1973, imports of dried grapes and grape juice were equivalent to about 1 500 tons of fresh grapes; assuming annual yields averagjng 5 t/ha, the additional area needed to satisfy the domestic wine market would be about 300 ha. At present, tariffs on wines imported into Kenya and other countries of the East African Community are prohibitively high for Ethiopian wines, even in competition with European wine. If however, Ethiopia were to join the Community, this would open up major opportunities for exporting wine.

Consideration also needs to be given to the small local domestic market for table grapes; this is largely confined to Addis Ababa. Other markets which could be exploited include the Middle East (particularly Saudi Arabia) and Western Europe.

Agronomy

Grapevines grown under a Mediterranean climate have a cycle of growth which is adapted to two distinct temperature regimes: a cold period (<10°C) to induce dormancy, and a warmer period (>10°C) when the plant breaks dormancy to bud and fruit. When vines are grown under equatorial conditions, however, the plant has no defined phenological cycle and tends to retain its leaves unless water stress induces dormancy. In Ethiopia, rainfed vines produce one crop a year. With correct pruning and irrigation, vines could probably be induced to fruit twice a year, possibly in November and June. At a similar latitude and elevation in the Coimbatore area of Tamil Nadu, Southern India, the *Vitis vinifera* cultivar Anab-e-Shahi has been induced to fruit three times a year yielding annually up to 25 t/ha (Madhava Rao, 1970). Closer to Ethiopia in the Jebel Marra area of Western Sudan (13°N), the double cropping of grapes at altitudes exceeding 1 500 m is usual under irrigation. Cropping occurs in March/April and October/November and the yields obtained have ranged from 12 tons to over 30 tons/ha. At these yields, the gross value of production in Ethiopia would have been $7 500-$18 000/ha (1974 prices).

The ability to induce two growth periods in a year is dependent on forcing the vine into early dormancy. This may be achieved by causing water stress after harvesting or by pruning. Cultivars adapted to equatorial conditions can be obtained either from Southern India or from South American countries such as Ecuador, Colombia or Venezuela. It is recommended that a programme of trials with both wine and table cultivars is carried out over several years at a number of representative sites to determine:

1. Whether double-cropping is feasible and, if so, the yields and quality of fruit that can be obtained

2. Planting, spacing, trellising, and pruning methods

3. Fertiliser and irrigation requirements

4. Suitable plant protection measures

The overhead arbour system of trellising, though costly, could well prove appropriate. This provides a stable support for the vine while sheltering the fruit against bird attack, gusty wind and sun-scald. The development of the vine is lateral, so exposing the vine arms equally with consequent higher yield due to the improved conditions for fruit development. The vigorous growth of some cultivars will need to be checked regularly by a suitable pruning programme if the vine is to remain healthy; otherwise growth is soon restricted to the periphery, so depriving it of leaf cover and exposing it to sun-scald, which could cause failure or even premature death. On a range of varieties at Thika (1 350 m) in Kenya, a pruning technique favouring development of the lateral buds caused an appreciable improvement in both leaf production and fruiting (Shalitin, 1974).

Fungal and virus diseases ought not to be too prevalent in the project area owing to the low humidity, though care will need to be taken to use disease-free stock when introducing planting material. The need for fungicidal sprays, particularly copper (which may also be beneficial as a nutrient), should also be assessed. It is anticipated that both nitrogenous and phosphatic fertilisers would also be required.

A record of temperature, rainfall, humidity and irrigation applications should be kept at experimental sites so that growth and fruit production can be related to these factors. Possible limitations are low night temperatures during the January to May period, and rainfall interfering with a June harvest. A June crop might therefore have to be sold to the wineries as fresh fruit, since at least one month of warm rainless days is needed for field drying. Research is already being carried out by the IAR at Melka Werer, Koka, Jima, Bako and Adi Ugri on some 20 imported table and wine cultivars; this needs to be extended to the project area before large-scale plantings can be recommended.

Vegetables

Prospects for vegetable production on irrigated farms in the Zwai area are favoured by the equable temperatures prevailing throughout the year, by the absence of frost, and by soils with suitable physical properties. With irrigation, it should be possible to grow and harvest a wide range of vegetable crops thoughout most of the year, the main constraints being lack of technical knowledge and skill in both production and processing, and possible difficulties in marketing.

The markets for vegetables are considered under the following headings:

Fresh vegetables
Canned vegetables
Processed tomato
Dehydrated vegetables

Agronomic requirements of individual vegetables are discussed after marked prospects.

Market prospects — fresh vegetables

The home market for fresh vegetables is limited, and any foreseeable increase in demand can be met with only a small increase in area devoted to vegetable crops. Large-scale production must necessarily depend on overseas markets. Figures for exports of fruit and vegetables are given in Table 46.

TABLE 46 Exports of fresh fruit and vegetables from Ethiopia, 1969-72 (t)

Year	Exports
1969	8 491
1970	6 876
1971	7 764
1972	9 406

Source: CSO, Annual External Trade Statistics

In 1972, 202 tons of onions and about 400 tons of tomatoes were exported direct to TFAI (Djibouti) and Somalia. The onions are however generally of the shallot type; bulb onions grown from seed are less common. The markets of TFAI and Somalia are both capable of limited expansion and, indeed, tomatoes grown in the project area in 1974 were exported to TFAI. Expansion prospects for onions largely rest with bulb onions rather than shallots.

In 1972, Ethiopia exported by air-freight over 3 000 tons of fresh vegetable produce to the off-season European market; this primarily consisted of beans, capsicums and courgettes from Asmara. Although opportunities exist for increasing air-freighted exports, sales to the European market are limited by the relatively short season, by intense competition from Mediterranean countries and, in Ethiopia, by the shortage and high cost of aircraft space. Those vegetables for which demand is still strong in off-season European markets include fresh beans, aubergines and capsicums. The opening of the Suez Canal may allow export by sea of additional fresh vegetables and fruits, especially tomatoes, grapes and citrus. An early appraisal of the potential for expansion in this market is suggested.

Market prospects — canned vegetables

Here the prospects are not good. A narrow range of canned vegetables is already produced in Ethiopia, but quality is generally poor and the price high, indeed often barely competing with comparable imported products. Canning vegetables for the export market is constrained by high quality requirements, static demand, and the high cost of canning materials.

Market prospects — processed tomato

Up to 750 tons of double-strength tomato paste are produced and consumed in Ethiopia, in addition to 300 tons of tomato juice and tinned tomato (Kissmeyer – Nielsen, 1970). Approximately 100 tons of puree, juice and extract are imported from Italy and Israel. Ethiopian products are highly priced, and can compete with imported produce only through protective tariffs and import duties. The former Elaboret Estates, which manufacture the bulk of Ethiopia's tomato paste, produce 100 g tins at an ex-factory cost of 20.5 cents. The equivalent quantity produced in Italy and sold c.i.f. Massawa costs only 8.5 cents. This difference in price can be attributed to inefficient high cost production and the high costs of canning materials, packaging and transport. However, consumption of tomato puree and extract is expanding rapidly both in the Middle East and in East Africa; total annual demand in these areas was estimated in 1974 to exceed 35 000 tons. Given the advantages afforded by the Ethiopian climate (particularly in the Zwai area), it should not be impossible to enter this market.

The prospects for tomato processing in Ethiopia have already been evaluated in two reports by Kissmeyer-Nielsen for UNIDO (1970 and 1971). The reports suggest that a tomato paste production unit could be economically viable, requiring some 600 ha of tomato crop yielding about 60 t/ha. It was further suggested that the Awash Valley would be a favourable location both for the factory and for the estate producing the tomatoes. New machinery imported from Italy and costing $1.6 m (at 1970 prices) would be installed. The projected annual production of 5 500 tons of triple-strength paste could be exported in large 5 kg tins (to reduce the costs of canning) mainly to the markets of the Middle East. The rising cost of imported technology and expertise, which would initially be indispensable at every level, must cast some doubt on the present feasibility of such an enterprise. Plant costs and farm input costs, such as fertiliser, have outstripped the price rise for tomato paste since 1969. The projected yield of 60 t/ha and the low production costs of $30/ton would both appear optimistic and an updated re-evaluation is recommended. If this proposal should still prove to be feasible, in view of the superlative growing conditions for tomatoes, consideration should be given to siting the factory in the Zwai area.

Market prospects — dehydrated vegetables

Dehydrated vegetables are easy to handle and store, lower in weight and bulk than fresh vegetables and inexpensive to pack. The market has been expanding since the Second World War. It was estimated (TPI, 1971) that in 1969 world imports amounted to over 50 000 tons, of which 46 000 tons were imported by Western Europe. TPI projected that, by 1975, the European market would have expanded by 19% above that in 1970, principally in France, Italy, Germany and the UK. Most countries do not distinguish between the various types of dehydrated vegetable in their trade returns; consequently it is not possible to determine the precise quantities traded. However, estimates of quantities and of the relative importance of different markets are indicated in Tables 47 and 48. By far the most important dehydrated vegetable is onion, accounting for over 40% of the total market. Other significant exports are potatoes, tomatoes and carrots.

TABLE 47 West European imports of dehydrated vegetables, 1970

Dehydrated vegetables	Imports (t)	% of total
Onions	18 685	40.5
Potatoes	5 832	12.7
Tomatoes	2 662	5.8
Carrots	1 504	3.3
Herbs	1 193	2.6
Peas	1 130	2.5
Mushrooms	1 066	2.3
Leeks	1 058	2.3
Green beans	548	1.2
Garlic	163	0.4
Celery	163	0.4
Swedes	160	0.4
Cabbages	85	0.2
Cauliflowers	67	0.1
Peppers	62	0.1
Asparagus	34	0.1
Unspecified	11 749	25.1
Total	46 161	100.0

West European countries include the EEC, Switzerland, Austria, Norway and Sweden.

Sources: TPI, 1971. International Trade Centre, 1972

TABLE 48 West European countries importing dehydrated vegetables, 1970

Country	Quantity imported (t)	% of total
United Kingdom	16 594	36.0
German Federal Rep.	13 270	28.8
Netherlands	6 721	14.6
Switzerland	2 520	5.5
France	1 817	3.9
Italy	1 445	3.1
Sweden	1 065	2.3
Austria	894	1.9
Norway	839	1.8
Denmark	566	1.2
Belgium/Luxembourg	430	0.9
Total	46 161	100.0

Sources: TPI, 1971. International Trade Centre, 1972.

Prices for dehydrated vegetables rose considerably during 1973-4 to record levels (see Table 49). It is considered that, though prices may weaken somewhat in the future, they are unlikely to decline to 1970-1 levels.

A number of countries already produce dehydrated vegetables, the USA being by far the largest but, although the quality is good, prices are high and little is exported. East Europe produces considerable quantities, much of which is exported to Western Europe. Other producer countries include Egypt, Portugal, Morocco and Taiwan. Most purchasers have stringent quality requirements with regard to bacterial count, dehydration time, moisture content, and freedom from foreign matter and additives The market is dominated by a small number of soup manufacturers, but there is evidence that new suppliers are welcomed providing quality is good, prices are competitive, and supply is orderly. It is believed that, overall, a real opportunity exists to develop vegetable production for the dehydrated market, given a determined and sustained sales drive.

TABLE 49 **Price ranges for selected dehydrated vegetables (£s/ton) c.i.f. London**

Vegetable	Type of product	1970-1	May 1973	June 1974
Onions	kibbled powder	496 – 606 441 – 496	350 – 551 287 – 350	940 – 1 008 717 – 762
Potatoes	dice flake powder	165 – 298 n.a. n.a.	264 264 – 300 154 – 220	n.a. n.a. n.a.
Tomatoes	flake powder	n.a. 606 – 1 102	1 103 800 – 840	1 428 – 1 523 n.a.
Carrots	flake dice powder	n.a. 331 – 397 n.a.	485 – 520 460 – 500 480 – 500	762 – 850 n.a. n.a.
Cabbages	flake	551 – 661	573 – 661	1 047 – 1 142
Leeks	flake	474 – 827	661 – 772	595 – 935
Garlic	powder	309 – 661	370 – 500	580
Celery	flake powder	441 – 992 n.a.	992 882	n.a. n.a.
Asparagus	tips centre-cut powder	4 409 – 5 511 2 756 – 3 307 882 – 1 212	6 615 3 307 – 5 733 992 – 1 380	2 240 – 3 360 (air-dried) 7 280 – 7 840 (freeze-dried) 1 130
Capsicum	all types	882 – 1 543	1 102 – 1 500	2 120 – 2 350
Beans	cross-cut sliced	882 496 – 827	1 102 992	1 428 – 1 523 1 428 – 1 523

n.a. : not available
Source: Information from TPI, 1974

Most dehydration plants use the hot-air process, but recent developments are based on the principle of vapour pressure differentials, using air circulated around vegetables under relatively low temperatures. This latter method has least detrimental effect on flavour, texture, colour and nutritional value; also running costs are reputedly low (approximately 27 cents/kg at 1974 prices).

Although processing plants can be installed with almost any capacity, economies of scale are considerable. It is generally accepted that the minimum economic size for a modern plant is one capable of processing about 50 tons of raw vegetables daily. A plant of this capacity working 300 days/year would need a cultivated area of 500 ha of vegetables assuming single cropping and a hypothetical yield of 30 t/ha. The modern trend is to integrate processing with crop production. Some processing plants are supplied with produce from their own estates; others enter into forward contracts with growers, often providing them with seed, chemicals and advice; still others combine both systems. To maintain continuity of supply, it is necessary for growers to operate under regulation. Intermittent supply and lack of standardisation of the raw material seriously impare processing efficiency. Some plants attempt to process too wide a variety of vegetables; this creates discontinuity in the process by requiring plant reorganisation and cleaning as one vegetable succeeds another. Newly-installed plants normally concentrate on two or perhaps three vegetables, of which the harvesting seasons do not overlap to any extent.

Costs of processing are not readily available. The f.o.b. UK port cost of a plant processing 50 tons of fresh produce a day was estimated (1974) to be approximately £500 000. Given a life of 15 years for such a plant, over $ 180/ton would need to be charged on the dehydrated produce to recover the capital and installation costs (at 10% interest rate). Most processing plants offer significant employment opportunities in the cleaning, preparing and packaging of vegetables.

Since the prices for dehydrated vegetables are principally determined by the end-purchasers, the farmer in effect receives the residual after deduction of processing, transport and marketing costs. Although it is usual for vegetables destined for dehydration to be below the prevailing fresh market prices, the convenience of supplying large volumes to an assured local outlet has considerable advantages from the point of view of the farmer. Table 50 shows the price the farmer could expect to receive for factory-delivered vegetables, as deduced from varying terminal market prices and dehydration ratios. These calculations assume that 45% of the value at Zwai of the dehydrated product represents the cost of processing. Table 50 is therefore a guide to possible price levels at the factory gate.

TABLE 50 Derivation of prices ($/ton) that could be paid for factory-delivered fresh vegetables at Zwai, based on a range of prices for dehydrated vegetables c.i.f. London and on varying dehydration ratios

London prices	Value of dehydrated vegetables at Zwai	Price payable for fresh vegetables on delivery to factory at various dehydration ratios						
		5:1	6:1	8:1	10:1	15:1	20:1	25:1
1 350	915	101	84	63	50	33	25	20
1 800	1 365	150	125	94	75	50	38	30
2 250	1 815	197	163	123	98	65	49	39
2 700	2 265	249	207	156	125	82	62	50
3 150	2 715	299	248	187	149	99	75	60
3 600	3 165	348	289	218	174	115	87	70
4 050	3 615	398	330	249	199	131	99	80
4 500	4 065	447	371	280	224	148	112	89
9 000	8 565	942	782	589	471	311	236	188
13 500	13 065	1 437	1 198	898	719	474	359	287

Assumptions: 1. Transport and handling costs, Zwai to London, at $435/t
2. Cost of dehydration = 45% of the value of dehydrated vegetables at Zwai

In view of what has been said above, it is recommended that any projected dehydration plant should initially concentrate on the processing of onions, sweet peppers, and carrots. It is emphasised that dehydrated tomato should only be considered at a later date, since different machinery and processing methods are required. With increasing proficiency and experience, other vegetables could be tried, including leeks and green beans. Current (1974) London prices paid for dehydrated onion are about £900/ton ($4 050/ton). With a dehydration ratio of 8:1, the farmer could expect a price of $249/ton for fresh onions delivered to the factory gate (see Table 50). In the case of dehydrated carrots, presently fetching about £700/ton ($3 150/ton) in London, the farmer could expect $149/ton for fresh carrots, assuming a dehydration ratio of 10:1. These returns are well above the estimated costs of efficient production.

Agronomy - tomatoes

Temperatures in the project area between August and March are very favourable for tomato production and good yields are possible with irrigation. Frost is most unlikely near the lake and nights are generally warmer than at Awassa, for example, where due to low night temperatures growth is often slow and the plants tend to succumb to disease. Moreover, fruit set at Zwai is not adversely affected by heat as in some hotter lower-lying areas.

Marglobe is one of the chief cultivars now grown and, although the size and quality of the fruit is excellent, better yields could probably be obtained from more recent disease-resistant cultivars developed in the USA. Tomato leaf blight *(Phytophthora infestans)* is the main problem and sulphur and dithiocarbamate fungicide sprays are currently used. The necessity for protective spraying at frequent intervals is appreciated by most farmers, though some start spraying too late or do not achieve adequate cover; in 1974 some crops were completely killed by the disease. Few farmers understand the importance of crop rotation and tomatoes are currently being grown repeatedly on the same land; this will inevitably lead to a build-up of soil pests and diseases, such as root-knot nematode, *Fusarium* wilt and bacterial wilt, and of *Orobanche,* the parasitic weed.

Plants raised in seed beds are transplanted in August to short rows on ridges; later they are individually staked (Plate 7). On most farms the crop is irrigated twice a week throughout the vegetative and fruiting period, using 90-100 mm of water a week. Since the consumptive use can only be about 35 mm per week, nearly 2/3 of the water applied drains away. A short irrigation interval is desirable but, since it is not practicable with present methods to apply less than 500 m^3/ha at each application, it is suggested that the irrigation interval in the picking period be extended to five days, with a total of 38 irrigations between August and March: i.e. a field allocation of about 18 000 m^3/ha. Current tomato yields are between 10 and 20 t/ha, and with present production methods costs are very high. Greater yields at lower cost could be achieved by the large-scale field production techniques developed in the USA; for example, by using determinate cultivars which ripen evenly and do not require staking, and by direct seeding to avoid transplanting. Such developments should be possible in the future but less sophisticated forms of production are more suited to the area at the present time.

Agronomy — onions

While vegetatively propagated shallots will retain some importance for local consumption, consideration is given here to bulb onions grown from seed. Onions are daylength sensitive; therefore cultivars developed in temperate zones do not form bulbs in the short days of the tropics. Although some short-day cultivars have been developed in southern USA, these are mostly mild-flavoured or red in colour, and are not suited for dehydration. Promising new short-day onion cultivars were produced at Nazereth in 1972-4 by T Jackson, through selections from the indigenous Sudan cultivars, Dongola Brown and Dongola White (IAR, 1974). These selections are now renamed Mermiru Brown and Mermiru White; they are pungent, good quality onions, which will store for three months or more and bulb all the year round in the project area. The white cultivar has a high solids content and is suitable for dehydration. Seed stocks of both cultivars are now being built up, and it will be possible to produce seed in the project area from selected mother bulbs.

The first onion crop could be planted in May or June followed by successive sowings until January. Thereafter, it would be possible to harvest and supply a dehydration plant during the dry season months from October to May, but it would be inadvisable to harvest during the wet season since field drying would be difficult. In the westerly more humid mid-Meki Valley, it might be possible to grow onions without irrigation in the wet season (but there would be transportation problems if a processing plant were sited near Lake Zwai).

An irrigated 140-day onion crop in the vicinity of Lake Zwai would use about 460 mm of water in the wet season and about 520 mm in the dry season (Appendix 2). Although the crop can survive 10-14 day drought periods once established, yields are enhanced by short irrigation intervals. Crops grown from May-June plantings would benefit from up to seven irrigations under average rainfall conditions near the lake; later dry season crops would require about 20 irrigations for maximum yield. The water delivered to the field for surface application would therefore range from 3 500 to 10 000 m^3/ha.

To obtain high yields, onions must be closely planted. The optimum population density is about 750 000 plants/ha which is rarely achieved by hand transplanting (Plate 8). There are therefore important advantages in direct seeding onions; either hand-pushed or tractor-operated drills can be used for this. Direct seeding would eliminate the transplanting operation, though weed control could prove a problem in the early

PLATE 7 Irrigation around Lake Zwai: tomatoes

PLATE 8 Irrigation around Lake Zwai: onions

seedling stage. Onion yields are notoriously dependent on husbandry skill and the crop is a demanding one for the farmer. Timely action is necessary for adequate pest and disease control, and especially for the control of onion thrips which is the major pest. Purple blotch *(Alternaria porri)* was thought to be present on some crops in the area (this requires confirmation); in which case protective dithiocarbamate sprays would also be needed. Onions should be rotated with other crops to prevent a build-up of *Fusarium, Sclerotium* spp and stem and bulb nematodes, which cause rots in both the growing crop and in the stored bulbs. *Botrytis* neck rot and downy mildew are also potential hazards.

Under well managed irrigated conditions,yields of 35 t/ha are possible, but in practice with transplanted crops the expected yield range would be 12-25 t/ha.

Agronomy — minor vegetables

The following vegetables have limited market prospects in dehydrated form or for export fresh, and can be expected with irrigation to grow and yield satisfactorily in the project area.

Carrots The soils and climate are very favourable for carrots, except that heavy rainfall on the lighter soils may result in exposure of the crowns and consequent greening. They should be direct-drilled, preferably by a precision seed-spacing machine to eliminate the need for thinning. Carrots should be rotated with crops resistant to root-knot nematodes. Yields of up to 25 t/ha may be possible.

Leeks Leeks may be grown throughout the year and could prove useful as a crop for dehydrating during the July to September period when wet weather precludes the harvesting of onions. The crop should be ready for harvest about 16 weeks after transplanting but can be held in the ground over a considerable period to obtain increased yields. With close planting and good management, yields exceeding 25 t/ha can be obtained.

Capsicums These can be grown either for export fresh to the European market or for dehydration. Cultural details are similar to those described above for red peppers, but capsicum should not be intercropped with maize. Seed of high-yielding cultivars should be obtained externally rather than saved locally. Capsicum and red pepper must be grown apart to prevent cross-pollination, if seed from either is to be saved. Capsicum can be picked over a long period if well supplied with water, though the highest yields are obtained from the earliest pickings. Fresh capsicum for export must be of very high quality. Yields of 6 t/ha over the October to March period could be achieved by skillful management. At 1974 price levels dehydrated capsicum is likely to be less profitable than either red pepper or fresh capsicum.

Green beans Green beans can be substituted for haricots in the rotation and can be dehydrated or exported fresh. Cultural requirements up to picking are the same as for haricots. The main costs are seed and hand picking. Mechanical harvesters could be used in large plantings where the beans are for processing. Yields of 5-10 t/ha could be achieved by expert management.

Celery. This can also be dehydrated. Rather sophisticated methods of production are necessary, especially in raising the seedlings; the use of pelleted seed is a distinct advantage. Irrigation applications after transplanting must be frequent since the crop is severely affected by even small soil moisture deficits. Costs of production would be high relative to most other crops but yields of over 20 t/ha are possible with close planting.

Asparagus. This is a perennial crop with a limited market in the dehydrated form. It can be produced on soil of moderately high salinity. IAR trials at Nazereth have given promising results from the cultivar Mary Washington (Jackson, 1973). Yields are expected to be about 1.5 t/ha. A major problem would be to prevent the establishment of perennial weeds; nutsedge *(Cyperus rotundus)* is likely to be especially troublesome.

Cabbages. Like leeks, cabbages can be harvested during the rains to extend the season over which dehydration can take place. A good rotation must be used to control the bacterial disease, black rot. The crop could be either grown from transplants or direct seeded. An intensive spraying programme may be necessary to control defoliating caterpillars. Yields of up to 40 t/ha could be achieved by skillful management.

Fodder

The development of irrigated fodder for fattening livestock may be a more notional proposal than most in this report. Irrigated fodder production is not widely practised in Africa, except as part of certain highly commercialised enterprises. However, more intensive livestock production systems with long-term prospects deserve to be considered, even though their applicability to the project area will have to be judged in the light of experimentation, not only on fodders but also on various types of livestock.

In the Middle Awash Valley, up to 40 tons/ha of dry matter have been obtained from an irrigated mixture of Rhodes grass and alfalfa under experimental conditions. In considering the possible utilisation of such fodder, the fattening of sheep is the most attractive proposition, since they demonstrate rapid liveweight gain and efficient feed conversion (better than that for cattle). Sheep can also be conveniently managed in intensive systems, and there is a strong demand for mutton and lamb in much of the Middle East and in Europe. The possible liveweight gain for sheep has been estimated and valued in Table 51, at varying levels of dry matter production and assuming no supplementary feed. Because it is recognised that feed and liveweight gain relationships are difficult to predict, a conservative ratio of 5:1 has been used (Evans, 1960). The gross value of the liveweight gain associated with the higher levels of dry matter production compares favourably with certain of the crops discussed above. However, dry matter content is not the only parameter for gauging liveweight gain; the composition of the dry matter may be equally important. Moreover, no indication can be given of probable costs; these would inevitably be high, because the costs of fodder production would be additional to the costs of sheep husbandry.

TABLE 51 **Projected sheep stocking rate, liveweight gain, and value of meat production at varying levels of irrigated fodder production**

Dry matter production (t/ha)	Dry matter consumed (70% of production) (t/ha)	Number of sheep per ha *	Total annual liveweight gain (kg/ha)†	Value of liveweight gain ($/ha) **
10	7.0	19.2	1.400	1 540
15	10.5	28.8	2 100	2 310
20	14.0	38.4	2 800	3 080
25	17.5	48.C	3 500	3 850

* Computed on the basis of dry matter consumption at a daily rate of 1 kg/sheep

† Assuming a conversion ratio of 5:1

** Price of undressed meat taken as $1.10/kg, a realistic export price for quality meat although slightly higher than 1974 rates for mutton in Ethiopia

Parts of the project area, and especially the lake margins, are considered more suitable for the production of deep-rooting perennial crops rather than annuals. In view of the increasing global demand and the projected world deficit in meat (Commonwealth Secretariat, 1973), it is recommended that long-term field trials be conducted along the following lines:

1. Irrigated fodder trials and investigations into feeding value

2. Assessment of liveweight gain by both indigenous and exotic sheep breeds, including crosses. Attention might later be given to trials on other kinds of livestock

3. Testing the adaptability of various types and breeds of livestock to irrigated fodder under intensive conditions of rotational and zero grazing

4. Testing various production systems, e.g. breeding extensively outside the project area and fattening under intensive conditions in the project area

5. Investigations into disease control requirements

Details of some of these recommendations are elaborated in Part 6 (Research). During these trials it may be shown that intensive livestock production fed from irrigated fodder is both practicable and economic. In that event, significant areas near the lake could be given over to intensive livestock production. The proposed Livestock and Meat Board stock routes north from the Kenya border could, in the future, provide additional outlets for irrigated fodder production.

Other crops

Other crops which have not been considered for development in the short term are discussed briefly below.

Sisal. The international price for sisal fibre more than tripled between 1972 and 1974, standing in October 1974 at over US $1 100/ton. This upsurge in price has been a result of decreased planting in East Africa, a declining supply from Mexico, and an increased demand for natural coarse fibres. Sisal could be successfully grown in the project area and being comparatively drought resistant would do well under rainfed conditions, though it would not respond adequately to irrigation. Sisal could also be useful as live fencing. While there might in the future be a case for establishing a decorticating plant near Zwai, a decision would have to take account, not only of the local demand at the time for sacking, but also of production levels at Awassa, where one decorticator currently (1974) processes leaf from about 1 200 ha.

Kenaf. Could be grown under irrigation, but trials in Kenya have shown that it is not easy to achieve sufficiently high yields. Moreover, apart from the Catar River, there are inadequate supplies of suitable water for retting. Nevertheless, Ethiopia imports about 4 700 tons of jute (for which kenaf is a substitute) at a cost of about $4.0 million. With increasing demand for soft fibre, there is scope for import substitution. Variety TH530 from Thailand is reputedly immune to root-knot nematode, and it is recommended that trials of this and other varieties be undertaken with a view to assessing the prospects for kenaf production in Ethiopia.

Tobacco. Is already grown as a minor crop for local use in the project area and would respond well to irrigation (both the burley and virginia types). However, all tobacco grown for the internal market is controlled by the Tobacco Monopoly which is already engaged in developing a large irrigated tobacco estate in the Bilate Valley. This estate is expected to produce sufficient leaf to obviate the need for imports in the near future. Under these circumstances, there is no case for expanding tobacco production in the Zwai area.

Potatoes. Is an excellent food crop for which there is a growing demand (especially during fasting), albeit a rudimentary marketing structure. At Awassa, it has been shown to have a high potential for yielding on poor sandy soils. Potato is a quick-maturing crop (3-4 months) and so can yield in a single short rainy season, provided the rainfall is adequately distributed or can be supplemented by irrigation. However, the rainfall at Zwai is too unreliable to have confidence in rainfed production, while irrigation could well prove uneconomic in view of the still limited and seasonal demand. Moreover, the few attempts observed at growing potatoes under irrigation in the Zwai area appeared to have met with disease problems and consequent poor tuber growth and low yields, though this could merely be due to inexperience in handling the crop. It might also prove difficult to keep planting material healthy if the seed were grown locally.

Cotton. Some poor quality cotton is already grown in the project area on a very minor scale but temperatures around Zwai are thought to be too low for commercial cultivation.

Citrus. Is successfully grown in the project area with irrigation. However, there have recently been large-scale plantings in the Middle Awah Valley and elsewhere, and the market in Ethiopia and the Middle East is unlikely to expand sufficiently to absorb the entire crop when these trees reach maturity.

Bananas. Could be cultivated under irrigation in the Zwai area and, indeed, are already grown on residual irrigation water. The drying winds and low humidity create conditions which are far from ideal for commercial production. As with citrus, an export trade is already being developed by growers in the Awash Valley, where commercial production should be concentrated.

Papaya. Is grown for its fruit on most irrigated farms and cannot be successfully cultivated without irrigation. However, the small local market for fresh papaya is already oversupplied. If production were to be expanded, the only market outlet would be for papain, a proteolytic enzyme extracted from the latex of papaya fruits. The international market for papain is not expanding rapidly and is already well supplied by producers in India, the Phillipines and elsewhere in Africa.

Miscellaneous crops. Of the possible field crops, *chickpeas* and *lentils* are grown occasionally, but are unlikely to respond adequately to irrigation. *Sunflower,* on the other hand, can only be grown near Zwai under irrigation, but it is unlikely that it could compete with rainfed sunflower now grown near Awassa. *Soyabean* has a high protein content and could form a useful constituent in the national diet. There is no market at present in Ethiopia, although world trade in soyabean is considerable. The beans would probably require inoculation with nitrogen-fixing bacteria, and this is an expensive process. In the Zwai area, soyabean might well be grown without irrigation in a year of average rainfall since its water requirement is similar to that of maize. Because of its possible long-term significance, it is suggested that trials be conducted with a wide range of cultivars, as varieties tend to be specific in their environmental adaptation.

FARMING PRACTICE AND ORGANISATION

Prior to land reform in 1975, agriculture in the Zwai area had of recent years become dominated by the large-scale commercial sector, and tenant evictions had infrequently accompanied the introduction of mechanisation. The situation following land reform has been outlined in Part 3 (Land Tenure). Unfortunately, this survey was undertaken during 1974 and therefore did not take account of the more recent profound changes in the local agricultural structure. In any case, the current (1975) situation is one of extreme flux and a description of what must essentially be a transitional stage would have been of limited value. Indeed, Land Reform officials emphasised that the current *ad hoc* tenurial arrangements were probably only to be applicable during the 1975 growing season.

Husbandry standards vary widely within the project area and it is convenient to distinguish between methods used on the traditional small farm, and those which were employed on larger commercial farms.

In the traditional small farm sector comparatively unsophisticated techniques are used. Variable costs, productivity, and the proportion of produce sold are all low, the major purchases being seed, equipment and materials (e.g. steel-tipped ploughs and ropes). Most labour is provided by the family; neither permanent nor hired casual labour feature largely in the local economy. Improved seeds, fertilisers and chemicals are rarely used, due to lack of knowledge, non-availability and cost. The farming system is in equilibrium in most years, in so far as there is usually sufficient grain and livestock produce for local consumption, and often there is some surplus which can be sold. Most farmers own at least one bullock which is the source of power for ploughing, harrowing and weeding maize. Nearly all other operations are carried out by hand with simple tools. The return to labour ranged (1974) from $1.60 (for maize) to $4.00 (for beans) per labour-day equivalent; for maize, tef and peppers, it approached the prevailing wage rate ($2 per day). Productivity is apparently not constrained by labour shortage, but rather by lack of technical knowledge and credit. Consequently, there should be a significant response to improved techniques.

Since land reform, EPID has undertaken ploughing on the developing communal settlements, using tractor fleets comprising a medley of tractors acquired from both former landlords and tenants. Shortages of diesel have occurred, and major problems can be anticipated over tractor spares because of the large number of makes. Improved hybrid maize seed (mostly ex-Kenya) is also provided by EPID though the settlers are responsible for broadcasting and weeding. Effectively the ploughing is free, though the cost of the seeds and the diesel is to be recovered after harvest. In the first year, food is provided by the Relief and Rehabilitation Commission through the 'Food for Work' Programme.

The commercial sector was divided into two subsectors – rainfed and irrigated. On the larger rainfed farms, ploughing, harrowing and transport were often mechanised, while weeding and maize harvesting were performed by hand. Combine harvesters were occasionally used on cereal crops other than maize, and some of the post-harvest work was mechanised. Capital investment per cultivated hectare averaged about $400. Land preparation and ploughing took place from January onwards though rainfed crops were only planted at the onset of the main rains. Haricot beans tend to be planted early (in June) but tef is not sown until the rains are well advanced. Beans were often harvested before the end of the wet season while maize was harvested over a period as it ripened. For threshing, tef, wheat, barley and haricot beans, piled up on flat ground, were either trampled by oxen as on the small farms, or flattened by tractors. The grain was then winnowed and stored, maize often being stored unshelled. Produce was generally kept in circular shaped silos set on stilts above the ground.

Irrigated farms tend to be smaller but have a comparable level of investment per cultivated hectare, concentrated mostly in water pumps and irrigation equipment. They are labour-intensive with 3-5 labourers per hectare. Occasionally, ploughing and harrowing are performed by hired machinery but most other operations (except water pumping) are by hand. The main irrigated crop is tomatoes. Other vegetable crops are also grown, together with maize, tef and haricot beans in the wet season. Standards of husbandry on commercial farms were generally high but the farmers would have benefited from additional technical advice, particularly regarding crop rotations and pest and disease control.

Post land reform requirements

Most of the irrigated farms are now being operated as Workers' Cooperatives; a few, along the Western Terraces, have become part of larger State Farms. Both the Cooperatives and the State Farms share similar problems from a chronic shortage of working capital, such that sales one week were having to be used for the payment of wages or the purchase of diesel the next. Of several irrigated farms visited in 1975, none was proposing to purchase fertiliser and most expressed doubts over continuing chemical control of diseases once existing supplies of chemical ran out. In view of the intensity of production, the present incidence of disease and the absence of effective rotations, this policy may spell early ruin for a majority of the irrigated farms, especially in view of continuing low prices. At the very least, these farms require immediate injections of credit; moreover, creation of a communal marketing organisation could prove beneficial.

Extension of irrigation in the Zwai area will require radical re-organisation of holding boundaries; this needs to be undertaken rapidly, not only to avoid solidifying the possessory situation during this transitional period but also to prevent prolonged interference with agricultural production. Many holdings will need to be re-organised, amalgamated and formalised to permit efficient water distribution. This presupposes a cadastral survey of present holding boundaries, and also a large measure of farmer cooperation in the realignment of holdings to accord with proposed water distribution systems. However, it is evident that the present (1975) beneficiaries will have a vested interest in maintenance of the *status quo.* Rapid implementation of land redistribution is therefore necessary if a situation in which the transitional arrangements become permanent is to be avoided. However, if irrigation is to be introduced on any scale it is essential for thought also to be given at an early stage to re-organising existing holdings in such a way, that the technical requirements of irrigation can be met and that farm sizes will approximate to the optimum when irrigated systems of cropping are applied.

Meanwhile, it is too soon to assess the effects of land reform around Zwai. Serious disputes may yet arise when the proceeds of the harvest are shared between the cultivators and the time comes to repay government (EPID) credit. Disputation between land allotments, the possible introduction of land taxation, and eventual land registration and demarcation, are all problems for the future.

PROSPECTS FOR IMPROVING AGRICULTURE

In deriving cropping patterns the following factors were taken into account:

1. The role of maize as a subsistence crop
2. Family labour constraints on production
3. Technical features, such as the need to avoid crop combinations conducive to the build-up of pests and disease
4. The managerial capacity of the smallholder
5. Market prospects and projected prices
6. The gross margins of the individual crops (see Appendix 10)

An analysis of gross margins was applied in the determination of economically optimum cropping patterns. The crops analysed were those that had been shown (above) to be both technically feasible and have favourable market prospects. A crop's gross margin is obtained by deducting direct costs from the gross value of output (direct costs being those specific to particular crops, including seeds, fertilisers, chemicals, hired casual labour, fuel, maintenance and hired mechanical inputs). Costs which are unaffected by the scale on which a particular crop is grown within a given farming system (i.e. fixed costs) are not taken into account in arriving at gross margins. Other things being equal, crops with high gross margins are preferable to those with low gross margins and the particular combination of crops which maximises gross margins over the farm as a whole will also maximise farm income (defined here as gross margin less fixed costs). Inter-crop comparison of gross margins within specific farming systems and comparison of farm income between systems will indicate the most economically attractive cropping patterns and systems.

Prospects for rainfed agriculture

The relevant data on gross margins are contained in Appendix 10 (Tables 1 and 2). Comparing the gross margins under traditional systems of rainfed agriculture with those that could be achieved through the adoption of improved techniques, it is evident that there is scope for a considerable increase in returns; in the case of haricot beans for example, the incremental value/cost ratio exceeds 2, and notable economic gains could also be achieved for maize and red peppers. Some of the ways by which rainfed agricultural production could be raised are given below:

1. A once-over mechanical cultivation would facilitate the subsequent use of improved ox-ploughs and ridgers, which in turn would reduce the number of ploughings required and so release the farmer and his family for more productive work. It would then be possible to plant crops earlier which, together with deeper tillage, would result in improved yields of maize. The use of ox-ridgers would encourage planting in rows and facilitate weeding.
2. Crops should be planted to set spacings thereby raising yields and reducing seed wastage. For maize, use of ox-drawn wooden tube planters would help reduce seed rates from the current 100 kg/ha to an optimum 35 kg/ha.

3. Better cultivars and improved seed (dressed with insecticide and fungicide) should be made available to those farmers who adopt the above measures.

4. In years with adequate rainfall there should be a response to nitrogenous and phosphatic fertilisers, especially when applied to improved cultivars. Instruction in the identification and control of pests and diseases would also assist in raising yields, while the more careful use of insecticides and fungicides would help to keep down costs.

5. Improvements should also aim at raising the quality of cash crops (especially haricot beans) and reducing waste (current annual storage losses may exceed 20%).

Many of these improvements could be implemented through an active extension service backed by simple crop trials (see Part 6). A combination of the proposed improvements would rapidly increase production, especially on small farms, so allowing a significant diversification into cash crops. At present, the most important cash crop is haricot beans and an increase in the area under beans should be encouraged. Groundnuts and peppers are potentially useful cash crops under both rainfed and irrigated conditions. Livestock would benefit from additional maize, bean and groundnut residues.

The proposed cropping patterns set out in Table 52 take account of physical and agronomic conditions and current socio-economic constraints.

TABLE 52 Possible cropping patterns for an improved 2 ha rainfed smallholding (based on current agronomic data)

	Area cropped (ha)			
Rotation	A	B	C	D
Maize	0.75	0.75	0.50	0.50
Beans	1.00	0.75	0.75	0.50
Peppers	0.25	0.25		
Sorghum			0.50	0.50
Sisal				0.50
Forage		0.25	0.25	
Annual gross margin ($/ha)	464	398	322	257*

*Does not include returns from sisal; this therefore is a minimal value

It can be seen from Table 52 that several variations and combinations of cropping are possible; the four rotations illustrated do not exhaust the range of possibilities. Rotation A maximises the use of farm resources within the constraints imposed by labour availability and subsistence requirements, and approximates to an economic optimum for a rainfed 2 ha smallholding. The annual farm income is estimated at about $850, which is more than double current average farm income. In the economic analysis in Part 8, this rotation has been used as a basis against which to judge the economic benefits to be derived from irrigation. The use of peppers in this rotation may only be possible, however, under conditions in which it is possible to irrigate the nurseries before the rains (i.e. in April and May). Supplementary irrigation is also likely to be needed in most years during planting out. Substitution of beans for peppers in Rotation A to give a simple, if labour intensive, rotation with 1.25 ha of beans would have the effect of only slightly reducing the annual gross margin/ha to $426. A more realistic substitution of maize or fallow for peppers would lower the gross margin below that of Rotation B, which shows the 10% reduction in gross margin consequent upon introducing 0.25 ha of forage (which is assumed only to contribute output equal in value to the direct costs involved in production). The introduction of 0.50 ha of sorghum (Rotation C) further reduces gross margins, though having the advantage of greater reliability of food production in dry years. In Rotation D, 0.50 ha of sisal is grown to provide a reliable year-round cash return, as well as some forage between the sisal rows.

In general, the gross margin declines as the proportion of high value cash crops (beans or peppers) is reduced. Farmers currently leave between 10 and 20% of their holdings fallow for the purpose of providing rough grazing for their livestock, especially draught animals. The question of how much fallow should be allowed for this purpose cannot easily be resolved. On intensively-farmed rainfed smallholdings in the Far East (e.g. even in the drier parts of Bali with a long 5-month dry season), few special fodder crops are grown. Farm sizes are usually less than 1 ha and fodder derives from crop by-products, legume browse grown on field margins and rough grazing close to the farmstead: the more intensive the cropping pattern, the greater the bulk of crop residues that will be produced, with resultant reduction of the area needed for forage.

Although the potential benefits from the development of rainfed agriculture are considerable, the projected returns would require a competent extension service and the efficient supply of agricultural inputs including seed, fertiliser and chemicals. However, the most crucial constraint to the improvement of rainfed agriculture is the unreliability of the rainfall; this is a major risk factor that all farmers must take into account. It has been estimated above that drought will cause serious reductions in crop yields on average about one year in six; response to fertiliser and other inputs would be negligible in such years. Because of this relatively high level of risk, farmers are in practice unlikely to invest either time or money at the recommended levels necessary to obtain a significant increase in productivity. Moreover, the farmer, unwilling to expose himself to the risk of purchasing food at a time when, due to general shortage, prices are high, will tend to give priority in terms of land and resources to food crops at the expense of cash crops; this tendency will also inhibit the adoption of improved practices. For all these reasons, projections of returns to be derived from rainfed farming may be of little more than academic interest. With the introduction of irrigation, however, these risks are largely avoided and improved techniques can be introduced with confidence. Moreover, irrigation provides opportunities for extending the range and duration of cropping, and for introducing double cropping with rotations extending through the dry season, thereby ensuring greatly enhanced production and a reliable return on capital invested.

Possible cropping patterns under irrigation

Four basic rotations have been defined (Tables 53-56).

Rotation 1

In Year 1, the land is ridged and red pepper seedlings, 20 cm tall, are transplanted. These are irrigated and picked fresh over the October to March period, and dried after picking. Then, in preparation for long-cycle maize, the land is cultivated and ridged, maize being planted on the ridges. After harvesting the maize in October, haricot beans are planted for an April harvest. In Year 3, the land is cultivated, and maize and groundnuts planted together in May, with the groundnuts on flat-topped ridges between the maize rows spaced 1 m apart in the furrows. The maize is harvested in October, followed by the groundnuts. Then wheat is planted for harvesting in March. Years 4 and 5 repeat years 2 and 3, except that no second crop follows the maize – groundnut intercrop in Year 5, and the land lies fallow for up to 6 months before the rotation is repeated with peppers as the first crop. This rotation allows for a five-year break between solanaceous crops, thus reducing pest and disease problems. (see Table 53).

TABLE 53 Rotation 1: five-year cycle

Year	Crops	Planting date	Harvest date
1	Red peppers	June 1976	Oct. 1976-Mar. 1977
2	Long-cycle maize Haricot beans	May 1977 Jan. 1978	Oct. 1977 April 1978
3	Maize intercropped with groundnuts	May 1978 May 1978	Oct. 1978 Oct. 1978
	Wheat	Nov. 1978	Mar. 1979
4	Long-cycle maize Haricot beans	May 1979 Jan. 1980	Oct. 1979 April 1980
5	Maize intercropped with groundnuts	June 1980 June 1980	Oct. 1980 Nov. 1980

Rotation 2

In Rotation 2 (Table 54) a more intensive cropping pattern is based on the intercropping of short-cycle maize with peppers or groundnuts. This should ensure maximum productivity from a relatively unsophisticated system. Nevertheless, the feasibility of the proposed intercrops will have to be tested at an early stage. Spacing of the maize, for example, will have to be such as to allow the peppers to grow normally prior to the maize harvest; this intercrop has been shown to be feasible in Kenya. The maize/legume intercrop is better documented, especially under Asian conditions. Experiments in the Phillipines and in India have demonstrated that maize with an intercrop can yield up to 96% of the pure stand, though the legume yield is more seriously affected. Under Zwai conditions, one would expect to gain the advantages from improved light interception and nitrogen utilisation than found elsewhere. More complete ground cover should also reduce the weed problem and minimise the need for inter row cultivation.

TABLE 54 Rotation 2: three-year cycle

Year	Crops	Planting date	Harvest date
1	Maize intercropped with red peppers	June 1976 July 1976	Oct. 1976 Oct. 1976-Mar. 1977
2	Maize intercropped with groundnuts Haricot beans	May-June 1977 May-June 1977 Jan. 1978	Oct.-Nov. 1977 Oct.-Nov. 1977 April 1978
3	Maize intercropped with groundnuts Haricot beans	May-June 1978 May-June 1978 Jan. 1979	Oct.-Nov. 1978 Oct.-Nov. 1978 April 1979

Because of the disease risk associated with growing a solanaceous crop every third year, it is proposed that the nematocide, carbofuran, be applied in the nurseries; allowance has been made for this in the gross margin for peppers (Appendix 10). In any case, the level of pests and diseases should be monitored experimentally, so that a periodic 6-year break can be introduced if this should prove necessary. Rotation 2 can also be criticised for the intensity of legume cropping. In general, it is believed that the incidence of most bean diseases is controlled by climatic conditions rather than by carry-over in the soil; i.e. healthy beans can be grown on land which previously had carried beans badly affected by rust and bacterial blights. If, during the initial experimental period, a disease hazard caused by the rotation shows up, then beans can be replaced by wheat in Year 3. Regarding the groundnuts/beans succession, since leaf diseases are not common to both crops, major problems are not anticipated, though some trouble may be caused by foot rots.

It is suggested that, for Rotation 2, the following cultivation procedures may prove appropriate. In Year 1, the land would be ridged at 50 cm centres and maize planted at 100 x 30 cm in alternate ridges. Pepper plants, 20 cm tall, should be made available from nurseries when the maize is 60 cm tall, and transplanted at a spacing of 100 x 60 cm on the unplanted ridges between the maize plants. After harvesting the maize in October, the red peppers would be irrigated and picked fresh over the October to March period, being dried after picking. The land would subsequently be cultivated, and maize and groundnuts planted together in May or June: with the groundnuts on flat-topped ridges between the maize rows, spaced 1 m apart in the furrows. The maize would be harvested in October, followed by the groundnuts; and then haricot beans would be planted in January for an April harvest. In Year 3, the second year cropping pattern would be repeated, before reverting to the maize/peppers intercrop in the following year.

Rotation 3

In Rotation 3 (Table 55) onions and haricot beans are substituted for the second year of Rotation 2. There is an implication in the adoption of this rotation that a vegetable dehydration plant has been established in the vicinity concentrating initially on a single line. The onions would be planted on flat-topped ridges between the irrigation furrows at 50 cm centres. The planting dates for onions are staggered as set out in Tables 4 and 5 of Appendix 2, and the area in Year 2 can be apportioned between onions and beans as required for an even spread of labour inputs and for factory supply.

TABLE 55 Rotation 3: three-year cycle

Year	Crops	Planting date	Harvest date
1	Maize intercropped	June 1976	Oct. 1976
	with red peppers	July 1976	Oct.-Mar. 1976-7
2	Onions	May-Aug. 1977	Oct.-Dec. 1977
	Haricot beans	Jan. 1978	April 1978
	or:		
	Haricot beans	July 1977	Oct. 1977
	Onions	Oct.-Jan. 1977-8	Mar.-June 1978
3	Maize intercropped	May-June 1978	Oct.-Nov. 1978
	with groundnuts	May-June 1978	Oct.-Nov. 1978
	Haricot beans	Jan. 1979	April 1979

Rotation 4

To increase farm incomes further, Rotations 2 and 3 can be intensified by substituting tomatoes or capsicum for maize/red peppers in Year 1; or by replacing maize/groundnuts/beans by cabbage/carrots in Year 3, as in Rotation 4, (Table 56) which is principally designed to supply produce for processing, i.e. tomatoes for paste or puree, and onions, cabbage and carrots for dehydration. Alternative crops are leeks in place of onions and green beans instead of haricot beans.

TABLE 56 Rotation 4: three-year cycle

Year	Crops	Planting date	Harvest date
1	Tomatoes	Aug. 1976	Nov.-March 1976-7
2	Onions	May-Aug. 1977	Oct.-Dec. 1977
	Haricot beans	Jan. 1978	April 1978
	or:		
	Haricot beans	July 1977	Oct. 1977
	Onions	Oct.-Jan. 1977-8	Mar.-June 1978
3	Cabbage	June-Aug. 1978	Sept.-Nov. 1978
	Carrots	Sept.-Nov. 1978	Jan.-March 1979

Discussion

The above rotations are intended to permit a gradual transition from traditional to new crops. The more advanced technology can thereby be gradually phased-in over a period of time as the farmers' standards of husbandry improve. To sustain the high costs of irrigation, multiple cropping and intercropping are necessary from the outset. In Rotations 1 and 2, only one new crop (groundnuts) is proposed. All the other crops (maize, wheat, red peppers and haricot beans) are widely grown in the project area and are included so that farmers' experience can be drawn upon and marketing problems avoided.

These basic rotations have been designed as far as possible to prevent a build-up of pests, diseases and weeds. For example, solanaceous crops, such as red peppers, capsicum and tomato, are restricted to a maximum of one crop per three-year period; this is necessary to prevent a large increase in root-knot nematode, in bacterial wilt or in the parasitic weed *Orobanche ramosa.* In the case of haricot beans, it is proposed to have two 'closed seasons' per year between the wet-season crop (planted in July and harvested in October) and the dry-season crop (planted in January and harvested in April), to prevent the carry-over of pests and diseases such as bacterial and fungal leaf blights, rusts, and red spider mite. Only one onion crop is proposed in each three-year period (Rotations 3 and 4) to avoid possible problems from stem and bulb nematode and other soil-borne diseases which cause bulb rots and leaf blights. Similarly, carrots and cabbage would only be grown on the same land once in three years. At any time it would be possible to change the sequence, e.g. from Rotation 4 to Rotation 2, if there were signs that disease or pests were increasing. Consequently, it is important for changes in the populations of pests, diseases and weeds to be monitored experimentally in advance of the widespread adoption of these rotations. Possible major hazards include a concentration of weed grasses and sedges as maize is progressively phased out of the rotations, and an increased incidence of soil diseases such as *Fusarium, Sclerotium* and *Rhizoctonia* for which most of the proposed crops are host plants. The use of seed dressings may prove an adequate preventive against these diseases, but this should be investigated at the earliest opportunity.

Throughout the year it is desirable, especially on the smaller farms, to have a reasonably uniform labour requirement which for all the proposed rotations will inevitably be greater than that for existing rainfed agriculture. For Rotations 1 and 2 the peak labour demand will be in October-November during maize, pepper and groundnut harvesting; some hired labour will be needed on most farms during this period or, alternatively, some mechanisation could be introduced, e.g. to assist in the digging and threshing of groundnuts or in the shelling of maize. During land preparation before the rainy season, it could prove desirable to have tractor contract services available to speed up the basic cultivations following late harvests of beans or onions, thereby ensuring that the succeeding crop is planted on time. Although the rotations should allow a progressive change to mechanised production, some operations, such as the picking of maize, peppers and beans, are unlikely to be mechanised in the foreseeable future.

To maintain supply to a processing plant, a long harvest season will be needed, especially if the factory is of small capacity. Harvesting of both tomatoes (for tomato paste) and onions (for dehydration) would be restricted to the dry season between October and May, since wet season harvesting is unlikely to be practicable. For onions, a staggered planting schedule would be necessary and this would even out labour requirements in growing the crop. Either cabbages or leeks could however, be produced to mature in the wet season, thus extending the operation of a dehydration factory.

Irrigation requirements

The methods used to determine the crop irrigation requirements are explained in Appendix 2. Evapotranspiration from various cropping systems was predicted by applying crop coefficients and water availability coefficients to open water evaporation estimates for the Lake Zwai area. The annual values obtained are summarised in Table 57.

TABLE 57 Estimated annual crop evapotranspiration (E_a) in mm for the main cropping systems

Cropping system	E_a
Maize intercropped with, and followed by, red peppers	1 013
Maize intercropped with ground nuts; followed by haricot beans in the dry season	971
Onions planted in the wet season; followed by haricot beans in the dry season	910
Haricot beans; followed by onions in the dry season	912
Tomatoes	973

In addition to meeting evapotranspiration needs, inefficiencies in field application due to inevitable losses from run-off and seepage must be taken into account. In the irrigation estimates it was assumed that surface methods of application by furrow or basins would be used, and that 50 mm of water would be the minimum amount of water which could be applied in a single application. The number of irrigations was determined by probable rainfall and the likely effect of moisture stress on crop growth. Minimum irrigation intervals were projected during rainless periods of 5-7 days, depending on the crop and its stage of growth. The estimated average annual field applications are summarised in Table 58. In practice, there would be considerable variation around these values depending on rainfall, soil type and the performance of the individual farmer.

TABLE 58 Summary of the proposed field allocations for surface irrigation

Cropping system	Number of applications		Water allocations in the field (mm)	
	Pre-plant	Post-plant	Per crop	Annual
Maize intercropped with, and followed by, red peppers	1	2 18	175 900	1 075
Maize intercropped with groundnuts; followed by haricot beans in the dry season	1	3 9	225 500	725
Onions planted in the wet season; followed by haricot beans in the dry season	1 1	6-17* 9	350-900* 500	850-1 400*
Haricot beans; followed by onions in the dry season	1 1	3 19	200 1 000	1 200
Tomatoes	1	37	1 900	1 900

*Depending on the precise date of planting

Irrigation applications have been designed (Appendix 2) to ensure that leaching is sufficient to maintain a favourable salt balance in the soil. The average leaching fraction (i.e. ratio of drainage water to water additions from rainfall and irrigation) for a typical rotation (Rotation 2) works out at 0.23; taking account of the conductivity and composition of the irrigation water, this should provide an adequate safety margin.

The distribution network efficiency is also considered in Appendix 2. Assuming that some 28% of the water is lost during conveyance from source to field, a total average annual irrigation requirement of about 12 000 m^3/ha has been projected for Rotation 2. The estimated maximum demand of 700 m^3/ha/week during the January to March period corresponds with a peak demand of 2.7 1/s/irrigated ha, assuming irrigation 12 hours per day and six days a week.

Labour requirements

Projected monthly labour requirements for crops irrigated by smallholders are given in Table 59. In practice the monthly labour schedules can be very flexible, since the time period over which many farm operations can take place may be extended or contracted according to labour availability. Nevertheless, the rotations have been devised to minimise hired casual labour. Labour projections have been based on the assumption that an average farm family of two adults and three children has a total monthly labour availability of 30 labour-day equivalents. Thus, when the monthly labour requirements exceed this figure, either the farm operation has to be extended or outside casual labour must be hired. It is not anticipated that there will be any shortage of casual labour in the Zwai area.

TABLE 59 Monthly labour requirements for crops irrigated on smallholdings, labour-day equivalents/ha

Crop	J	F	M	A	M	J	J	A	S	O	N	D	Total
Long-cycle maize				24	11	11	14	10	15	18			103
Tef					23	16	18	24	14	24	19		138
Wheat				23	17	19	14	4	34	19			130
Groundnuts						23	18	19	19	20	27		126
Red peppers	34	26	18				23	33	20	24	21	43	242
Haricot beans (wet season)							33	21	25	33			112
Haricot beans (dry season)	33	32	9	33								29	136
Maize-groundnuts (intercropped)					37	19	23	23	24	22	36		184
Maize-red peppers (intercropped)	24	23	13		28	27	7	20	25	25	38	28	258
Tomatoes	33	32	28				33	47	28	47	27	40	315
Onions (dry season)	43	43	51	45							44	45	271
Onions (wet season)							44	46	41	39	58	35	263
Cabbages*							56	53	42	47	45		243
Carrots*	30	59								46	33	57	225

*These labour requirements should be treated with caution, since the estimates are derived from outside the project area

Proposals for the employment of labour are bound to be arbitrary. People vary considerably from place to place in their desire to work for improved living standards, and cropping systems vary accordingly. While 150 days/person/year is the maximum that can be expected in West Africa and the Caribbean, in many other areas the agricultural labour input is much higher; to take an extreme example, in East Java it can range from 300 days to over 500 days equiv./year. The figure selected for Zwai of 30 labour-days/month is based on 20 days worked by the farmer and 10 days by his family. This averages out at around 225 days/person/year.

In the project design (Part 6, Vol 2), it has been assumed that each irrigated holding will be of 1.5 ha, this area being sufficient to provide almost continuous employment and a reasonable income for the farm family, with a minimum of casual labour employed from time to time. Table 60 lists the estimated labour requirements for the three major crop rotations proposed (insufficient is known of the labour requirements for carrots and cabbages to include Rotation 4). It has been assumed for each rotation, that the farm is divided into three equal plots of 0.5 ha, each plot being in a different year of rotation. In this way, the staggering of crops results in a levelling out of the monthly labour requirements, and also a stable annual requirement for both family and casual hired labour. Peak demand for labour is associated with the planting of tomatoes and onions and harvesting of onions and groundnuts.

Role of livestock

The prospects for livestock production in the project area are limited, and the proposals in this report are primarily concerned with intensification of crop production through irrigation. It has already been shown that it is unlikely that irrigated fodder could at this stage prove an attractive substitute for intensive crop production, Ethiopia's livestock industry being based on low-cost production from extensive rangeland producing medium-quality meat. The internal market currently offers no price advantage for higher-quality meat produced under more intensive systems, which are likely to yield relatively high cost produce. In neighbouring markets, such as Saudi Arabia which is already being penetrated by Ethiopia, the main demand is also for medium-quality meat, while the quality markets of Europe and elsewhere are either fully supplied or screened by disease restrictions. As regards milk, the main centre of consumption - Addis Ababa - is too far away for surplus production, beyond local needs, to be encouraged in the project area.

TABLE 60 **Estimated annual labour requirements, family and hired, for irrigated smallholdings of 1.5 ha, for Rotations 1, 2 and 3; labour-day equivalents per smallholding**

Month	Labour requirements					
	Rotation 1*		Rotation 2		Rotation 3	
	Total	Hired	Total	Hired	Total	Hired
Jan.	33	3	45	15	44	14
Feb.	31	1	44	14	44	14
Mar.	10		16		16	
April	35	5	33	3	33	3
May	34	4	51	21	33	3
June	30		33	3	45	15
July	35	5	27		38	8
Aug.	27		33	3	42	12
Sept.	30		37	7	44	14
Oct.	30		35	5	53	23
Nov.	40	10	55	25	55	25
Dec.	35	5	43	13	43	13
Annual totals	370	33	452	109	490	144

*The data for Rotation 1 are the averaged monthly labour requirements over the five years of the rotation

It is however envisaged that oxen would cultivate the proposed irrigated farm units of 1.5 ha. For this, at least two oxen would be required to plough, ridge, harrow, weed and thresh. In Rotations 1 and 2, up to 60 ox-pair days/ha/year would be required. The maize, groundnuts and beans should produce up to eight tons of crop residue dry matter per annum, sufficient to sustain two oxen and a cow if a supplementary ration of maize or groundnut cake is also provided. Replacements would have to be bought in. While the lake margins, and certain areas elsewhere, may provide additional grazing, it is probable that most cattle feed would have to be produced on-farm. If this proves to be so, then it will be important for livestock numbers to be strictly controlled; otherwise animals will be undernourished and unable to perform the work expected from them. In addition, uncontrolled movement of livestock would have to be discouraged, possibly even by fencing, since damage to crops and irrigation structures could be considerable.

Sheep and goats are capable of almost as much destruction as cattle and, since crop residues will be insufficient to feed more than three adult cattle per farm, irrigation farmers should be discouraged from keeping them. Indeed, with considerably increased incomes, these farmers should be able to purchase livestock products locally, thus promoting a useful interchange in the local economy.

If control of livestock proves too difficult, ownership would have to be restricted to working oxen. As an extreme measure, farmers might have to hire working oxen or even machinery. However, the institutional problems of allocating working animals or machinery at times of peak demand are such that comparatively minor inefficiencies are liable to lead to major disruption in farm production. It is recommended therefore that cattle on small irrigated farms should be restricted to two working oxen and a cow, with all other livestock except poultry discouraged. Consideration may need to be given to protecting irrigation blocks from livestock by means of perimeter fencing.

There is a place however for commercial poultry production, both for meat and for eggs. To this end, it is proposed that improved breeds be introduced (e.g. from CADU), together with the provision of advice on housing and feeding.

SUMMARY

In Part 5 it has been shown that a number of crops of economic importance (especially red peppers, haricot beans, groundnuts, sugar, tomatoes and onions) are well suited for production under irrigation in the Lake Zwai area, despite the prevalence of subsoil alkalinity in certain soil types. Indeed, the altitude of the project area (around 1 650 m) confers a comparative advantage in the production of certain vegetable crops (and probably also sugar cane) over the more extensive areas of irrigation potential having higher ambient temperatures at lower elevations. The most favourable climatic factors are the equable temperatures, high solar radiation and ability to ripen and dry crops throughout much of the year. Although the soils are far from ideal, evidence is presented that the main potential constraint, subsoil alkalinity, should not prove too critical on most soil types and that, apart from the bicarbonate content, the irrigation water will be of good quality. A total of 12 800 ha are regarded as being physically suited to irrigation with no amendment other than levelling, thorough cultivation, and addition of nitrogenous and phosphatic fertilisers. A further 5 600 ha are currently unsuitable due to poor drainage, periodic surface inundation or flooding from Lake Zwai; this area could nevertheless be developed following river and lake regulation. On the heavier-textured terrace soils with subsoil alkalinity (9 100 ha) development must await a satisfactory outcome to long-term irrigation trials.

Part 6

Proposals for irrigation development

Evaluation of the project area

In this section each locality within the project area is described in terms of its topography, soils, land use and potential for irrigation. Especially detailed treatment is given to the delta of the Meki River, since this is where about 45% of the proposed irrigated area is located. Development is envisaged as a two-phase process, initiation of the second phase being dependent, not only upon the success of the first phase, but also on the introduction of measures to control the lake outflow as prescribed in Part 4. The proposed irrigation development areas summarised in Table 68 are shown on Text Map 8.

MEKI DELTA

The Meki Delta (shown on Text Map 7) comprises some 5 500 ha of alluvial land south-east of Meki town. It is bounded to the north and west by lacustrine terraces. The Meki River flows across the delta from the north-west to its Lake Zwai outlet in the south-east. The entire delta is topographically suited to irrigation, although other factors limit the area of potential for irrigation, the most important being:

1. Saline groundwater, which appears to underlie much of the delta at a relatively shallow depth (Text Map 3; Part 3)

2. Flood hazards from the river and the lake

3. Subsoil salinity, a considerable area of land on the right bank of the river being affected (separate Map 2)

It should be noted that the 800 ha of saline land along the south-west fringes of the delta (separate Map 2) have been regarded as part of the Western Terraces for the purposes of this report.

Land use

Since about 1965, much of the delta area has been transformed from dense *Acacia albida/Croton macrostachys* woodland into productive farmland. Remnants of this woodland still exist to the south-east of Meki Town and these, amounting to some 350 ha, are rapidly being cleared. Associate tree species include *Ficus, Acacia tortilis* and *Albizia amara,* with an often dense undergrowth of *Adhatoda schimperiana, Achyranthes aspera, Capparis tomentosa* and *Solanum campylacanthum.*

Elsewhere, much of the better drained land was until 1975, intensively cultivated with a few commercial farms of between 50 and 400 ha and many small farms with an average size of 2 - 3 ha. About 75% of the farmers were tenants. The most important crop is maize which, in 1973, occupied about 82% of the cultivated area; other crops included haricot beans (12%) and tef (4%). Livestock play an important role in the farming system, with an average, in 1973, of 23.5 head per household. Although Meki Delta farmers appeared to be generally less market-oriented than those elsewhere in the project area, there were along the banks of the Meki River nine irrigated farms most being leased under a formal contract. Furrow irrigation is used with relatively sophisticated distribution systems. The water is raised 4-8 m out of the Meki by means of small 10-12 horsepower pumps. On these farms, tomatoes were the most important crop, though the area of irrigated haricot beans was increasing and several other crops were irrigated including cabbage, lettuce, red peppers, potato, onion, papaya, banana and sugar cane. One farm was irrigated by pumping (6 m pump lift) from a 3 km long canal from the lake. Here the farmer was growing a wide range of crops including, in addition to some of those listed above, irrigated coffee under banana shade, avocado pear, leeks, and lucerne for sale as hay.

Grassland subject to seasonal flooding or affected by surface salinity is left uncultivated; this represents an important source of dry season grazing. On these sites (Separate Map 1), the grass is dominated by species of *Sporobolus, Digitaria, Chloris, Cynodon* etc. Trees scattered throughout this grassland include species that are also commonly found as remnants in the cultivated areas, e.g. *Ficus sp., Acacia albida, A. tortilis, Balanites aegyptiaca, Croton macrostachys* and, on heavy soils, *Acacia seyal.* Close by the lake-shore, along the margin subject to seasonal inundation, there is a peripheral thicket of *Aeschynomene elaphroxylon.*

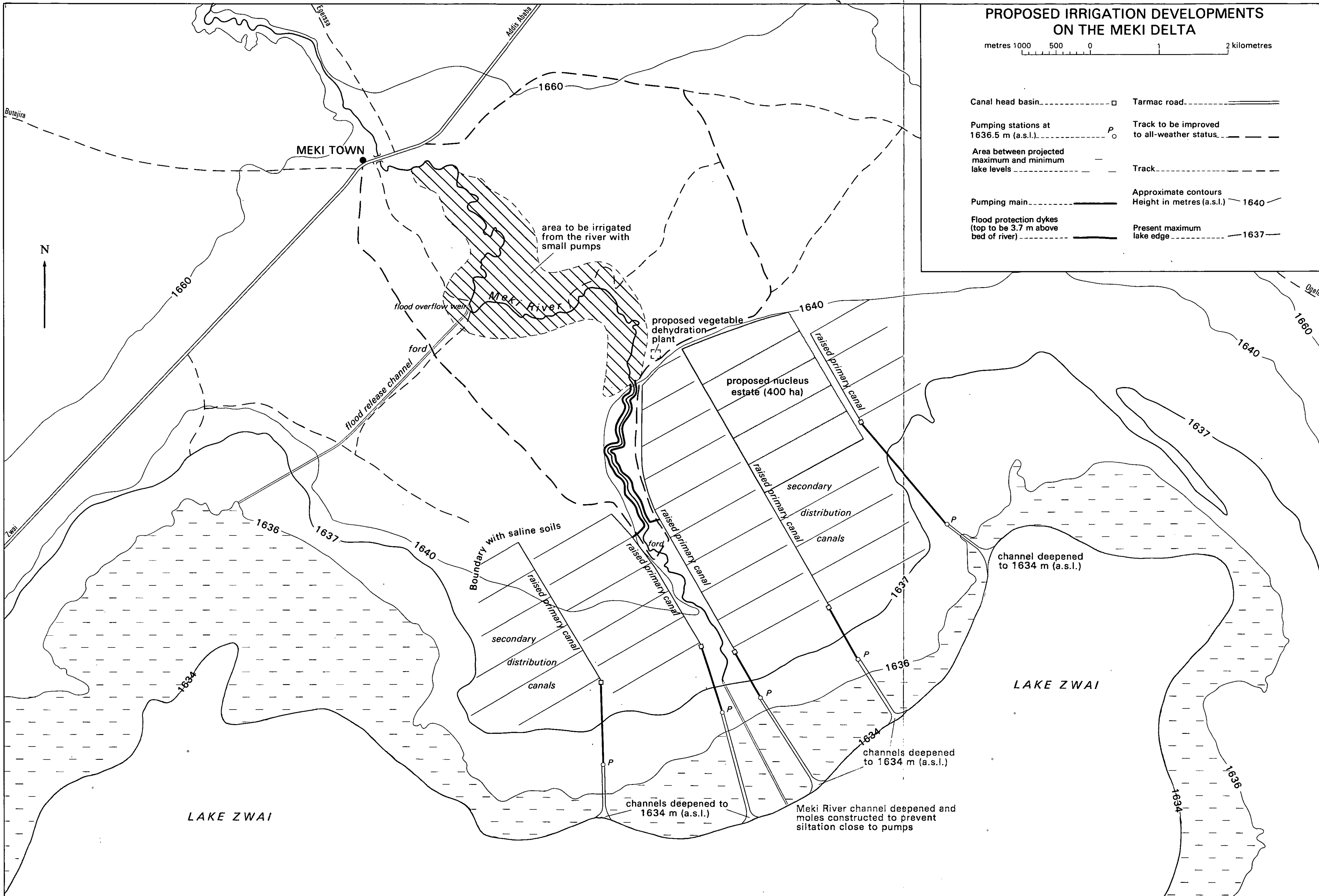
Topography and soils

Meki Town is sited at the apex of the delta 20 m above lake level. The delta slopes gently down towards the lake (with an average slope of 0.1%). Locally however, the land is slightly undulating. Typical topographic cross-sections have been reproduced as Figure 17.

The distribution of the main soils is shown on Separate Map 2. On the upper delta, the Meki is flanked by low natural levees, from which the land slopes away at less than 1% for between 200 and 500 m towards an almost level plain with heavier-textured soils. Occasionally, channels cut through these levees to a depth of 2-3 m. In addition, there are two major overflow channels, on the right and left banks of the river, 4 and 8 km respectively downstream from Meki Town. The river perennially overflows into both these channels to inundate about 1 100 ha, mostly of grassland. A further 500 ha are periodically flooded by the lake along the southern and eastern margins of the delta, and an additional 500 ha are liable to waterlogging. The central delta comprises about 2 000 ha of alluvial deposits, of which some 20% (in the west) are adversely affected by subsoil alkalinity and a high saline watertable. Frequent low sandy levee ridges form gentle undulations flanked by more level areas of heavier-textured soil.

The Meki Delta encompasses the most favourable land in the project area, but also includes significant areas of problem soils. The most suitable areas for irrigation are the central and northern parts of the delta comprising about 2 800 ha of Class 1 and 2 land (see Separate Map 3). The fertile, free-draining clay loams and clays with variable subsoil are generally free from harmful accumulations of salt and alkali; where traces of salt are present in the subsoil, it is as a result of locally high saline groundwater. However, much of this land is too far from the lake or the river to be irrigated economically. In contrast, on the lower part of the delta near the lake where the total hydraulic head for pump irrigation is relatively favourable much of the land is seasonally waterlogged and affected by subsoil alkalinity. The 2 100 ha approximately of seasonally flooded, slow-draining Class 4 land, on the lower part of the delta and adjacent to the Meki and its overflow channels, comprise variable topsoils overlying clay. This land could be raised to Class 2 status by means of flood control and drainage (Separate Map 3).

Nevertheless, the high and locally saline watertable (see Text Map 3) will remain a major hazard. Consequently, it is urged that, in the event of irrigation development, the following action should be taken:



Prepared by the Directorate of Overseas Surveys 1976

FIGURE 17

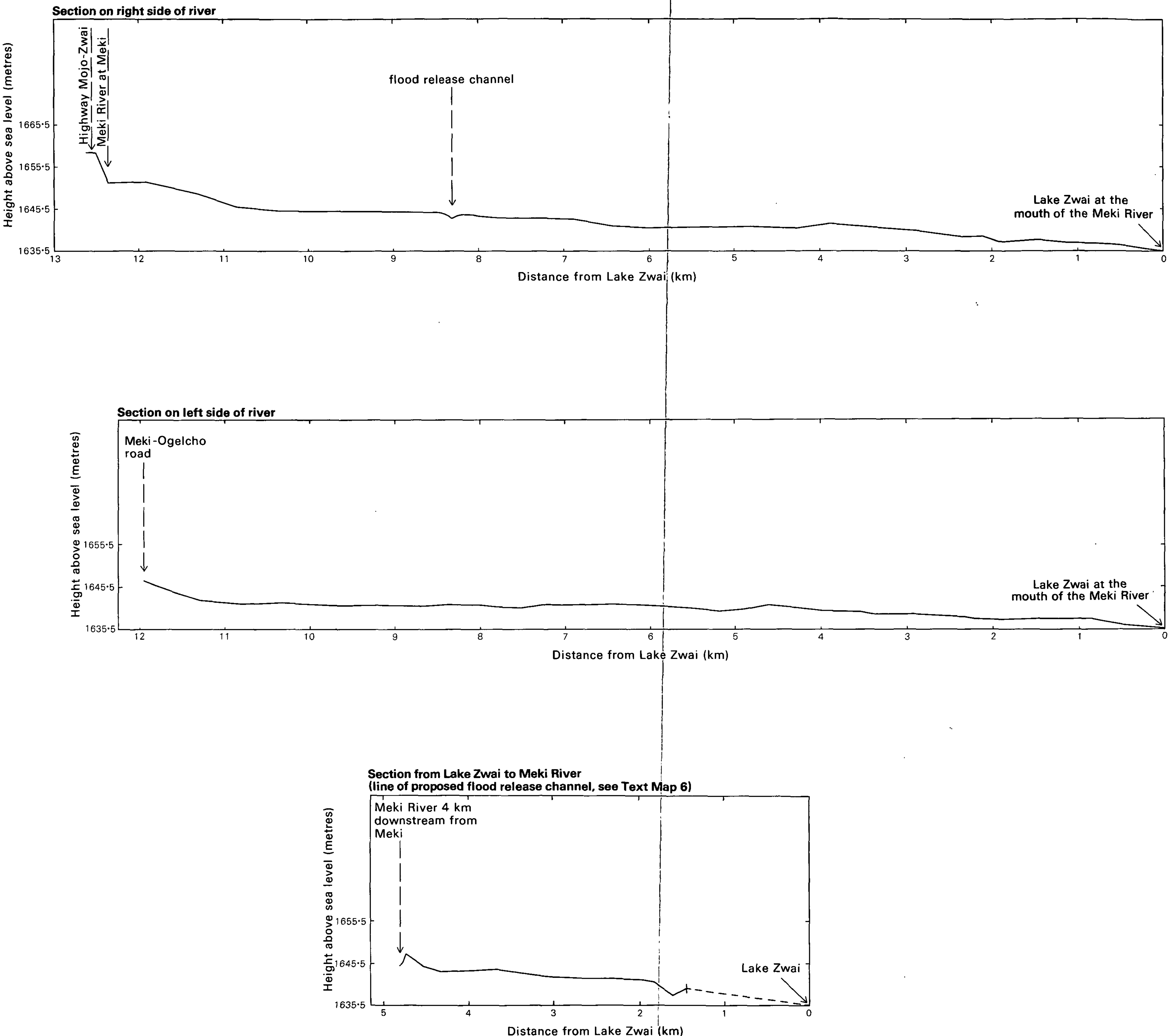


FIGURE 17 Sections through the Meki Delta (vertical scale exaggerated)

Prepared by the Directorate of Overseas Surveys 1976

1. Construction of an effective system of relatively deep drainage

2. Regular monitoring of groundwater levels by means of strategically-sited piezometer tubes

Flood control

Since much of the delta is liable to flooding, realisation of its potential for irrigation must depend on flood control, which could also have the important effect of lowering the watertable. The major causes of flooding are overflow from the Meki River and flooding at high lake levels. In addition, local flooding can be caused by high intensity rainfall and poor soil drainage. Since there is only limited scope for increasing the area under irrigation without flood control, the developments proposed below should be preceded by adequate flood protection. This can be achieved by controlling the overflow of the Meki, by regulating the level of the lake, and by providing adequate field drainage.

Meki River flood control

During periods of high discharge, the Meki is liable to overflow into the two natural flood channels mentioned previously (see Text Map 7). Between Meki Town and the first overflow, the river has the capacity to carry all flood flows. However, when the river water depth exceeds about 1.5 m, it overtops the bank at the first flood channel (see Plate 9), and water spills into a shallow depression about 1 km from the main channel; any excess flood water then drains south-westwards into Lake Zwai along a well defined channel(Plate 10). Between the first and second overflow channels, the main river can carry the reduced flood flow, even though the river bank heights become steadily lower, and the river bed slope decreases. Spillage into the second overflow occurs when the Meki river water depth is about 1 m; this overflow channel splits into several distributaries, causing a large area to be subject to inundation. The Meki channel can carry the remaining flow for the next 4 km but, thereafter, both channel cross-section and gradient are too small, and over the final 3 km before reaching the lake the river may divide into two or more channels.

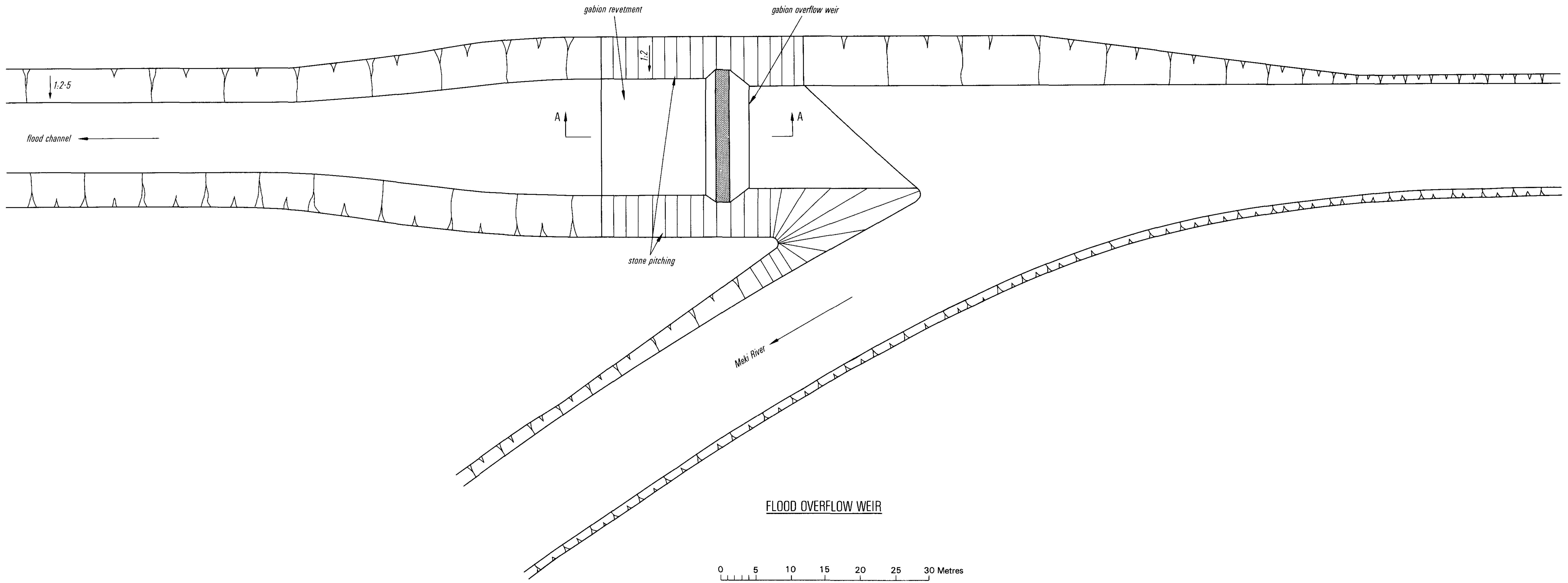
The measures proposed to control the Meki flooding (shown on Text Map 7) are based on a maximum flood flow assessed for design purposes as 200 m^3/s. This is the average discharge rate in one day at Meki Town with an estimated chance of occurrence of once in a thousand years (Part 4). In the absence of a detailed survey of the river however, the following estimates of channel capacities and slopes are tentative. In the reach from Meki Town to the first overflow channel, the average longitudinal bed slope of the river is 0.15% and the minimum cross-sectional area at bank-full stage is 60 m^2. The carrying capacity of this reach is estimated to be greater than 200 m^3/s, so confirming that no flooding should occur in this sector. Between the first and second overflow channels, the average slope of the bed is 0.12% and the minimum cross-sectional area at bank-full stage is 24 m^2. The maximum carrying capacity of this section is estimated at 80 m^3/s. These results indicate that to prevent flooding from the river along the reach between Meki and the second natural overflow channel, up to 120 m^3/s should be diverted at the first overflow channel (Plate 9), which it is proposed should be realigned and re-graded to allow the rapid release of flood water into Lake Zwai. The necessary overflow control structure would be a fixed weir, constructed of stone-filled gabions and sited on a bend in the river just upstream of the existing flood release point (Figure 18). The weir crest should be 15 m long with a crest level 1.5 m above river bed level. The channel bed and the banks both sides of the weir will require protection against erosion. It has been assumed in the costing that the flood channel itself would not require protection, though future studies of the topography, soils and river sediment load may indicate otherwise. Suitable stone for the weir could easily be transported by road from an already existing quarry 4.5 km west of Zwai town (on Separate Maps 1-3).

The flood flows in the Meki having been reduced to 80 m^3/s, it remains to consider the measures required to contain this flow farther downstream, since it is proposed that the second overflow channel be closed and the land to the east of the river reclaimed for

PLATE 9 Meki Delta: site for Meki River flood release channel

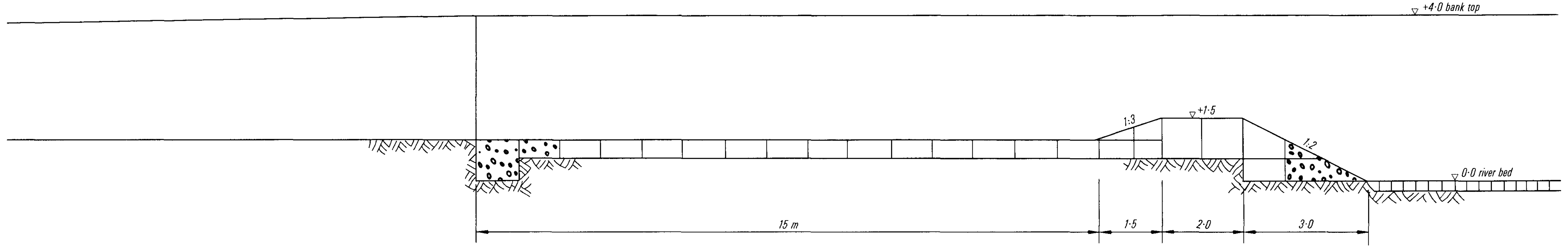
PLATE 10 Meki Delta: natural flood channel through *Acacia/Croton* woodland

FIGURE 18



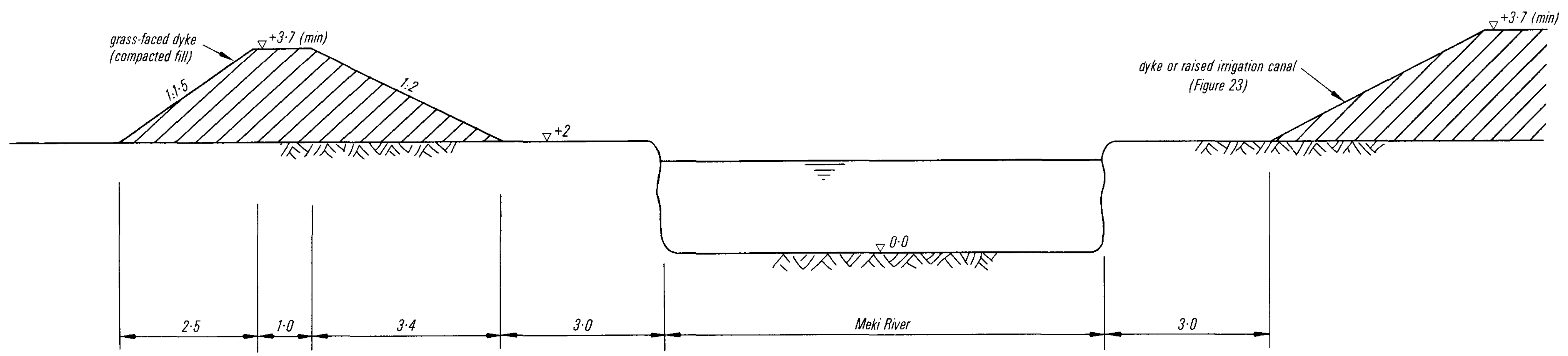
FLOOD OVERFLOW WEIR

0 5 10 15 20 25 30 Metres



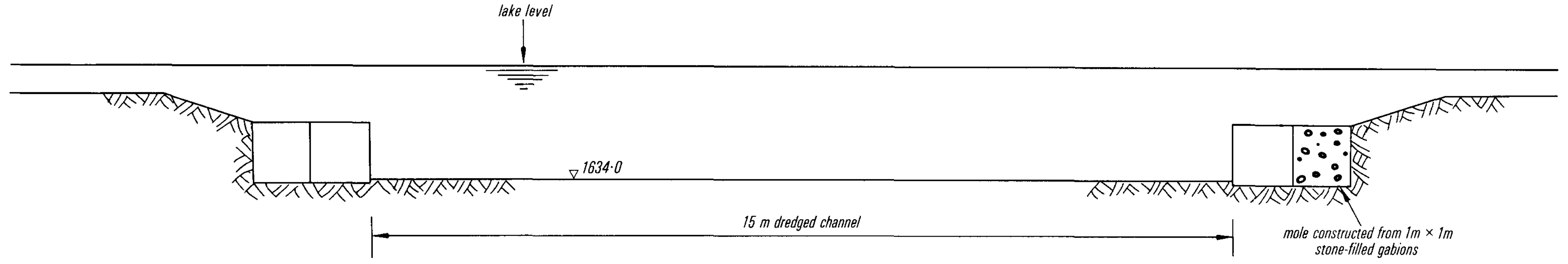
SECTION A-A

0 1 2 3 4 5 Metres



FLOOD CONTROL DYKES

0 1 2 3 4 5 Metres



MEKI RIVER INLET CHANNEL TO LAKE ZWAI

0 1 2 3 4 5 Metres

Note:- This Figure should be read in conjunction with Text Map 7

Prospects for Irrigation Development around Lake Zwai

FLOOD CONTROL WORKS ON THE MEKI DELTA

Land Resources Division, Ministry of Overseas Development | 1976

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irrigation. Over this final reach of 7 km the average bed slope is estimated at 0.08%. With a channel width of about 8 m, the Meki would need to have a depth of 3.5 m to carry the projected flood flows. Since this is not the case, it is proposed to construct flood control dykes with a top level at least 3.7 m above river bed level to avert flooding. These dykes could be constructed inexpensively from locally available heavy-textured soil in the form of trapezoidal-section grass-covered embankments. Nearer to the lake, raised irrigation canals leading inland would also act as control dykes, thus greatly re reducing the cost of flood protection in the lower reaches.

On the lowest part of the delta below about 1 637.5 m (a.s.l.), the Meki River outlet into Lake Zwai will require special attention to avoid additional flooding along the delta margin. Here the flow should be contained within a single straight channel by the construction of low dykes, combined with channel deepening to allow for lower lake levels in the future. Tentatively, it is suggested that the channel be graded to the 1 634 m contour, and partially contained under water by lateral moles constructed with gabions. The moles would both stabilise the channel and ensure that silt-laden river water is carried out into the lake well clear of the irrigation pumps (Text Map 7).

Control of flooding from Lake Zwai

Under present conditions the entire delta margin is liable to flooding during high lake levels. The area inundated annually varies considerably due to cyclic variation in average lake level. Some of the delta margin could be reclaimed by creating polders; i.e. the lake could be held back at high stages by constructing an enclosing dyke and the protected area drained by pumps. However, although the reclaimed land would compare with some of the best land on the delta, such a scheme is unlikely to be economic. Maximum development of the delta margin must therefore continue to be governed by the maximum lake level. If this level is gradually reduced by irrigation abstraction, more land will become available for reclamation.

Flooding due to poor soil drainage.

A proportion of seasonal flooding on the delta results from slow infiltration by rain-water. Since this occurs where the slopes are generally suitable for the construction of drains, there should be no major problems in installing field drainage to control the watertable at least 1.2 m below ground level. The drainage water could be led away by gravity towards either the river or the lake. In particularly level areas, it may prove necessary to install supplementary perforated pipe field drains.

Irrigation potential

Irrigation development on the Meki Delta is restricted by the low and unreliable dry season flows in the Meki, the high capital cost of constructing storage reservoirs in the upper catchment to regulate dry season flows, and the distance of much of the land from the lake. Ideally, the delta would be commanded by the diversion of regulated Meki flows immediately downstream from Meki Town. Since, however, construction of a storage reservoir, diversion structure and distribution system is likely to prove uneconomic for such a relatively small area, irrigation will have to be restricted to land which can be irrigated from'

1. The Meki River, using run-of-river flows pumped on to Class 1 land adjacent to the river on the upper part of the delta.

2. Lake Zwai, by pumping followed by gravity distribution via canals raised on embankments above the surrounding land (see Text Map 7).

Analysis of the record of flow in the Meki River has shown (Part 4; Figures 8 and 9) that there is a tendency for the river to dry up for limited periods between the middle of December and the end of March, and that very low flows can be expected anytime from the middle of November to June. The prospects for run-of-river irrigation are therefore quite limited. The most reliable flows occur in the period July to October, but this is the rainy season when demand for irrigation will be small.

Run-of-river irrigation during the dry season is nevertheless feasible on a small area and up to 1974 was being developed on the Meki Delta at a rate of about 20 ha/year. To determine the extent to which this can continue without incurring too great a risk of failure through lack of water in the Meki, the total dry season flows for the period 1963-4 to 1971-2 were analysed to determine the water availability in the months December to March - the period of maximum demand for irrigation. By approximating the distribution of total dry season flows with a log-normal distribution, estimates of dry season low flows were derived (Table 61).

TABLE 61. Estimated dry season (December - March) low flows in the Meki River at three levels of probability

Probability	Flow (mcm)	Estimated 95% confidence limits of flow (mcm)	
		Upper	Lower
50% (50 years in 100)	21.4	48.3	9.5
80% (80 years in 100)	7.05	23.4	2.4
90% (90 years in 100)	4.34	15.5	1.2

Any analysis must however be interpreted with great caution since the data available cover only a short period and show marked variation from year to year. Moreover, the rating curve, by which low flows are interpreted from daily records of gauge height, has been unconfirmed in recent years (indeed, only a very few discharge measurements have been made) and the published data are possibly overstating the true discharges. Dispite these difficulties, there is justification for cautiously increasing the area to be irrigated from run-of-river flows. Based simply on the total dry season flow with a 90% probability of occurrence, 4.34 mcm, and the average irrigation requirement between December and March, 7 230 m^3/ha, the area that could be irrigated from run-of-river is estimated at 590 ha (see Appendix 2 for the details of irrigation requirements). However, this involves two assumptions which in practice cannot be met, so causing the potential irrigable area to be less than 590 ha. These assumptions are (a) that the entire flow (4.34 mcm) would be abstracted for irrigation, whereas the actual irrigation period will almost certainly be less than 24 hours per day; and (b) that water would be abstracted at rates according to the natural variations in flow, whereas actual abstraction rates would in practice be related to other factors.

In order to maximise irrigation from run-of-river, it will be necessary to pump water during periods of low flow for a maximum length of time each day, and certainly for longer than the 12-hour schedule proposed for other areas. It would also be prudent to install surplus pumping capacity along the Meki, so that under critical low-flow conditions maximum use can be made of the available water. In these ways, it should prove possible to irrigate up to 300 ha (about 60 ha of irrigation had already been developed by March 1974). Even so, there will still be some risk of flows which will be too low for too long a period to avoid serious losses in crop production. While the suggested maximum development of 300 ha would apply to total run-of-river irrigation throughout the Meki Valley, since the area involved would be so small, it is recommended that developments be confined to the delta where returns from irrigation are likely to be highest. Developments would take the form of an extension of current practice using small pumps to irrigate plots not further than 1 km from the river.

By pumping water inland from the lake along raised gravity canals, a further 2 160 ha of Class 2 and Class 4 land can be commanded within 5 km of the lake. Text Map 7 shows the developments proposed on the delta. It will be noted that these more major developments must await completion of the flood control works proposed above and installation of effective field drainage. In contrast, the run-of-river developments can proceed without flood control, though in the project costing a small sum has been allocated to cover minor dyke construction.

Water distribution and irrigation development

With run-of-river development it is unlikely ever to be economic to provide large pumping stations and supply canals. The existing system of small pumps (10-12 hp) each supplying up to 12 ha should be continued, but it will be necessary for river-side farms to provide access for feeder canals to farms further away from the river. Since the present system of bunded furrows should continue to be employed, water use can be carefully regulated and no formal drainage system will be necessary. Along the lower reaches of the Meki it may prove necessary to construct temporary low bunds in the river bed in order to pond water during periods of low flow. Strict control should be enforced by a central project organisation on the operation of pumps to ensure equitable use of the available water.

The main developments proposed for the delta (Text Map 7) would be based on pumping water up out of the lake to the head of an elevated canal at a level of 1 641 m (a.s.l.), and conveying the water inland by gravity to irrigate suitable areas below the 1 640.2 m contour. Secondary canals laid approximately along the contour would lead off each main canal at regular intervals. The connection between the raised primary canal and the secondaries would be via chutes. The secondaries would in turn supply a tertiary system of canals from which individual farmers would draw. A complementary system of drains would be provided both to remove any excess irrigation water (and rainfall) and also to control the groundwater level. Deep subsoil drainage is essential in view of the very real risk of saline groundwater rising up into the root zone.

The proposed method of irrigation is by basins of 0.5 ha (100 x 50 m). The usual area per farming family would be 1.5 ha, consisting of three basins in series. Water would be supplied from tertiary canals by plastic siphons and excess water from one basin would be able to spill over by gravity into neighbouring basins. Some land levelling within the basins will be necessary and it will be essential, given the proposed systems of cropping, to provide drainage furrows at about 1 m intervals. The irrigation supply system (as shown on Figure 23, page 177) has been designed for a maximum irrigation demand of 700 m^3/week per hectare (2.7 1/s per hectare) and a maximum irrigation frequency of once every five days. Primary access roads on the delta would have to be upgraded to allweather status; road improvements, including a ford across the Meki River, are shown on Text Map 7.

Vegetable production

The Meki Delta offers the most favourable location for developing vegetable production, as suggested in Part 5. Necessarily, this development must await proving trials and a final feasibility study. If proved feasible, encouragement should be given to an experienced company to assist in establishing a factory and nucleus estate. Tentatively, a factory capable of processing 50 tons of fresh produce per day is suggested. Basing capacity calculations on the dehydration of onions and assuming an average yield of 30 t/ha, such a factory could in one year take up the total production from 500 ha. To ensure a basic uniform level of supply to the factory, it is advisable for the bulk of its requirements to be derived from a nucleus estate operating under the control of the factory. A suitable size for the nucleus estate would be about 400 ha. An additional 5 ha would have to be set aside for the factory, which should be sited at a suitable location as regards electricity, water and access. Possible locations for both the nucleus estate and the factory are shown on Text Map 7. The estate area is currently subject to periodic flooding and used primarily for grazing. Establishment of a nucleus estate in this area would therefore cause a minimum of disturbance to existing land use on the Meki Delta.

Operation of the proposed factory at maximum capacity would also depend on an adequate supply of vegetables from outgrowers. In the early stages of development, outgrowers contributions would probably be small in comparison with the output of the nucleus estate. In time however, the nucleus estate could be gradually reduced in size and partially settled by smallholders. It is probable that a factory of the capacity proposed would require a permanent workforce of up to 300. Much of the work would be cleaning and preparing vegetables prior to dehydration and could be performed by both male and female labour.

MID-MEKI VALLEY

This part of the project area, lying to the west of the Mareko Ridge in the middle reaches of the Meki River, is relatively isolated both from the remainder of the project area and from Addis Ababa (Text Map 1). The distance from Inseno, in the mid-Meki Valley, to Zwai town is about 35 km and to Butajira 15 km. The mid-Meki Valley is a wide, gently undulating plain drained to the north-east by the Meki River.

Although Italconsult (1970) reported that 'roughly 3 000 ha' of land in this area were suitable for surface irrigation, its precise location was not given. The initial LRD reconnaissance (Makin *et al.*, 1975) identified a potentially irrigable area of some 12 000 ha centred north-east if Inseno. The Meki River skirts the northern edge of this area, following a meandering course and incised 14-17 m below the level of the plain; this ruled out the possibility of direct gravity irrigation, but prospects for local pump irrigation appeared to be sufficiently favourable for the area to merit additional investigation. Since it was clearly essential to view irrigation developments in the Zwai catchment as a whole, this part of the mid-Meki Valley was added to the project area. However, more detailed investigations showed the topography to be less favourable than had initially been supposed. Consequently, the area was reduced to about 2 500 ha, extending 3-6 km south of the Meki and bounded to the east by the Weja River.

It should be emphasised that there are no prospects for irrigation from the Weja River tributary, both because of its very low, saline dry season flow, and the considerable vertical and horizontal pumping distances necessary. Consequently, the following discussion relates solely to the prospects for irrigation from the Meki River.

Land use

The pattern of land use is indicated in Table 62; in this table the 'total area' relates to the wider tract of about 8 000 ha shown on Separate Map 1 surrounding the immediate confines of the project area.

TABLE 62 Land use in the Mid-Meki Valley, 1974

Physiognomic type	Land use class	Total area on Map 1 (ha)	% of total area	Project area (ha)	% within project area
Woodland and bushland	*Acacia/Croton* woodland	140	1.7	30	1.2
	Acacia bushland	160	2.0	40	1.7
	Hillside bush-grassland (undifferentiated)	750	9.3	100	4.4
	Total	1 050	13.0	170	7.3
Grassland	*Setaria* grassland	730	9.1	620	26.7
Cultivation	Small-scale	5 970	74.6	1 290	55.0
	Large-scale	250	3.1	250	11.0
	Total	6 220	77.7	1 540	66.0
Other	Urban land	20	0.2	-	-
	Overall total	8 020	100.0	2 330	100.0

Much of the mid-Meki Valley is intensively cultivated, maize accounting for up to 90% of the cultivated area. Small farms predominate with an average holding size of 1.9 ha and cultivation is long-established. In 1973, over 90% of the farmers were tenants. In most years, because of the relatively early onset of the rains, the cropping cycle is in advance of that around Zwai; moreover, the greater frequency and reliability of the rains generally ensure heavier yields. Cattle ownership is less important than in other parts of the project area, average numbers per household being about four head.

Maize and red peppers are the main cash crops. Pepper nurseries, clustered around well heads and on terraces close by the Meki River, account for about 1% of the cultivated area. These form the focal point for local activity 2-3 months before the wet season and so absorb a high labour input. Haricot beans and lentils are subsidiary cash crops. There are some recent minor plantings, especially along road verges, of *Eucalyptus camaldulensis* for fuel and building poles.

On level ground towards the east of this area, cultivation gives way abruptly to extensive *Setaria* grassland (with subsidiary *Hyparrhenia, Sporobolus* and *Themeda)* which is used for grazing. The grassland is associated with a regular formation of termite mounds which, though showing clearly on aerial photographs, are often found to be so eroded as to be almost level with the ground. In many places the mounds are bare of vegetation; elsewhere they may be covered by short turf or even clumps of thicket. Such patterns can be indicative of seasonal poor drainage. Minor pockets of cultivation within the grassland carry poor stands of maize and sorghum, with tef and lentils as subsidiary crops.

Topography

The mid-Meki Valley is part of a down-faulted plain covered by Pliocene ash deposits. The level appearance of this plain, as seen from the main track through the centre of the area, is deceptive. The land is in fact traversed by two dry valleys, each leading northwards towards the Meki and probably representing part of an earlier drainage system. In any event, they fragment the potentially irrigable area (see Separate Map 3); close to the Meki, incipient gullying creates further undulations. Apart from these local features, the country south of the Meki slopes almost imperceptibly uphill away from the river towards the south and south-west (i.e. towards Inseno). This implies that, for irrigation, water would not only have to be pumped up out of the river, but also away from the river; or, alternatively, pumped to an even higher level so as to command the land by means of raised gravity canals. In the centre of the area for example, a 17 m vertical pump lift would command some 2 km away from the river. Thereafter, rising levels would require additional pumping: e.g. a further 6 m lift over the next 4 km to the south. To the east, towards the Weja River, the land levels out at around 16.5 m above the bed of the Meki River. Although some of this area might conceivably be commanded by a carefully sited main canal and although pump irrigation may also be feasible locally, it must be concluded that the topography is such that any scheme for irrigation development would be both expensive and fragmentary.

Soils

The soils have developed from ash which has weathered over a long period under conditions of moderately good drainage. Clays and silty clays have formed which are 80-100% base saturated with a high cation exchange capacity (30-45 meq/100g). Towards the east of the area, a subsequent and presumably recent layer of relatively unweathered grey ash has been deposited over these clays to a depth of up to 50 cm. This ash has a particularly high silt content, relatively poor fertility and a low cation exchange capacity (as low as 10 meq/100 g). Along the flanks of the gullies that dissect the area, on slopes exceeding 2%, there is a prevalence of shallow soil and a tendency for weathered ignimbrite to outcrop. Locally, on lower terraces close by the Meki there are small areas of friable brown silt loam presumably of alluvial origin.

The two main soils of the plain (Soils R and S on Separate Map 2) have several characteristics in common. The soil reaction is close to neutral (pH 6-7.5) throughout the profile except in localised instances where free carbonate, and even caliche, occur at depth associated with pH values of 8-8.5. Soil salinity and alkalinity are invariably at low concentrations within the surface 1.5 m, and calcium dominates the exchange complex. The surface organic content varies between 2 and 3%. Although well endowed with potassium, all soils are deficient in both available and total phosphate, the silty soils especially so. Although calcareous subsoil below 1 m is uncommon, near the base of the terrace edge along the western boundary, a sheet of caliche occurs at between 80 and 120 cm depth; this presumably has been deposited as a result of long-continued seepage and is associated in the upper soil layers with high levels of manganese.

Soil R, the predominant soil in the west of the area, comprises dark greyish-brown clay or silty clay overlying dark yellowish-brown clay to a considerable depth. Despite the heavy texture (40-65% clay content, and 30-50% silt), the soil structure is such that drainage is only slightly impeded and it is anticipated that permeability rates will be moderate (up to 45 mm/hour). Nevertheless, the land cannot be cultivated following heavy rains and, though the soils are suitable for the main crops discussed in Part 5, due to the heavy texture, they are not ideal for groundnuts; consequently, they are regarded as Class 2 for irrigation.

Soil S, which occurs extensively in the east of the area, comprises silt loam or silty clay loam topsoil (50-60% silt) with two distinct layers, a dark greyish-brown surface horizon and a characteristic light grey sub-surface horizon with prominent brown mottles and concretions indicative of seasonally impeded drainage. The profiles are non-calcareous throughout. There is an abrupt transition to the underlying heavy dark grey clay (60-70% clay and 20-30% silt) which, when dry, is extremely hard; at depth, this merges into a more friable uniform brown clay. This combination of surface silt with heavy clay subsoil must cause impeded profile drainage and poor soil aeration. The soil infiltration rate is moderately slow (measured at one site as 21 mm/hour). Moreover, when cultivated, the soil surface may form a hard crust not easily penetrated by seedlings. Hence the classification of these soils as Class 3 for irrigation. Poor physical soil properties presumably account for the preservation of grassland on a plain that is otherwise densely populated and intensively cultivated; certainly a gradual decline in rainfall towards the east cannot explain the abrupt transition from cultivation to grassland. Local people reported a lack of fertility in these soils, such that a long fallow period and application of large quantities of cattle manure were essential to obtain even modest yields of any crop. The beneficial effects of such treatments may not be related to soil fertility *per se,* but rather to improvements in soil structure and hence in soil aeration; it may be significant that the *Setaria* grasslands were being brought under cultivation by commercial farmers using tractors.

Irrigation potential

The combination of generally level topography and reasonable soil, free of the alkali problem which affects much of the land elsewhere in the project area, renders the mid-Meki Valley superficially attractive for irrigation. However, the preceding discussion has pointed to a number of technical problems - the relatively high pump lift (substantially higher than that on the Meki Delta), the gradual slope up away from the river, the small and fragmentary nature of any possible irrigation blocks and the relative inaccessibility of the mid-Meki from the more extensive potentially irrigable areas near Lake Zwai. There is, moreover, the small but significant difference in climate between the mid-Meki and the Meki Delta, the former area experiencing somewhat heavier, possibly earlier and certainly more reliable rainfall, and lower evapotranspiration consequent upon the higher humidity. Because crop yields without irrigation tend to be higher in the mid-Meki Valley than those around Lake Zwai, the economic benefit from irrigation in the mid-Meki Valley will be less than that elsewhere in the project area.

It is therefore concluded that, since the low dry season flow of the Meki River is the crucial factor limiting the area that can be irrigated along the river, the entire available flow should be conserved for use on the Class 1 land of the Meki Delta. It is therefore recommended that, rather than irrigation, available investment in the Meki Valley should be concentrated on developing an effective agricultural extension service, the returns from which should surpass those from irrigation. The first priority of such an extension service should be improvements in the standards of husbandry, in the varieties grown and in the quality of red peppers for processing. In the event of regulation being provided on the upper reaches of the Meki (discussed in Part 4) so that more water is available for irrigation throughout the year, it still follows that priority should be given to developments on the Meki Delta.

WESTERN TERRACES

The Western Terraces cover a considerable area between Zwai and Meki, bounded to the west by a prominent scarp 2-6 km from the lake and to the east by lakeside swamps. The lake margins, varying in width from 0.5 to 2 km and representing the lowest terrace, are considered separately in a later section (page 153).

Land use

Almost the entire area is cultivated, remnant patches of *Acacia tortilis* bushland and woodland being largely confined to terrace scarps and still un-utilised fields on large farms. Before 1975, most of the larger farms exceeded 200 ha and there were few medium-sized farms. The average small farm was 1.9 ha and over 80% of farmers were tenants. Of the total cultivated area in 1973,56% was under maize and 34% in haricot beans. Beans represented the main cash crop, being grown extensively on large farms. Other cereals included tef (3%) and sorghum (1.5%). Livestock comprised a significant element in the farm economy with an average of 12.5 head per farm holding, bullocks representing the main source of draught power. Although cattle ownership increases in importance with distance from the lake, the periodically inundated lakeside also represents an important source of forage at low lake levels when migrant stock owners graze large herds on the *Cynodon plectostachyus* grasslands.

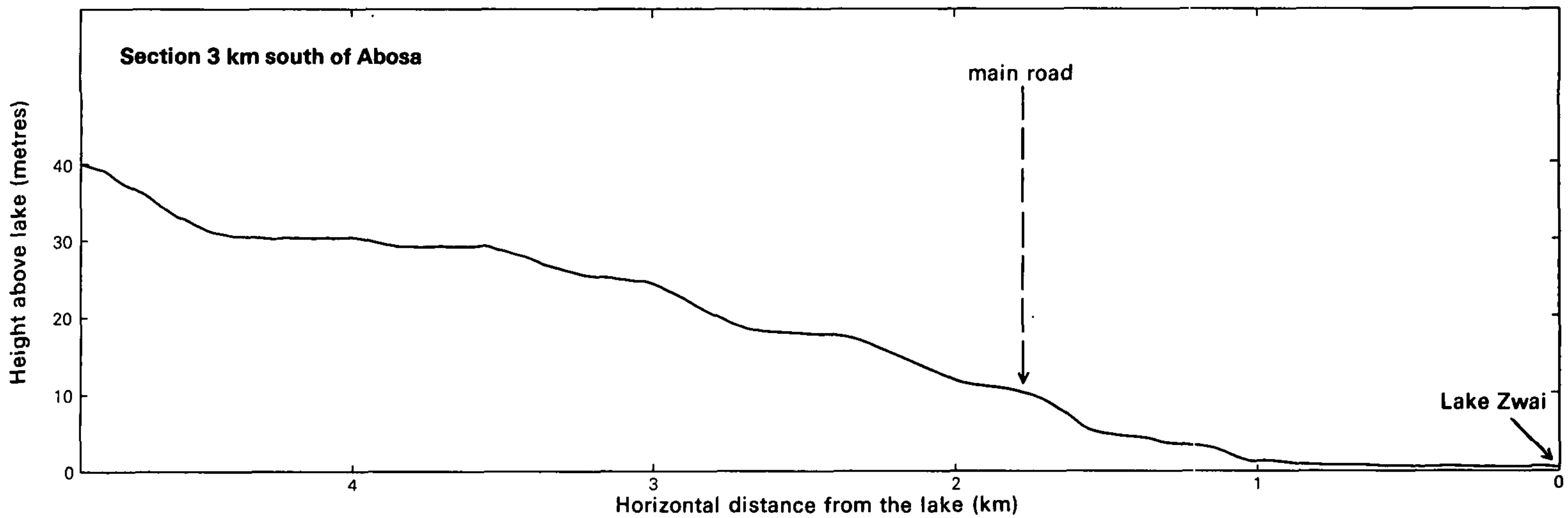
There are a few irrigated plots on the first terrace above the periodically inundated grassland. These are served by small pumps, with a pump lift of some 5-7 m from the ends of canals excavated inland an average of 1 km from the lake edge. Although about half the irrigated area was devoted to tomato production, a wide range of crops is irrigated including cabbage, cauliflower, green beans, capsicums, celery, red creole onion, cantaloupe and water melons.

Topography and soils

Around Abosa, there are five distinct terrace levels at about 5, 10, 20, 25 and 35 m (a.s.l.) (Figure 19). The terraces slope at less than 0.5% towards the lake and are separated by scarps, in places discontinuous, from 1.5 to 4 m high. Slopes along the lengths of the terraces are very slight; for example, the variation in level over a distance of 3 km along the main road between Zwai and Abosa is only 0.5 m. North of Abosa, the terraces are close together and the area of irrigable land is limited; but, towards Zwai and also immediately to the south of Meki, the terraces broaden out, the terrace edges become more subdued and the potential irrigable area increases correspondingly.

Coarse and medium-textured soils, of pumice and ash respectively and with high levels of subsoil alkali (mean ESP of 22-42; pH 8.0-9.2), predominate over most of the area. The detailed distribution of these soils is shown on Separate Map 2 and their chemical and physical characteristics have been discussed in Part 5, where it was concluded that only the coarser-textured (Class 3) soils could be considered suitable for early irrigation development. Generally, sandy loam overlies structureless loamy pumice sand on the first and second terraces and also on the highest terrace at the foot of the prominent western scarp. Sandy loams, loams, and even clay loams occur on the middle terraces over-lying weathered, variable and often compact volcanic ash at 30-70 cm depth. Exceptions to this general pattern are common however. Loams and clay loams occur on the lower terraces just north of Zwai; east of Abosa; and South of Meki. Immediately north and south of Abosa, sandy loam overlying loamy coarse sand occurs on the middle terraces. Intermittently at the foot of the western scarp and also to the south-west of Meki, the soils are high in silt. Surface salt and/or alkali occurs extensively to the south of Meki, and locally along eroding terrace scarps.

South of Meki on the western edge of the Meki Delta, terrace soils have formed from a mixture of lacustrine and riverine deposits. Generally clay loam overlies clay though sub-surface sandy layers may be present. Subsoils are alkaline and slightly saline (the EC of the saturated extract averaged 6.7 mmhos/cm). Saline and alkaline top soils border the north-west shore of Lake Zwai, 3.5 km south of Meki, varying from sandy loam to clay loam.



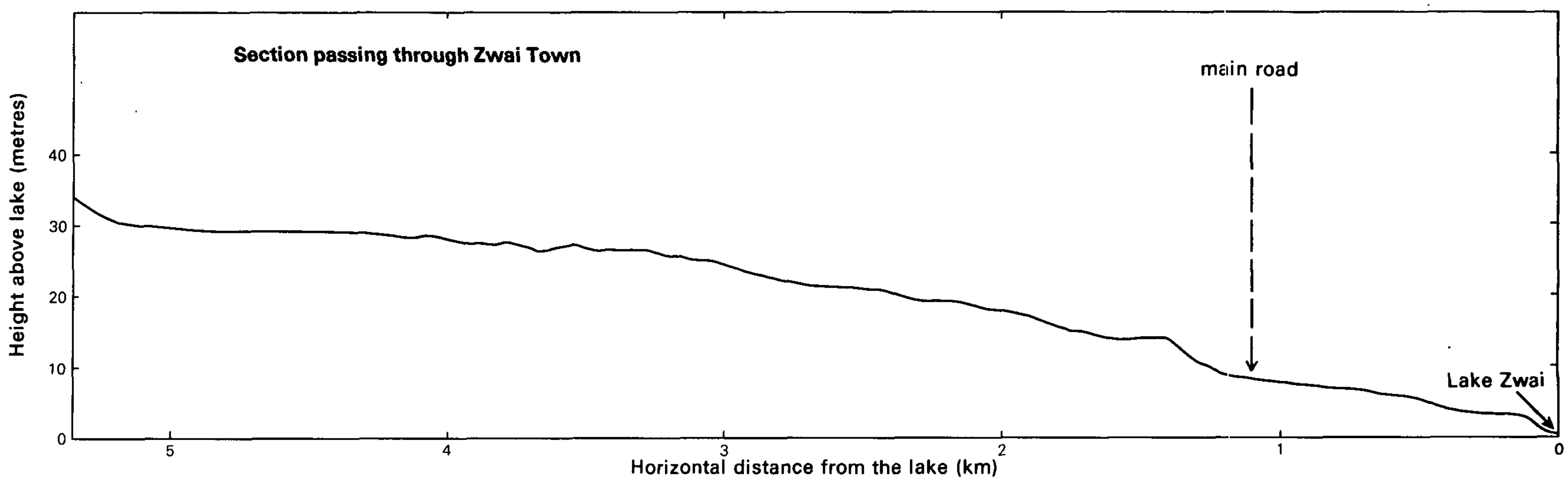


FIGURE 19 Cross-sections through the Western Terraces (vertical scale exaggerated)

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FIGURE 19

Irrigation potential

The irrigation potential of the Western Terraces is limited by extensive areas of medium-textured alkaline soil which is unsuitable for early development and by an absence of large blocks of level land on the terraces nearest to the lake. It is moreover unfortunate that the worst soils occur to the west and south-west of Zwai Town and south of Meki, in areas topographically most suitable for irrigation. Around Abosa, where the coarser-textured Class 3 land is most widespread, the presence of three scarps within 1 km greatly restricts the irrigable area. Nevertheless, a total of 1 380 ha are suitable for phased irrigation development (see Table 63 and Text Map 8).

TABLE 63 Summary of potential irrigation sites on the Western Terraces (see Text Map 8)

Development	Phasing* (on Text Map 8)	Area (ha)	Maximum pump distances+	
			Horizontal (km)	Vertical (m)
Low-lift pumping on to the lowest terrace	A3	810	1.5	8
Pumping on to higher terraces	B2	570	3.0	25
Pumping on to the higher alkaline terraces; between Abosa and Adamitulu, and west of the Meki River	C1 (conditional on long-term trials)	2 780	5.0	25

*See section: 'Development phasing'
+ Related to present average lake level

It is envisaged that the early irrigation of 810 ha on the lowest terrace would broadly follow the practice already established on existing irrigated holdings. Since the maximum width of this terrace is only 700 m, and the highest point above lake surface is 8 m, virtually the entire terrace could be commanded by the type of 12 hp pump in common use. However, while it is expected that 12 hp pumps should meet the needs of individual plots of less than 2 ha, larger pumps could be used communally as the area under irrigation increases. Pumps would be sited on the edge of the lowest terrace to extract water from canals excavated inland 0.5 to 1.5 km from the lake. For the larger pumps, several canals would have to be linked to maintain an adequate inflow of water to the terrace margins. As development proceeds, control over the siting and fencing of these canals will be essential if the seasonally flooded grassland is to be maintained for grazing.

In the longer term, irrigation of the second and third terraces (570 ha) around Abosa may be feasible. Such development would necessitate the use of large pumps sited on the lakeshore and could only take place following lake level regulation. Water would be piped to the terraces and supplied to individual farms via hydrants. Irrigation would be on a larger scale and would require considerable technical expertise and institutional control. The possible irrigation of a further 2 780 ha of medium-textured alkali-affected land on the higher terraces will depend on the outcome of field trials to monitor the effect of irrigation on soil compostion, physical structure and permeability.

BULBULA AREA

This is defined as land south of Zwai on both sides of the Bulbula River ('Bulbula East' and 'Bulbula West') up to 7 km from its outlet from Lake Zwai. In this area there are opportunities for irrigation both from the lake and from the river. The 1 520 ha Adamitulu Cattle Breeding Station has, on account of its special status, been considered separately below. Bulbula East, comprising over 1 500 ha, is bounded by volcanic cones 1-2 km east of the river. Bulbula West, however, extends for 6-9 km across several ill-defined lake terraces to the base of an east-facing scarp at about 29 m above the lake, the ultimate limit for pump irrigation.

Land use

Much of Bulbula West is cultivated. A few patches of acacia bushland and woodland still remain but these comprise less than 5% of the land area. Some fallow is reverting to dwarf acacia bushland through the invasion of *Acacia tortilis* and *A. Senegal.* Elsewhere, the land is given over to the single-season cropping of maize, haricot beans and tef. Whereas similar hectarages of maize and beans were grown in 1974, maize occurs throughout the area, while beans tended to predominate on the larger farms. The hectarage of tef was less than half that of maize. Minor irrigated plots close to the Bulbula are used to raise a wide range of crops, including tomato, citrus, onion, *chat (Catha edulis)* and bananas.

Bulbula East was always an area of small communally-owned farms and relatively intensive cultivation. Along the river there are several small irrigated plots producing vegetables, principally tomatoes. Elsewhere, maize is the major crop, though there are also significant hectarages of tef and haricot beans and a much smaller area of wheat and barley.

Topography

The lake terraces to the west of the Bulbula River are a continuation of the Western Terraces described above. In contrast with the terraces around Abosa, those in Bulbula West are broader with a correspondingly greater distance between terrace scarps (c.f. Figures 19 and 20). While the microtopography may be slightly undulating, any slope along the terraces (i.e. north-south) can barely be discerned. The level nature of these terraces is evident along the main road between Zwai Town and Adamitulu, the elevation remaining at 10-11 m (a.l.s.) throughout a distance of 5 km. Overall elevations range from 5 m along the bank of the Bulbula to almost 30 m near the base of the western scarp. Exceptions to this general pattern of gradually increasing elevation towards the west are uncommon and include the steep-sided volcanic plug at Adamitulu and a ridge of siltstone extending up to 3 km north of Adamitulu.

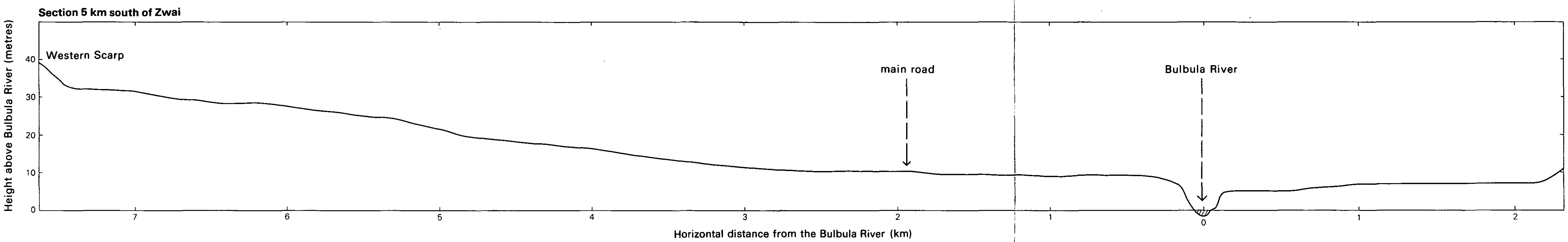
For a very short distance to the east of the Bulbula River the land is almost level at around 4 m (a.l.s.). Thereafter it rises towards the bouldery footslopes surrounding the volcanic cones to the east, the base of which approximates to the 15 m contour. The land similarly slopes up away from the southern shore of Lake Zwai.

Soils

Just as the terraces west of the Bulbula are a continuation of those to the north, so the soil pattern also repeats that found on the Western Terraces north of Zwai, and the properties of the soils are in all essentials similar. The soil distribution shown on Separate Map 2, though complex, is related to the terraces. The lowest terrace comprises well drained coarse loamy sand with pumice inclusions and alkali at depth (Class 3). The terrace scarps are of similar composition. Much of the second terrace is finer textured, with loam, fine sandy loam and silt loam overlying partially consolidated and highly alkaline ash (Class 5). On the highest-lying terraces towards the west, there is again coarser-textured material with coarse sandy loam overlying loamy sand (Class 3). There are two significant exceptions to this pattern. Some 4 km to the west of Adamitulu, an area of about 300 ha is underlain by shallow siltstone at depths ranging from 10 to 50 cm, and on the low hill extending over about 250 ha north of Adamitulu soils rarely exceed 25 cm depth.

In Bulbula East the low-lying soils near the river have a silt content which is significantly higher than that found on comparable sites to the west. Typically, greyish-brown silt loams or fine sandy loams overlie grey, somewhat gravelly and indurated, calcareous silt loam or even silty clay loam. Subsoils are invariably highly alkaline. Ascending the footslopes to the east, the soils become sandier and subsoil alkalinity occurs at increasingly greater depths. Close to the base of the hills, the ground surface is covered with stones and boulders of pumice, tuff and lava, and the soil profile contains gravel layers; some localised gullying also occurs. Surface salt and alkali are evident along the terrace margin close by the lake, and also near the Bulbula about 1.5 km south of the lakeshore.

FIGURE 20



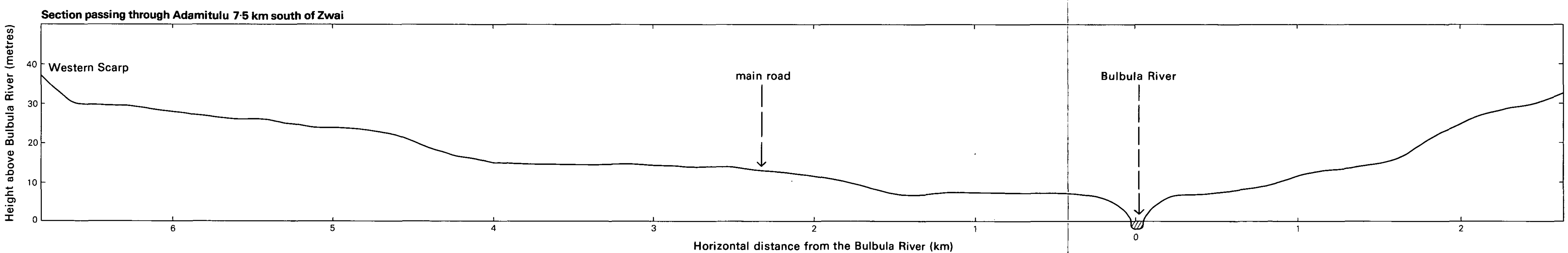


FIGURE 20 Cross-sections of land adjacent to the Bulbula River (vertical scale exaggerated)

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Irrigation potential

The irrigation potential is restricted by unfavourable soils and topography. Better quality Class 3 land tends to occur on the high-lying terraces farthest from the water. Consequently, the total pumping head over much of the area would be prohibitive for the development of irrigated agriculture. Nevertheless, some significant areas remain, on the lower terraces close to Lake Zwai and the Bulbula River, where it is considered that irrigation should prove economic.

It is proposed that early developments should comprise low-lift pumping along both banks of the Bulbula, and from Lake Zwai on to the lowest terrace south of Zwai Town (see Table 4 and Text Map 8). For low-lift pumping in Bulbula East, use could be made of communally-constructed elevated earth embankments (as proposed for the Meki Delta) to command all the Class 3 land up to the 5 m contour (160 ha). In Bulbula West, some 390 ha of almost level Class 3 land could be commanded by means of a pump lift of 9 m over a distance of some 2 km. Here, it should prove possible for the farmers to benefit from economies of scale by installing communal banks of pumps in conjunction with an extensive canal distribution network. Higher-lift pumping in Bulbula East should have a significantly lower priority. Of the three separate areas of Class 3 land which could be developed in this way, the two northernmost sites, lying between 1 and 3.5 km south of the lake (total area 240 ha), could be commanded from the same point by means of a lift from the Bulbula of about 12 m over a distance of 1.3 km; hydrants could be used to irrigate land at intermediate levels. An additional area (of only 110 ha) to the south is less viable, involving a lift from the Bulbula of 15 m over 1.5 km.

TABLE 64 Summary of potential irrigation sites in the Bulbula area (see Text Map 8)

Location	Phasing* (on Text Map 8)	Area (ha)	Maximum pump distances†	
			Horizontal (km)	Vertical (m)
Bulbula East	A2	160	1	5
Bulbula West	A3	390	2	9
Bulbula East	B3	(240	1.3	12
		(110	1.5	15
Bulbula West	C1 (Conditional)	1 820	4.5	17

*See Section: 'Development phasing '
- † Related to present average lake level

Development of up to 1 820 ha west of the Bulbula would be largely confined to alkaline Class 5 land and is therefore conditional on a favourable outcome to field trials, as proposed in Part 5. Because of the generally level nature of this land and the difficulties anticipated over water distribution, it is further recommended that a detailed topographic survey (suggested scale 1:2 500 and contour interval 0.1 m) to be carried out prior to designing an irrigation layout. It is possible that development would entail two or three large pumping stations on the lakeshore, with a primary feeder (gravity) canal of up to 7 km in length. It should be noted that 350 ha of this 1 820 ha lie within the Adamitulu Cattle Breeding Station (Text Map 8); the implications of this are considered below.

ADAMITULU AND ABERNOSA RANCHES

Of the two government-owned ranches between Zwai and Bulbula, the larger, Abernosa Ranch (4 240 ha), lies just to the south of the project area. This is owned by the Ministry of Agriculture and leased on a 5-year contract (1971-6) to the Dairy Development Agency (DDA). Some 24 000 ha adjoining the western boundary of this ranch are retained by the Ministry as a Range Development Area. The Adamitulu Borana Cattle Breeding Station (1 520 ha) lies to the north of Abernosa Ranch and within the project area. Like Abernosa it is bounded to the east by the Bulbula River (see Text Map 1). This Station is used by the Ministry of Agriculture for developing quality beef-type Borana strains through culling and selection.

Land use

Both ranches are used for rotational grazing, each being divided by fencing into a number of grazing blocks. Other than in very dry years and locally near water points, the ranch lands tend to be understocked. Vegetation cover comprises *Acacia tortilis* bushland and woodland, with limited areas of *Hyparrhenia* grassland. The main components of the bush cover include *Acacia tortilis, A. senegal, A. seyal, A. etbaica, A. persiciflora, Balanites aegyptiaca, Capparis tomentosa, Dichrostachys cinerea* and *Opuntia* sp. There is a wide range of grasses, though relatively few species are of major importance. *Hyparrhenia* spp. dominate the grass cover in many parts, with the unpalatable *H. hirta* on the higher-lying and more gravelly sites and the highly palatable *H. anthistirioides* forming the mainstay of the dry season grazing elsewhere. Other palatable grasses found on the more favourable sites include *Cenchrus ciliaris, C. pennisetiformis* and *Chloris gayana.* Contrasting the vegetation protected within the ranch fencing with that subject to frequent and severe grazing outside, it is evident that the regulated grazing regime has led, not only to an increase in dry matter production, but also to a significant spread of acacia bushes such that in some areas thicket is starting to form. Since it is also evident that noxious broad-leaved weeds thrive under the shade at the expense of valuable grass species, it would be advisable to take steps to reduce the bush density.

Topography

The ranches lie on indistinctly defined lake terraces occasionally interrupted by volcanic extrusions; in the case of Adamitulu Station, these terraces are a continuation of those in Bulbula West (described above, and see Figure 20). In general, there is a gradual increase in elevation westwards away from the Bulbula River. The western boundary of the ranch lies at 15 m (a.l.s.) in the north and up to 22 m in the south. To the east of Adamitulu, the Bulbula River is only slightly incised and the pump lift onto the north-eastern corner of the ranch would be about 9 m. Towards the south, however, where the Bulbula is incised to between 7 and 10 m, the prospective pump lift is up to 22 m.

A low ridge and an isolated volcanic plug separate Adamitulu from Abernosa Ranch. Abernosa is itself effectively divided by an ignimbrite ridge, to the north of which about 3 000 ha lie in a shallow basin 12-25 m (a.l.s.), bordered to the east by the deeply incised course of the Bulbula and to the west by low ignimbritic hills. Several lake terraces are represented and the topography is correspondingly undulating. Irrigation is not considered to be feasible on Abernosa because of its distance from the Bulbula and from the lake (a minimum of 7 km) and the difficulty of commanding the ranch area because of the ridge to the north. Similarly, the southern section of Abernosa Ranch, comprising a close succession of terraces leading down to Lake Abiyata, cannot be considered for irrigation development.

Soils

Much of Adamitulu Station is located on a single lake terrace and all soils are formed on variable volcanic ash, normally consolidated in the subsoil and containing inclusions of pumice gravel. The proportion of gravel increases south of Adamitulu. Soil textures vary from gravelly coarse sandy loam to clay loam (Separate Map 2), the heaviest-textured loams and clay loams being located in the north-western grazing blocks. Most soils investigated comprised moderately well drained dark greyish-brown sandy loam with pH near 8, overlying consolidated pale brown calcareous coarse loam with a strongly alkaline reaction (pH 8.2-9.6). Topsoils are prone to compaction and are less permeable than might be anticipated from the texture. The main chemical characteristics are the calcareous subsoil (3-13% carbonate), the low levels of available and total phosphate, and the exceptionally high levels of alkalinity found generally below 1 m depth though sometimes, in the heavier soils, even within the surface 50 cm. While topsoil pH values averaged 7.9 with a mean ESP of only 2, the average subsurface pH was 9.2 with a mean ESP of 21; at depths below 1 m the mean value of the ESP exceeded 50. The significance of this degree of alkalinity has been discussed in Part 5. On that basis, the area of Adamitulu Ranch has been divided between Class 5 land, provisionally unsuitable for irrigation and occupying the entire western half as well as the north-eastern corner (see Separate Map 3), and Class 3 land with inherently higher permeability and lower levels of subsoil ESP. The Class 3 land, confined to the south of Adamitulu village, amounts to about 500 ha.

Abernosa Ranch has generally well drained dark greyish-brown gravelly sandy loams, underlain by layers of loamy pumice gravel becoming calcareous and highly alkaline at depth.

Irrigation potential

It is clear from the foregoing that Abernosa Ranch and the greater part of Adamitulu Ranch are unsuitable for irrigation; in Abernosa because of the topography and distance from water, and in Adamitulu for reasons of topography and soil alkalinity. Unfortunately, the best area on Adamitulu Ranch, the 500 ha of Class 3 land, is the most difficult to command. Not only does the land rise in directions both away from the river and to the south, but the river flowing south along the eastern boundary of the ranch, falls rapidly in level and water would have to be pumped onto this block of land from its north-east corner (see Separate Map 3). It is concluded that irrigation throughout this 500 ha block is impractical.

On topographic grounds, the best prospects for irrigation are in the north-west, to the north of Adamitulu. This is, however, Class 5 land strongly affected by subsurface alkali and not recommended for irrigation unless a favourable outcome has been achieved from irrigation trials. In that event, irrigation could cover approximately 350 ha (Text Map 8), with a primary feeder canal from the north designed in conjunction with similar developments on this terrace in Bulbula West (described above).

Although it is unlikely that irrigation would ever be introduced into the area since Adamitulu Ranch is already committed to an alternative form of land use, a situation might arise in the future when irrigated fodder was required for a specific purpose; this could be produced close to the Bulbula by means of pump irrigation. Alternatively, pressure on land might increase to such an extent that the introduction of intensive settlement would be necessary. In that event, the 350 ha block described above could be designated as one area for irrigated settlement. With 1 ha farms, and allowing about 15% of the area for infrastructure, this land could support up to 300 families. If necessary, certain of the functions of Adamitulu Ranch could be transferred to the more extensive Abernosa Ranch.

NORTH–EASTERN TERRACES

These comprise some 4 000 ha extending around Lake Zwai from the north-eastern edge of the Meki Delta to 5 km south of the Catar Delta. The limit to irrigation is marked by a well defined scarp at a height of 30 m (a.l.s.), between 2 and 4 km from the lakeshore. The lacustrine terraces are flanked by extensive swamps along the lake. At the foot of the terraces, and also within the swamps, groundwater seepage has locally given rise to high levels of salt and alkali. Several low rocky hills occur near the mouth of the Catar, where the river enters Lake Zwai across a partially submerged delta comprising some 450 ha of alluvium.

Land use

The eastern side of Lake Zwai has recently witnessed an influx of settlers such that much of the land area is now cultivated. Nevertheless, close to the lakeshore and locally elsewhere, there are remnant thickets dominated by *Acacia* spp., *Acokanthera schimperi, Balanites aegyptiaca, Capparis tomentosa, Carissa edulis, Croton* *macrostachys, Maytenus senegalensis* and *Rhus* sp. It may be significant that remnant trees (predominantly *Acacia tortilis* and *Balanites aegyptiaca)* within the cultivated areas are of greater stature than those on similar sites along the west of the lake implying rather more humid conditions along the eastern shore, perhaps due to the relative proximity of the Arussi Highlands.

Most farms in 1974 were smallholdings of less than 5 ha, with an average size of 1.6 ha. Holding fragmentation was marked with an average of 2.9 plots per farm. Seventy per cent of all farms were tenanted, the majority paying cash rents. A wider range of crops is grown than elsewhere in the project area, possibly due to the indirect influence of CADU, which operates extension and marketing services at Ogelcho and Chefe Gila. In 1974, maize occupied about 59% of the cultivated area, barley 12%, wheat 8%, tef 6% and haricot beans 5%. The predominent position of maize is reflected by its relatively high yields. Crop yield estimates for the general area are presented in Table 65.

TABLE 65 **Estimated crop yields (q/ha) to the east of Lake Zwai under rainfed conditions (after Anselmsson, 1972)**

Maize	Barley	Wheat	Tef	Haricot Beans
16	10	6	7	12

Livestock are an important element in the farm economy, numbers averaging 11.8 head per household, cows (8.8 head) predominating. Pastures are of generally low carrying capacity comprising fallow, remnant scrub and bush-grassland. *Chloris pycnothrix* is the most important grass species, with frequent *Cynodon* and *Eragrostis tenuifolia.*

Topography and soils

Topographically, the area can be subdivided into three parts: (a) the terraces north of the Catar River, (b) the Catar Delta, and (c) the terraces south of the Catar.

Terraces north of the Catar River

The land slopes gently up from the lakeshore for 1.5 km to the first significant scarp at about 25 m (a.l.s.). Thereafter, several small scarps occur in close succession and, topographically, the land becomes increasingly unsuitable for irrigation. Towards the Catar the lower terrace is confined to 0.5 km width by a hill area near the lake. The swamps bordering the lake vary in width from 1 to 2.5 km. Although the topography of the lowest terrace is well suited for irrigation, the extensive occurrence of surface salt and alkali, often at high concentrations, seriously limits the potential of this area.

On the higher terraces loams and clay loams occur. The clay loams flank the Meki Delta and the northern edge of the Catar alluvium. North of the Catar, where subsoils tend to be slightly saline, the presence within the profile of dark clay layers and bands of sand suggest that the soils have formed on a mixture of lacustrine and alluvial material. Elsewhere, the clay loam overlies yellowish-brown weathered ash. Loams, occurring between the areas of clay laom, are less alkaline and contain a higher proportion of silt than is usual in medium-textured terrace soils.

Catar Delta

The Catar is incised some 12 m into its delta and no longer floods over it. The actual area of alluvium is small and interrupted by two small hills south of the river. The land slopes gently down from the river towards the lake. North of the river, old channels cause slight undulations in topography. The river alluvium grades into lacustrine material along the delta edges; in the south this transition is marked by scarps. South of the Catar termitaria are numerous towards the lake. The alluvial soils comprise friable loams and clay loams overlying variable clay loam and clay. Coarser layers of gravel, loamy sand and sandy loam often occur in the subsoil. Chemically, these soils are similar to those on the Meki Delta and there is a high level of alkali (ESP 30) in the subsoil, presumably due to a periodically high saline watertable.

Terraces south of the Catar River

Here four distinct terrace levels have the effect of limiting the area of level land. Moreover, the second and third terraces have been dissected by an old tributary of the Catar, resulting in uneven topography. Termitaria are numerous on the lowest terrace. The soils are similar to those on the Western Terraces: the lowest and highest terraces with loamy sand over coarse pumice sand, and the middle terrace with clay loam overlying variable ash.

Irrigation potential

Several factors combine to give the north-eastern shoreline a low priority for irrigation:

1. Not only is the area comparatively inaccessible, especially south of the Catar, but the distance from the proposed electricity transmission line may well preclude the use of electrically-powered pumps

2. Irrigation of the terraces north of the Catar is dependent upon several kilometers of pumping in pipes from the lake over saline and alkaline swamp

3. Due to unsuitable topography, there is only a limited hectarage which can be commanded by pumping direct from the Catar River

The following developments could, nevertheless, be conceived:

Low-lift pumping from Catar About 160 ha of alluvium on each side of the river (320 ha in all) could be commanded by a 12 m pump lift. Two main canals, each 2 km in length would run north-east and south-west from pumps located 3 km upstream from the river mouth.

High-lift pumping from the Catar About 200 ha of coarse pumice soils on the south side of the river could be commanded by a 30 m pump lift 5 km upstream from the river mouth. It is not envisaged that this development would actually take place unless the balance of economic advantage changed substantially in favour of irrigated agriculture.

LAKE ZWAI MARGINS

About 5 500 ha around the edge of Lake Zwai are liable to inundation as a result of seasonal fluctuations in lake level. These swampy lake margins vary in width from 2 km just north of Zwai Town to only a 100 m or so along the south-eastern shore.

Land use

The lake margin vegetation has been described in Part 3. Much of the lakeshore is fringed by a narrow belt of *Cynodon* grassland above permanent water level, and by Papyrus and *Phragmites* in open water. Around the northern shoreline to the east of Meki Delta however, there is a broad belt of land fringing the lake which is influenced by the seepage of groundwater highly charged with Alkali. The most characteristic zones of succession are summarised in Table 66.

TABLE 66 Successional zones along the northern shore of Lake Zwai

Site	Vegetation association
Open water under sheltered conditions	Floating *Phragmites* and *Nymphaea*
Lake edge: permanent shallows	*Cyperus papyrus* and *Typha latifolia*
Lake edge (level): seasonally inundated	*Aeschynomene elaphroxylon* thicket
Lake edge (sloping): seasonally inundated	*Typha* thicket, with *Juncus* and *Panicum repens*
Lakeshore with high watertable: unaffected by alkali	*Cynodon plectostachyus* grassland
Lakeshore with high watertable: affected by alkali	*Sporobolus spicatus* grassland
Lakeshore strongly influenced by alkali	Bare ground
Hinterland with seasonal high watertable	*Acacia albida* woodland, with *Ficus*, *Croton macrostachys* and *Acacia tortilis*

Although periodically flooded, the *Cynodon* grassland sustains a very high density of cattle at times of low lake level, which generally coincide with the latter part of the dry season and the early months of the wet season when livestock feed is in short supply. Some of these cattle belong to farmers around Zwai, while others are herded in from the surrounding bushland as natural grazing falls short. Stocking rates on an annual basis may be as high as one livestock unit/ha and it is estimated that herbage yields could be up to 10 tons/ha. Until recently, this lake edge was the preserve of Arussi semi-nomadic herdsmen; land rights have become less clear as a consequence of extensive settlement in the hinterland.

Topography and soils

The lake margins slope imperceptibly down towards the lake and away from the terraces and deltas which they fringe. Along the western and north-eastern shorelines there is a low scarp between the first terrace and the swamps. In contrast, much of the south-eastern side of the lake is bordered by steep rocky hills.

The soils along the lake margins resemble the deposits forming the lake bed, analyses for which are shown in Table 67. At the northern end of the lake fringing both the Meki and Catar deltas, heavy-textured organic alluvium has been deposited. Along its western side, the lake bed comprises inert pumice sand. Along the western lake margin, this sand is overlain by about 30 cm of clay on the higher-lying, occasionally flooded *Cynodon* grassland near the foot of the terraces, and by organic loam in *Cyperus*, *Typha* and *Juncus* swamps towards the edge of the lake. The clay soils are flooded only during high lake stages (as in 1971). The organic loams, however, are more or less permanently waterlogged and tend to exhibit rather high levels of exchangeable sodium (average ESP of 24) at the surface, which may be due to the seepage of alkali-rich groundwater.

Along the north-east margin of the lake, heavy-textured clays and silty clays are associated with alkaline seepage from the foot of the terraces and hence with patches of saline/alkaline soil. Otherwise, the swamp soils are generally salt-free, though alkali concentrations (measured ESP up to 42) frequently occur in areas adjacent to seepage. At the southern end of the lake, alkaline seepage has also adversely affected several hundred hectares of land. Moreover, the soil surface is strewn with pumice boulders deposited by torrents draining the flanks of Mount Alutu.

Irrigation potential

Irrigation development along the lake margins depends upon the prior lowering and regulation of the lake level. It is estimated (below) that, if all irrigation development options around the lake were taken up, the lake would have a maximum elevation of 1 636 m; hence a considerable area (some 5 500 ha) at present seasonally flooded could be subject to reclamation. Any reclaimed land would be government-owned. Of the 5 500 ha that would become available, about 10% is unsuitable for development because of extreme alkalinity on about 350 ha in the Chefe Gila area, and the inaccessibility of some 200 ha along the south-eastern lake margin.

TABLE 67 **Analyses of sub-aqueous soil samples from the bed of Lake Zwai (see Appendix 6 for details of the analytical methods)**

Characteristic	Soil texture at 0-30 cm	
	Sandy *	Clay ≠
Bulk density g/ml	1.09	0.78
Organic matter %	0.62	4.46
Total N %	0.06	0.42
pH (1:5) soil: water	8.0	7.4
Conductivity μ mhos/cm	80	230
Carbonate %	0	0
Soluble Na meq %	0	0
Exch. Na meq %	0.6	1.8
Exch. K meq %	0.9	1.5
Exch. Mg meq %	3.6	10.3
Exch. Ca meq %	7.5	25.5
TEB meq %	12.6	39.2
CEC meq %	9.2	41.8
Base saturation %	100	85
Exch. Na % (ESP)	7	6
Available P (Olsen) ppm	2.3	8.8
Total P ppm	315	346
Total K ppm	3 725	6 757
Total Mg ppm	3 487	6 021
Copper ppm	7	21
Manganese ppm	715	1 111
Zinc ppm	70	137

* mean of 4 samples ≠ mean of 18 samples

The development of 500 ha of swamp bordering the Meki Delta has already been considered in conjunction with other developments on the delta. The remaining land comprises 2 570 ha and 1 850 ha respectively along the western and north-eastern lake margins. The main impediment to the development of these areas is the localised occurrence of alkali; the high porosity and low fertility of the sandy subsoils along the western margin are also significant constraints. It is impossible to predict with certainty the effect of lake lowering on alkaline seepage from the foot of the terraces, but it is possible that seepage would continue to influence adversely the neighbouring lake margins, possibly to a greater extent than at present.

The question of grazing rights will not be easy to resolve and it may prove necessary as irrigation extends on to the lake margins, to offer compensation in some form to those who can prove customary usage but who will be denied access to lakeside grazing in the future. It is envisaged that there will be a minor reduction in the periodically flooded lake margin available for extensive grazing and there will be a need for control of access and of stock numbers. Introduction of a simple system of rotational grazing might be considered, to maximise herbage utilisation. In any event, lakeside developments should be planned so that avenues of access are preserved for cattle to be moved to the lake edge for feed and watering. Moreover, farmers on adjoining terraces may need to dig inlet canals across the lake margin to bring lake water closer to their farms and hence reduce pumping costs. It is therefore imperative for any development authority to plan the future use of this land at an early stage. Since the entire area below the present mean maximum lake level is goverment-owned, it is proposed that the NWRC should formally establish these rights before any major change is made in lake level.

Development of the higher-lying areas with clay topsoil could be initiated as and when the lake has receded sufficiently. The heavier-textured soils could prove suitable either for irrigated fodder or, if free of alkali, for more intensive cropping. The sandy soils are however likely to prove less suitable for intensive cropping in view of their lack of fertility. In both areas, it will be important to establish small-scale trial plots on representative soils to test the cropping systems prior to initiating extensive irrigation. It is also emphasised that a detailed soil survey (at 1:10 000) is another essential prerequisite.

The most promising long-term prospect, on the more accessible lake margins with a minimum of 25 cm of heavier-textured topsoil, is for sugar production associated with a small-scale cane factory. Despite the relatively low fertility of much of the soil, once the cane had succeeded in rooting to groundwater high yields might be obtained without further irrigation. Planting could be timed to coincide with the onset of the rains and some supplementary irrigation given during cane establishment. Spread over the productive life of the crop, irrigation costs would be low. Moreover, since the lake margin is the only significant part of the project area which is uncultivated, this is the one area that affords opportunities for irrigation development on a relatively large scale. As suggested in Part 5, in view of the limited area available for a nucleus estate, it would be necessary for a high proportion (up to 70%) of the cane to be supplied by outgrowers elsewhere in the project area; this would have the beneficial effect of spreading the returns from cane over a considerable number of local farmers. A nucleus estate would have to be sited on the western margin just north of Zwai Town, since this is the only area that can provide the necessary minimal hectarage in a single block. Again it will be crucial to precede development by several years' experimentation, including variety trials with yield assessment of both the plant crop and the ratoons, and an investigation of soil and water management techniques.

Irrigated asparagus could also be considered for the lake margins. Although low yields, coupled with the known poor conversion ratio on dehydration, may militate against this, encouraging results at Nazareth suggest that this is an option that may be worth pursuing, at least on an experimental basis.

Reclamation and subsequent irrigation of a more extensive area of the present-day lake bed is a remote long-term possibility which could only be realised if the balance of economic and ecological advantage allowed the flushing of a substantial amount of Zwai water into Lake Abiyata. This is, however, unlikely to prove a very valuable exercise since, of the major areas to be exposed by a further fall in lake level, the western lake beds mostly comprise raw pumice gravelly sand, while the north-eastern sector of the lake seems likely to be affected by alkaline seepage.

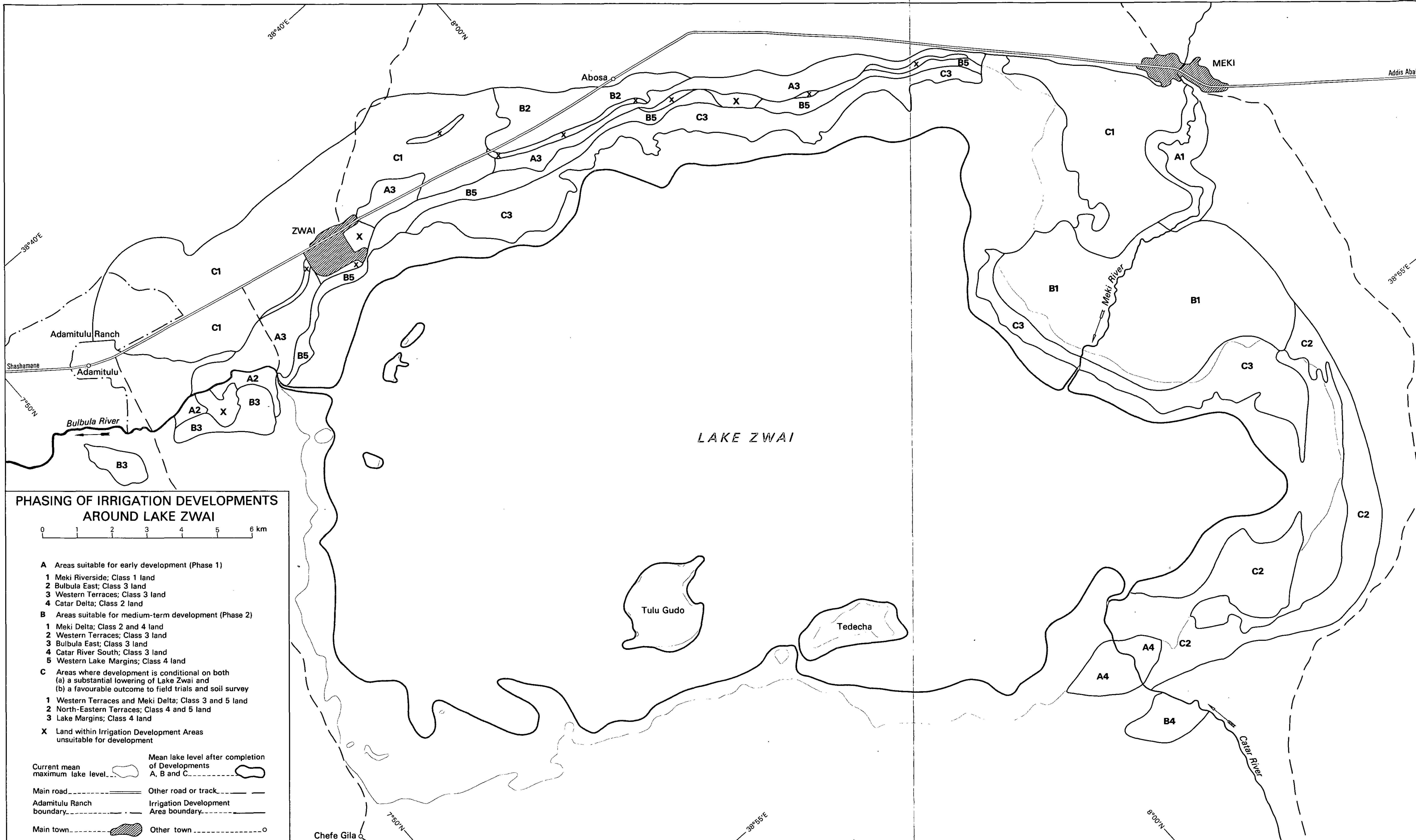
Development phasing

The potential irrigation areas around Lake Zwai have been grouped into three categories depending on their priority for implementation.

1. Early development (Phase 1)
2. Medium-term development (Phase 2)
3. Conditional long-term development

The location and extent of the irrigable areas are shown on Separate Map 4 and Text Map 8, and are summarised in Table 68. No irrigation is envisaged in the mid-Meki Valley.

Phase 1 comprises relatively small-scale schemes on the better quality land close to sources of irrigation water, where development can proceed with low levels of capital investment and without lake outlet control works on the Bulbula River. The total area which could be irrigated in this phase is 1 730 ha, requiring an annual water abstraction of 20.4 mcm (see Appendix 2 for derivation of estimated irrigation requirements). Using Table 21 (Part 4) as a guide to the effect of abstraction from Lake Zwai in its present state (i.e. with no outlet control), it is estimated that an annual



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irrigation abstraction of 20.4 mcm would lead to a decrease in evaporation from the lake of about 3.0 mcm and an annual reduction in Bulbula flows of about 17.4 mcm. From Figure 10, it can be deducted that an annual reduction in lake evaporation of 3.0 mcm would reduce the average lake level to 0.87 m or 1 636.02 m (a.s.l.) (compared with the long-term average level of 0.92 m or 1 636.07 m). The estimated reduction in Bulbula flow is quite small and should not influence significantly the level of Lake Abiyata.

With the exception of the Catar Delta, limited irrigation has already been introduced on the area identified for Phase 1 development. It is envisaged that the entire Phase 1 area could be developed within five years. The procedures applied in implementation would no doubt be modified in the light of experience gained during the course of Phase 1; in this sense Phase 1 can be regarded as a pilot scheme.

Phase 2 would follow the completion of Phase 1. The Phase 2 developments, however, require greater capital investment and involve higher running costs than Phase 1. Owing to the level of abstraction envisaged as a result of Phase 1, it will be necessary to regulate the Bulbula outflow from the outset of Phase 2, so as to maintain adequate flow into Lake Abiyata. The total proposed irrigation area under phases 1 and 2 is 5 500 ha, with an annual irrigation water requirement of 65 mcm. It will be seen from Figure 14 (Rule 4) that, with an annual irrigation abstraction of 65 mcm, the bed of the Bulbula channel will need to be lowered 1.1 m from the present maximum bed level, which is 1 635.6 m (a.s.l.) at the rock sill near Adamitulu. The outlet channel from Lake Zwai and the upper part of the Bulbula River should therefore be no higher than 1 634.5 m, while the average lake level on completion of Phase 2 is projected as 1 635.2 m (see Table 26; Part 4).

Phase 2 developments on the Meki Delta (B1, on Text Map 8) depend on provision of adequate flood control.

It is envisaged that the lake level and outflow will be regulated by sluices in the Bulbula River. These will enable the lake level to be controlled within fairly narrow limits($\pm$ 0.5 m from average level), regardless of periodic inflow variations. As Phase 2 development proceeds there will be increasing water abstraction, requiring the lake to be regulated at lower average levels. This will permanently relieve the high-lying lake margins from flooding and, subject to encouraging results from the proposed crop trials, this land could eventually be developed (B5, on Text Map 8).

Development of irrigation on land in the long-term category is conditional on several factors, among which are (a) the acceptability of high development and running costs and (b) a successful outcome to irrigation trials on the heavier-textured Class 5 alkaline soils (especially Soil J). At present these developments cannot be recommended, though with changing circumstances they might be reconsidered.

Should all the potentially irrigable areas listed in Table 68 be eventually developed, the estimated total water requirement would be 150 mcm/annum and in consequence, the Bulbula (upstream of the sluice) would have to be deepened to at least 1.8 m below the existing level of the rock sill, i.e. the level of the bed of the lake outlet channel would then be below 1 633.8 m (a.s.l.).

Regulation of Lake Zwai outflow

Following development of the 1 730 ha projected for irrigation in Phase 1, it will be necessary to construct regulation works on the outflow of Lake Zwai prior to further irrigation development. In order to provide regulation throughout the year in accordance with Operating Rule 4, it will be necessary to construct a sluice across the Bulbula River so that the essential discharges can be released at lower average lake levels and to deepen the approach channel from the lake to the sluice to ensure that under all conditions this channel has sufficient capacity.

TABLE 68 Summary of irrigation development areas (see Text Map 8)

Priority	No. on Text Map 8	Land class	Location	Type of development envisaged	Area (ha)	Area less 15% (ha)	Running total (ha)
Early development (Phase 1)	A1	1	Meki Delta Riverside	Low-lift pumping from the Meki River	350	300	300
	A2	3	Bulbula East	Low-lift pumping from the Bulbula River	160	140	440
	A3	3	Western Terraces and Bulbula West	Low-lift pumping from Lake Zwai and from the Bulbula River	1 200	1 020	1 460
	A4	2	Catar Delta	Low-lift pumping from the Catar River	320	270	1 730
Medium-term development (Phase 2)	B1	2 + 4	Meki Delta	Pumping from Lake Zwai Reclamation of Class 4 land	2 540	2 160	3 890
	B2	3	Western Terraces	High-lift pumping from Lake Zwai	570	480	4 370
	B3	3	Bulbula East	High-lift pumping from the Bulbula	350	300	4 670
	B4	3	Catar River South	High-lift pumping from the Catar	200	170	4 840
	B5	4	Western Lake Margins	Reclamation and low-lift pumping from Lake Zwai	770	660	5 500
Conditional long-term development	C1	3 + 5	Western Terraces and Meki Delta	High-lift pumping from Lake Zwai	4 600	3 910	
	C2	4 + 5	North-Eastern Terraces and Shoreline	Pumping from Lake Zwai	1 840	1 560	
	C3	4	Lower Lake Margins	Reclamation and low-lift pumping from Lake Zwai	2 040	1 730	

Two possible sites have been considered for the sluice: Site 1, close to the point where the Bulbula River leaves Lake Zwai; and Site 2, at the rock sill near Adamitulu, 6 km downstream from the lake. Both sites have been surveyed and are shown on Map 7. The upper control site (Site 1) has the advantage of being close to the point of outflow from the lake, so eliminating the need to dredge the 6 km of channel to the rock sill; assuming the rock sill were lowered about 2.5 m the channel could scour to its natural gradient. Dredging would then be confined to construction of a deeper entrance channel in the lake. This consideration apart, the upper site is inferior to the lower Site 2 due to (a) the need for a wider structure at the upper site (though the number and size of gate openings would be similar) (b) difficulties in construction, since it would be necessary to bypass normal flows into the Bulbula and the site would have to be continuously de-watered, and (c) difficult foundation conditions. The underlying soil is a fairly uniform medium to fine sand (the grading curves are in Appendix 9; Figure 29), which would require a cut-off, by means of a large concrete sill or vertical sheet-pile walls, to prevent the foundation being washed out.

Unless considerable deepening of the Bulbula channel is necessary, the balance of advantage rests with Site 2 (Plates 12 and 13).

DREDGING REQUIREMENT

In order to assess the dredging requirement in the Bulbula channel, a survey was made of the Bulbula from Lake Zwai to the rock sill, the results of which are presented on Separate Map 6. In general, cross-sections were measured at 100 m intervals, with extra sections where the channel appeared to be constricted. Soundings were also made of the lake bed adjacent to the Bulbula River outlet (Map 5). The aim must be to deepen the Bulbula Channel so that it can pass flows in accordance with the selected operating rule after the Phase 2 developments are completed. It has been calculated (above) that the bed level of the Bulbula channel at its outlet from the lake should not exceed 1 634.5 m (a.s.l.). In the natural state there is no overall bed slope between the Bulbula outlet and the rock sill (a distance of 6 km). Since the channel section is large in relation to the flow, the outflow is dependent on a very slight slope in water surface towards the rock sill (Plate 11). For example, at a discharge of 12 m^3/s, the drawdown along the 6 km channel is only about 0.2 m. Once the sluice is constructed and the average lake level lowered however, the effective cross-sectional area of the Bulbula channel will be reduced. In order to discharge at low lake levels therefore, it will be necessary to create a slope on the channel bed.

It has been assumed in the calculations that, at the lowest lake level (about 1 634.8 m), the channel would continue to discharge a minimum of 1 m^3/s in order to serve domestic needs along the Bulbula. Further,assuming a minimum channel cross-sectional area of 6.4 m^2 (trapezoidal section with base width of 20 m and side slopes under water of 1 in 4) upstream of the sluice, and a maximum bed level of 1 634.5 m at the lake outlet sloping down to 1 634.0 m at the rock sill, the minimum depth of water in the Bulbula channel would be 0.3 m.

With only minor exceptions, the Bulbula channel from the lake to the rock sill already has a bed level below 1 634.0 m (Separate Map 6). Consequently, very little dredging is required in association with construction of a control sluice at Site 2 (Map 7). The estimated volume of dredging (excluding rock close to the lava sill) is 3 000 m^3, limited to those parts of the channel between cross-sections 0-5, 28-36, 42-6 and 52-9 (see Separate Map 6); the remainder of the channel is of adequate depth. Apart from the section of channel in immediate proximity to the rock sill, dredging will be in medium to fine sand or only slightly compacted pumice, and it is envisaged that the work could be carried out manually during periods of low lake level. This work will not be necessary until a major part of the Phase 2 developments has been completed. At the lower lake levels then prevailing, it will be possible to excavate as necessary so as to maintain the Bulbula flow; the work could be spread over several years. Labour demand would be quite low and restricted to only a few weeks in the year. Dredging using a bank-operated excavator is impracticable due to thick riparian vegetation along most of the channel. It should not be necessary to construct revetments to protect the channel from scour or subsidence, since the velocity at maximum discharge should not exceed 0.6 m/s. Some slumping of the sides may occur however, as the water level is lowered; this would increase slightly the volume of dredging required. Furthermore, during construction of the outlet sluice, it will be necessary to remove by blasting about 2 700 m^3 of lava rock.

The bed of Lake Zwai will itself require considerable dredging to form a channel into the Bulbula River (Figure 21). Assuming a channel of base width 40 m at a level of 1 634.5 m and with side slopes of 1 in 5, it is estimated (from Separate Map 5) that the dredging requirement would be about 10 500 m^3. Selection of a suitable technique for carrying out this work will depend on the resources available. Ideally, in view of the nature of the lake bed material (medium to fine uncompacted sand), a suction dredger and floating pipeline would be used. Such equipment is not yet available in Ethiopia; nor are pontoons on which dredging equipment could be floated. It is therefore tentatively suggested that the channel be dredged using a suitably sized dragline working out from shore on either side of the channel. The excavated material could then be used to form causeways along which the machine would travel as work proceeded. Some additional material might however be needed for the causeways as they advanced, since the volume of excavation would be reduced in the deeper water.

DESIGN AND CONSTRUCTION OF THE OUTLET SLUICE

It will be evident that the natural flows in the Bulbula River vary greatly from year to year depending on cyclic variations in the level of Lake Zwai (compare Plates 13 and 14). Nevertheless, the outlet control works should be capable of releasing approximately

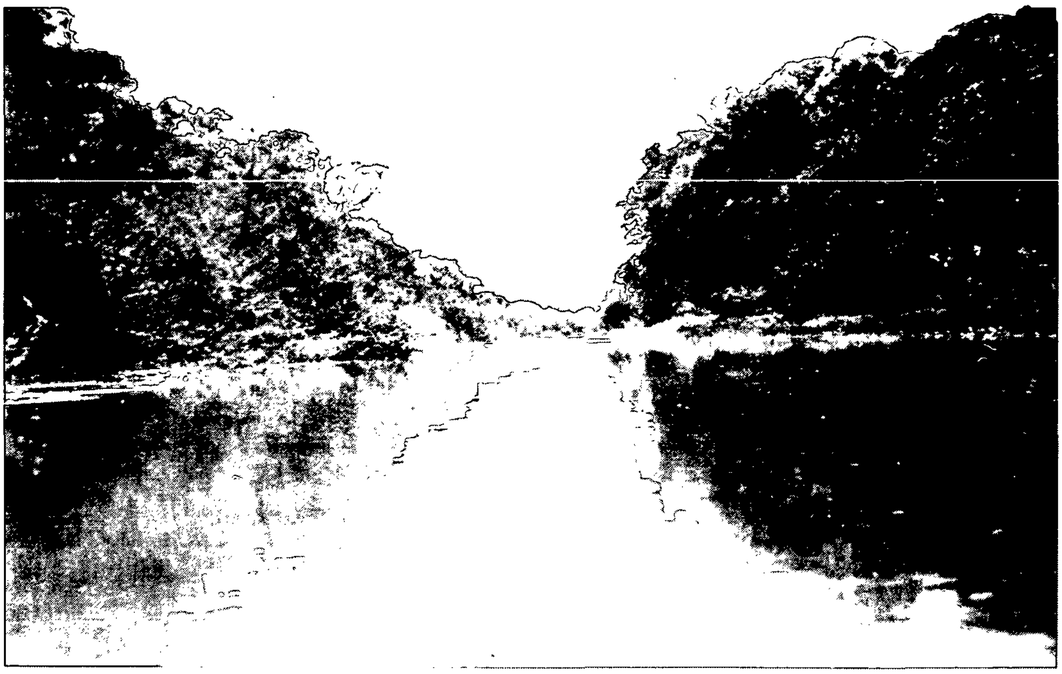


PLATE 11 Bulbula River: above the rock sill

PLATE 12 Bulbula River: at the rock sill

PLATE 13 Lava rock sill on the Bulbula River: April 1974

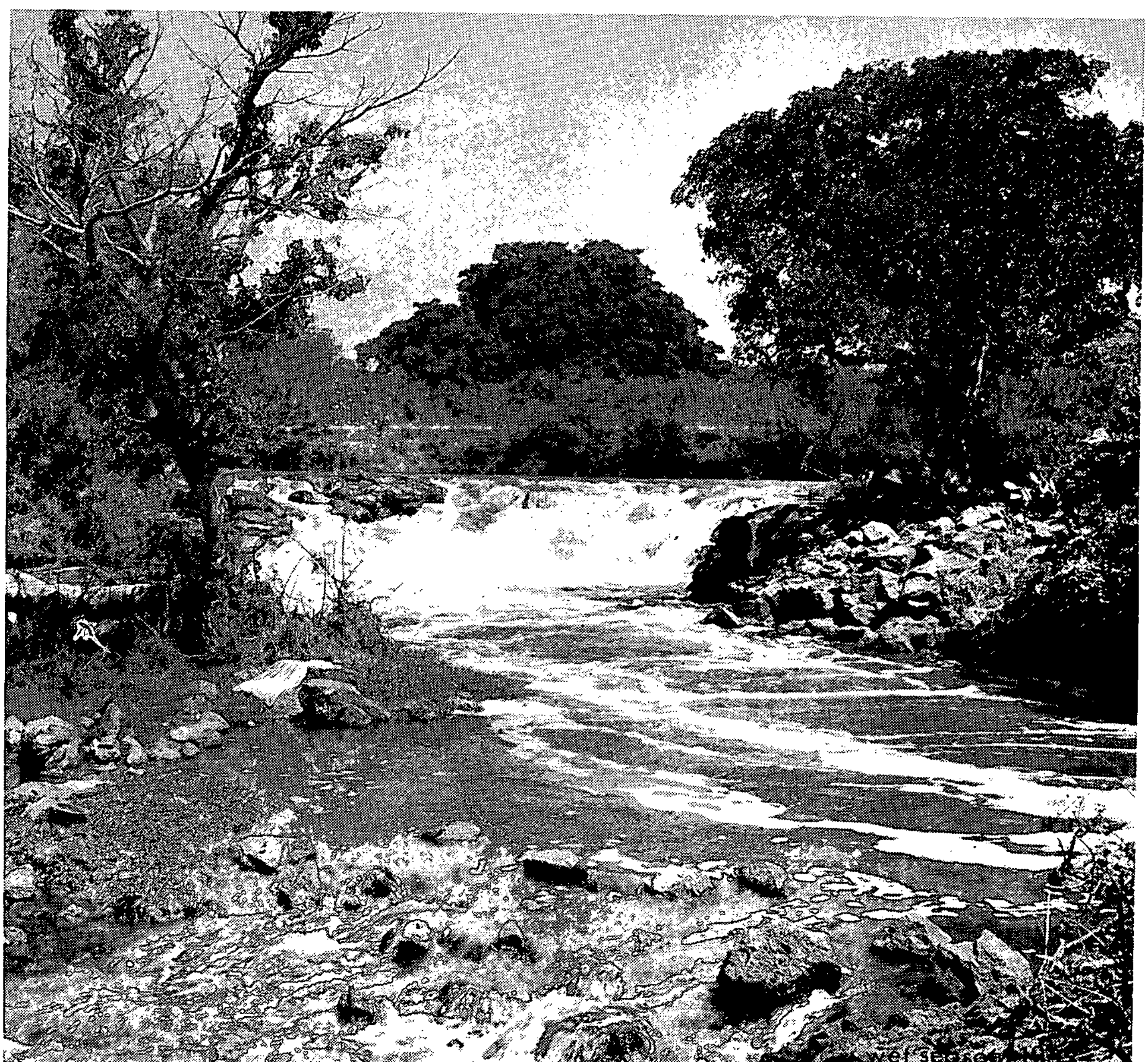


PLATE 14 Same rock sill as in Plate 13: wet season 1969 *(photo: Italconsult)*

constant discharges down the Bulbula. For this purpose, underflow gates or sluices provide a simpler and more effective solution than a movable overflow weir. The sluices should be constructed with a base level sufficiently low to allow maximum future exploitation of the water resources of Lake Zwai, even though projections of ultimate future demand cannot be made at present. On the assumption that the conditional long-term developments prove feasible in the future, the total irrigable area around the lake could reach 12 700 ha (Table 68), with an annual irrigation requirement of 150.5 mcm; this would necessitate deepening the Bulbula channel to 1 633.3 m (a.s.l.) at the rock sill. Since, however, this need not represent the ultimate development of the water resource, which would be limited by factors other than water supply, it is suggested that the sill of the sluice be set at 1 633.0 m (downstream of the lava sill, the Bulbula channel is generally below 1 631 m - see Separate Map 7). Assuming the use of Operating Rule 4 (Part 4), the maximum discharge will be 50% greater than the natural maximum average monthly discharge. Maximum flows currently occur in September when they average 44 mcm per month (17 m^3/s). Therefore, the maximum design discharge is 17 m^3/s + 50% = 25.5 m^3/s.

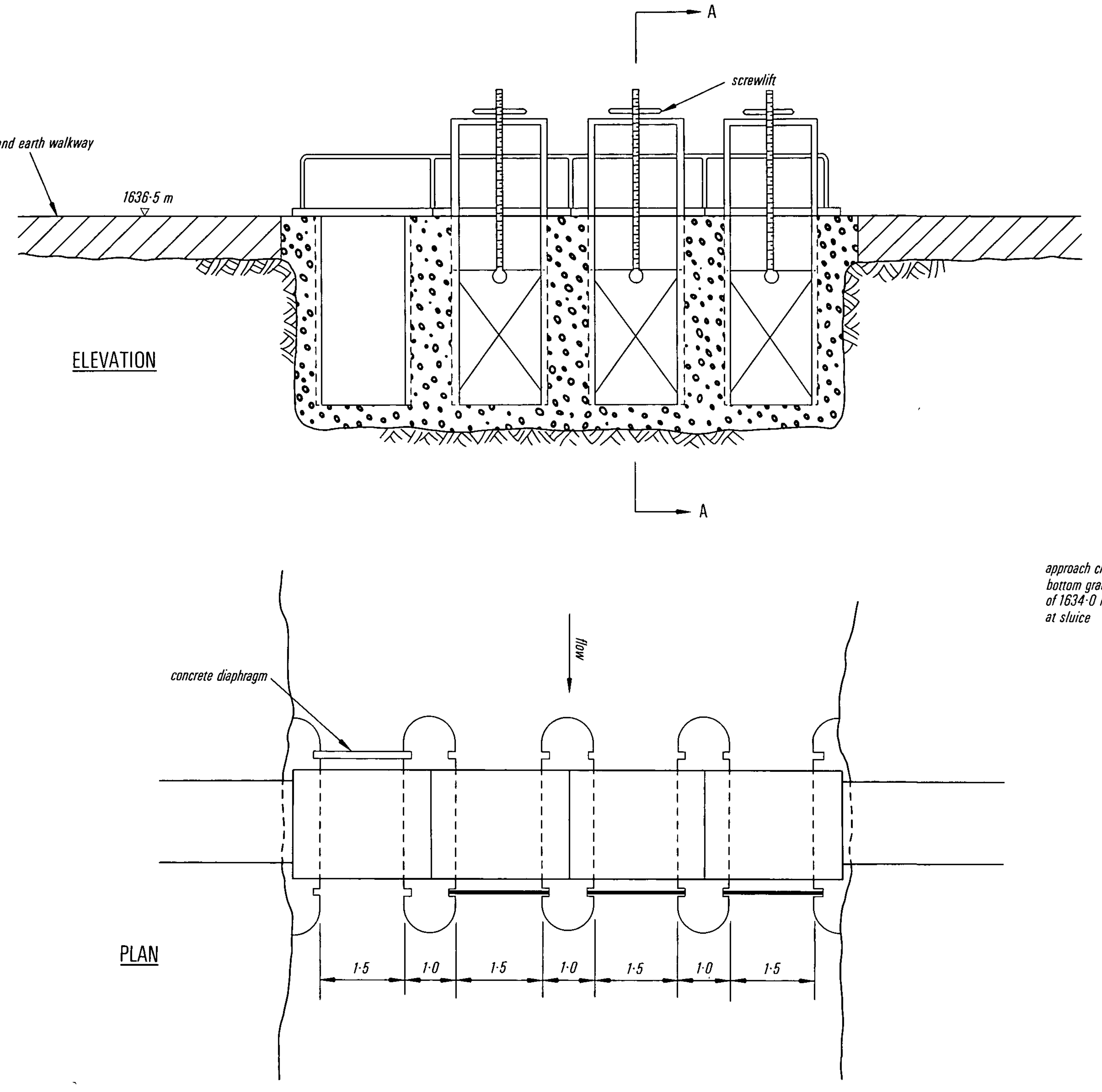
On completion of Phase 2, the maximum level of Lake Zwai is predicted to be 1 635.7 m, corresponding with a maximum discharge of 25.5 m^3/s. Under conditions of maximum discharge, allowing for slope on the water surface in the channel and no submergence of the flow downstream of the gate (a condition assured by the natural waterfall immediately beyond the sluice - see Plate 13 and 14), it is proposed that three gates each 1.5 m wide would be adequate. The gates should be so constructed that, given maximum discharge, they can be raised above the water surface.

Should development continue beyond Phase 2 to include some or all of the areas designated for conditional long-term development, it would be necessary to increase the number of sluice gates since, at the resulting lower lake levels, a greater width would be required to pass the same discharge down the Bulbula River. In the event of all conditional developments being implemented, the projected maximum lake level would be 1 634.9 m, representing a head above the sluice of about 1.9 m. In this case the necessary gate width would be 6 m, which could conveniently be provided by four gates each 1.5 m wide. Thus, development of irrigation beyond Phase 2 would necessitate the construction of one additional gate, plus considerable supplementary dredging of the Bulbula channel.

It is proposed that the sluice be constructed in dry conditions and that the existing hydraulic ram drive-pipe ditch be used as a bypass for flows during construction (see Separate Map 7). To enlarge the ditch for the flows envisaged, the hydrams and drive pipes would have to be removed and the ditch deepened to a level of 1 634.0 m. Since sluice construction could easily be completed in a single dry season (December-July), the bypass would not need to carry flows greater than 4 m^3/s. Prior to drainage, the main Bulbula channel would need to be cut off with an earth embankment just downstream from the point at which the drive-pipe ditch leaves the main channel. In this way, it would be possible to reduce by blasting both the sill and the approach channel in reasonable working conditions. It is suggested that the sluice be constructed initially with three gates (manually-operated), but that the piers for an additional gate be provided and infilled with a concrete diaphragm wall which could subsequently be removed (without the need for blasting and de-watering) once the new gate is installed.

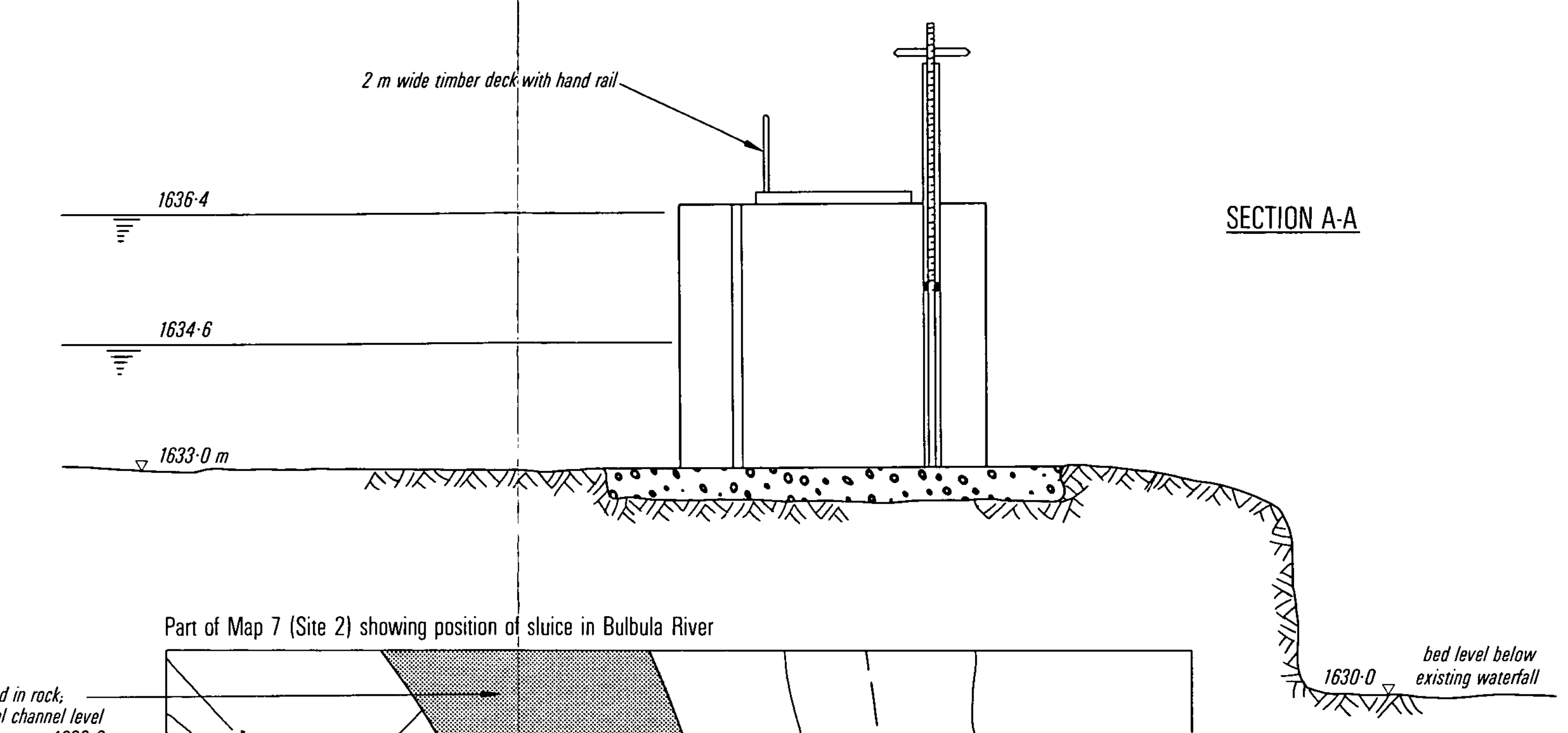
Details of the proposed structure are shown on Figure 21. On either side of the sluice it will be necessary to embank up to a level of 1 636.5 m so that even during the early stages of Phase 2 development when lake levels will be only marginally lower than those in the natural state, full regulation of the Bulbula flow can be provided throughout the year. The embankments would also provide access to the sluice during periods of high lake level. Provision would have to be made to pump water in lieu of the hydram supply to Adamitulu Ranch during construction. Followingthe dredging of the Bulbula channel to the rock sill, it will be possible to shorten considerably the length of drive pipe to the rams. Furthermore, if water demand on the Ranch should increase, several more rams could be simply and cheaply installed.

FIGURE 21



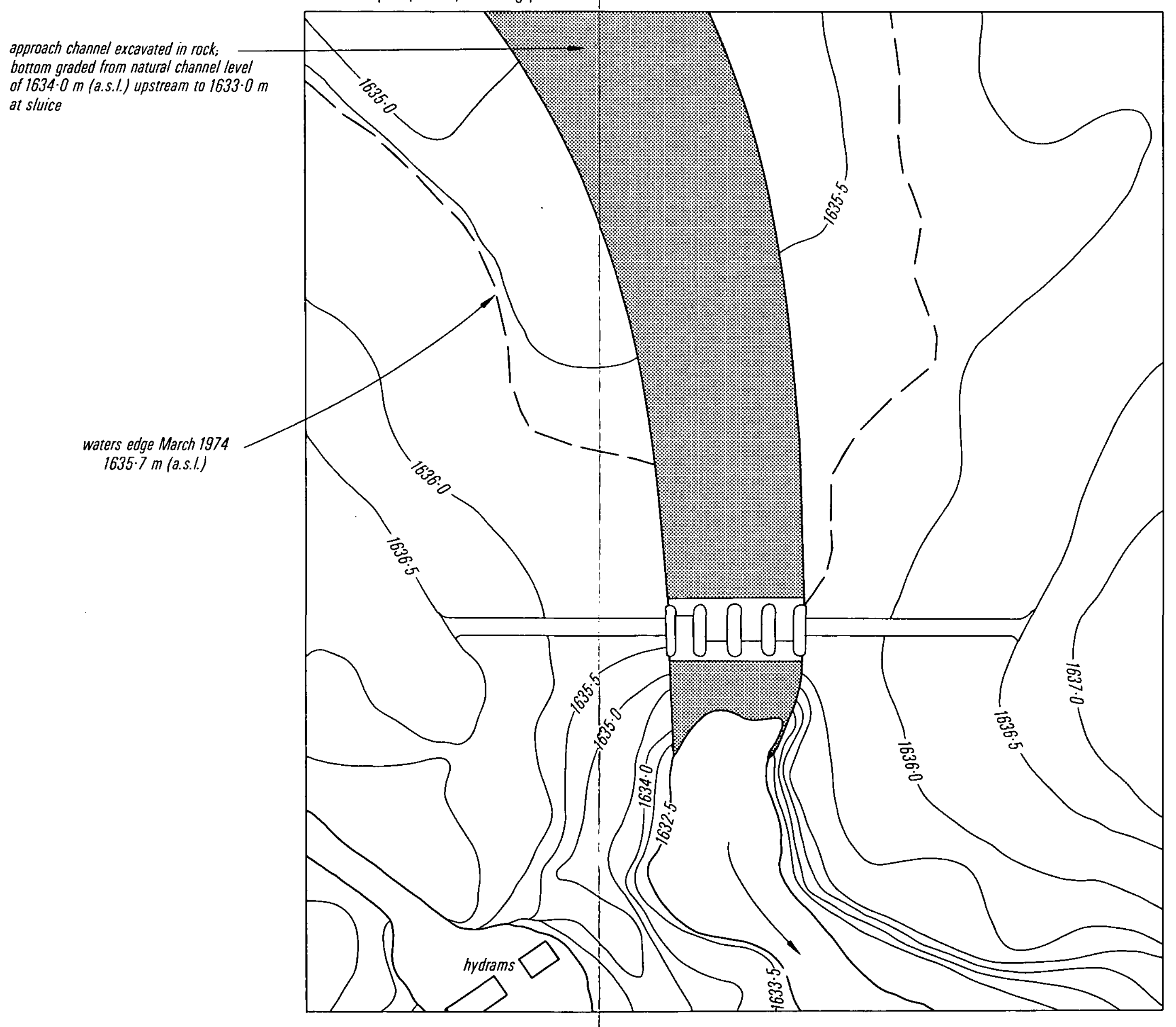
BULBULA SLUICE

0 1 2 3 4 5 Metres



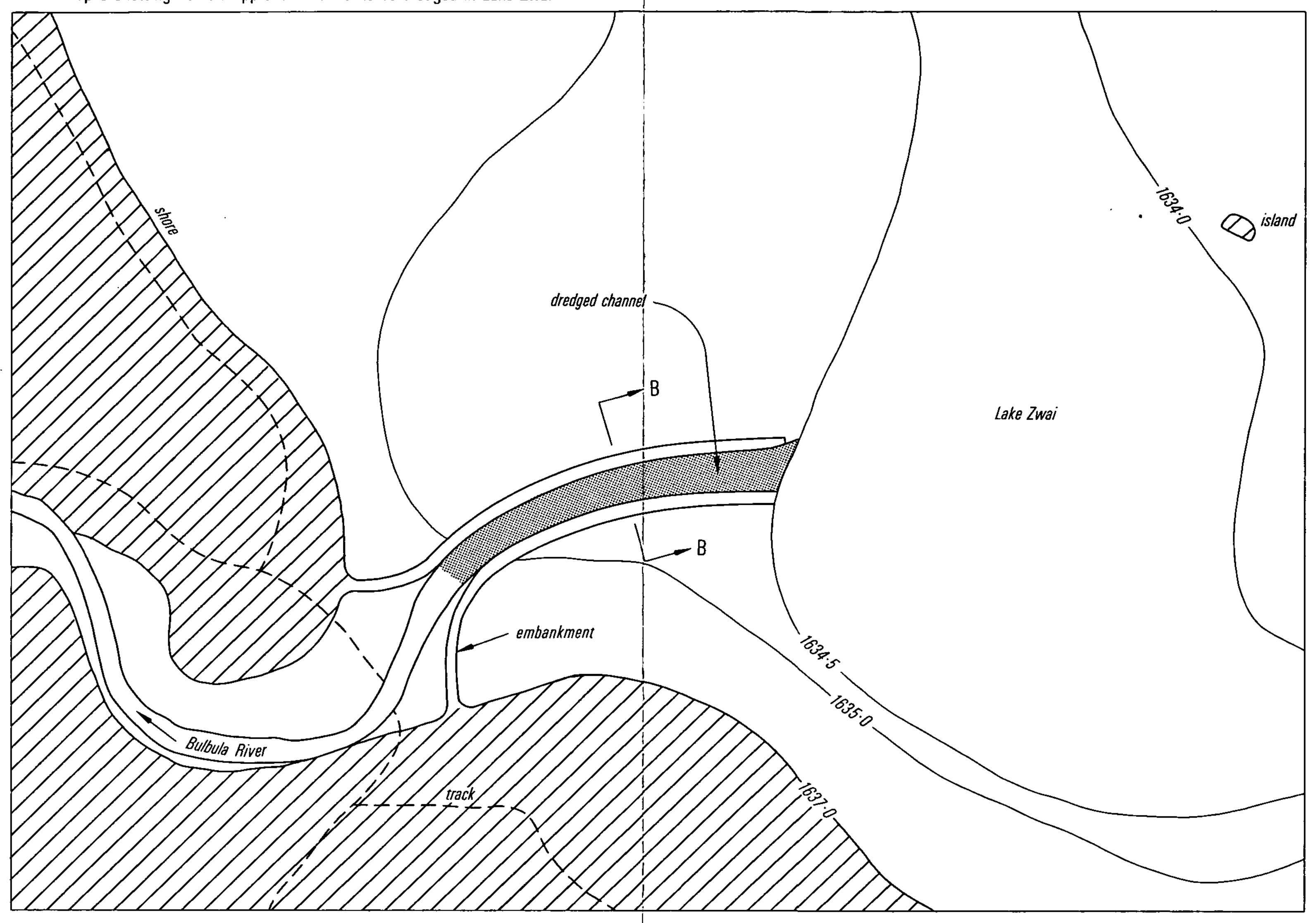
SECTION A-A

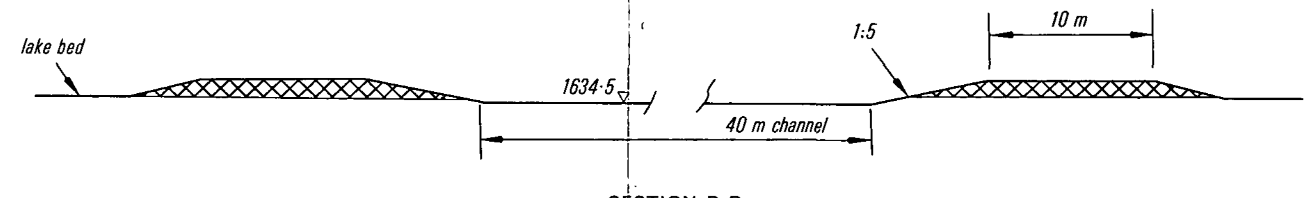
Part of Map 7 (Site 2) showing position of sluice in Bulbula River



Note:- 1. Gate size 1·5 m wide × 2·5 m high.
Phase Two development–3 gates required.
Long term maximum irrigation development-4 gates required. i.e. 1 additional gate to be provided and concrete diaphragm removed.
2. Maximum water levels upstream of sluice:
(a) At start of Phase Two development 1636·4 m (a.s.l.)
(b) On completion of all Phase Two developments 1634·6 m (a.s.l.)

Part of Map 5 showing Bulbula approach channel to be dredged in Lake Zwai





SECTION B-B

Prospects for Irrigation Development around Lake Zwai

CONTROL WORKS ON THE BULBULA RIVER

Land Resources Division, Ministry of Overseas Development | 1976

D.O.S. 3228 V

Prepared by the Directorate of Overseas Surveys 1976

Alternative sources of power

During the early stages of irrigation development, water needs will no doubt continue to be met by small diesel-driven centrifugal pumps in the 10-20 hp range. As the irrigated area increases and as land further from water sources and at higher elevations is brought into production however, it will be essential, both for economic reasons and to restrict the number of feeder canals, to rationalise the distribution system and provide larger, permanently-sited pumping stations controlled by a central authority. The authority would regularly allocate water to the individual farms and recoup the cost of water on a seasonal basis.

Since the main recurrent irrigation cost will be the power to run the pumps, it is important that the cheapest source of power should be used. At Zwai, the alternative sources of power comprise wind, diesel oil and electricity. Wind power was briefly considered in view of the prevalence of consistent winds, particularly during the dry season - the period of maximum irrigation and hence of power demand. Although windmills have been designed to raise large quantities of water through small heights, e.g. for drainage and land reclamation purposes, the present tendency is for pump manufacturers to produce mills with high head and low output characteristics. These do not readily meet the irrigation demand pattern proposed for Zwai, since most of the irrigable areas lie at an elevation of less than 30 m above the lake and the proposed irrigation period is only 12 hours a day. It is felt that, at present, the use of windmills appropriate for irrigation needs around Lake Zwai would not be economic. However, in view of the rapidly rising cost of power from oil and the resulting premium placed on alternative cheaper power sources, it is conceivable that the range of wind-driven pumps will increase; and, with the development of more advanced designs (wind turbines), more efficient energy conversion may be obtained.

The current choice of a power source therefore lies between diesel oil and electricity. With large-scale development, it should become possible for an organisation to purchase power centrally, at which time electricity should prove cheaper than diesel, since it is proposed that, by 1978, the Ethiopian Electric Light and Power Authority (EELPA) will have constructed a 132 kV transmission line from the Awash hydropower stations near Nazareth to Asella, Adamitulu, Shashamane, Yirga Alem and Dilla. From a transformer substation at Adamitulu, it is planned to supply electric power at 220 v single-phase or 380 v three-phase to Zwai and Meki. Electric power should therefore be directly available (within a few kilometres) to all the development areas except those on the North-Eastern Terraces and the Catar River, where special provision would have to be made. In the project costing, no allowance has been made for the transformer substation at Adamitulu, responsibility for which will be vested in EELPA, since this would be required whether the project goes ahead or not. Considerable sums ($ 60 000 in Phase 1, and $ 50 000 in Phase 2) have however been allowed for electrical starting equipment and for transmission lines to the pump stations, including $ 10 000 for a special line from Meki to the Catar River.

It is anticipated that the tariff rate will be negotiable with EELPA and dependent on the installed pump capacity. To negotiate the most favourable terms, it is important that all power should be bought and distributed by a central irrigation authority and in determining a suitable power tariff, account should be taken of the production cost of electrical energy. The estimated production cost at the Awash plants is 2.36 cents/kWh (Jovanovic, 1972). However, the projected costs at Finchaa and at power stations proposed for the future are considerably lower than those on the Awash. Hence the average power cost from the interconnected grid should be significantly below 2.36 cents/kWh. Nevertheless, it has been assumed for the purpose of conservative cost estimation that a rate of 2.50 cents/kWh can be negotiated by the irrigation authority for agricultural use around Zwai. The estimated pump power requirements for phases 1 and 2 are set out in Tables 69 and 70.

At a time of increasing imported energy costs, it is important and very much in the national interest that Ethiopia should maximise the use of a major natural energy resource i.e. cheap electric power; and it is only by fixing agricultural tariffs close to the low production cost that speedy use will be made of the generated power for the production of competitively priced produce. Moreover, the sooner the potential capacity of each electricity-generating plant is taken up, the lower the level at which an economic tariff can be fixed.

Current investigations may reveal potentially viable geothermal sources for electricity generation around Mount Alutu (to the south of Lake Zwai). The commercial development of this power source, close to the proposed irrigation area, could, given a reasonable policy on tariffs, help promote the rapid uptake of irrigated agriculture around Zwai.

The prospects of producing electricity on the Bulbula River were also briefly investigated. Although a waterfall of 14 m, suitable for siting a generating station, was located about 12 km downstream from Lake Zwai, the output of any hydro-electric generating station on the Bulbula would be dependent on the regulated releases from the lake. Since these will follow a seasonal pattern, so that the lake can be regulated to meet the demand for irrigation, the output of such a generating station during the dry season - the time of maximum power demand - would be extremely small. Therefore this possibility was not pursued.

TABLE 69 Pump power requirements by areas - Phase 1

Location	Area on Text Map 8	Area (ha)	Minimum power requirement (kW)	Annual power consumption (kWh/ha)	Annual cost ($/ha)
Meki Delta Riverside	A1	300	25	92	2.30
Bulbula East	A2	140	55	456	11.40
Western Terraces and Bulbula West	A3	1 020	625	731	18.27
Catar Delta	A4	270	145	642	16.05

It is assumed that electric power is available close to all areas; costs based on an electricity tariff of $ 0.025/kWh

TABLE 70 Pump power requirements by areas - Phase 2

Location	Area on Text Map 8	Area (ha)	Minimum power requirement (kW)	Annual power consumption (kWh/ha)	Annual cost ($/ha)
Meki Delta	B1	2 160	770	427	10.67
Western Terraces	B2	480	650	1 623	40.57
Bulbula East	B3	300	225	893	22.32
Catar River South	B4	170	210	1 458	36.45
Western Lake Margins	B5	660	50	86	2.15

It is assumed that electric power is availbale close to all areas; costs based on an electricity tariff of $ 0.025/kWh

Outline operation of a Zwai Development Agency

It is clear that the development proposed in the Zwai area, modest though it may be in comparison with the scale of developments in the Awash Valley for example, does require a separate administering authority. Without local direction and co-ordination it will be impossible to accomplish the complex operations envisaged in an intensive scheme of this nature. Nevertheless, a special feature of the scheme is its gradual projected acceleration as technical, financial and personnel considerations allow. Thus a limited organisation for Phase 1 can be extended as Phase 2 developments proceed (Figure 22).

It is proposed that this administering authority (termed here the 'Zwai Development Division') be constituted as part of the selected implementing agency. The proposed Zwai Development Division (ZDD) would be responsible for the design, implementation and management of all irrigation schemes within the Zwai Catchment (including the Meki and Catar catchments). Further, it is considered that such a project could not be affectively administered from Addis Ababa; hence the ZDD should from its inception be based on a regional office close to the development areas. Meki Town would be a suitable site for this. Because of the relative proximity of Meki to Addis Ababa, it is nevertheless envisaged that the ZDD would make use of certain centralised support services, such as accounting and procurement, soil laboratories and map production.

To facilitate necessary liaison between the ministries and departments concerned, it is proposed that a co-ordinating Committee be constituted with responsibility for formulating policy and ensuring that the development of irrigation is efficiently managed. This committee could be given executive powers in certain specified fields. The following organisations should be represented on this committee: the National Water Resources Commission; the Ministries of Agriculture, Land Reform, National Resources, and Planning and Development; the Relief and Rehabilitation Commission; the Awash Valley Authority; EPID; the Institute of Agricultural Research; and local *awraja* representatives. From time to time, consideration will need to be given to attendance by the following additional organisations: the Ethiopian Electric Light and Power Authority; the Chilalo Agricultural Development Unit; and the Wildlife Conservation Organisation.

Specific responsibilities of the ZDD should include the following:

1. Budgeting: control of capital and recurrent expenditure

2. Survey and implementation, including

   Topographic, cadastral and soil survey
   Conduct of feasibility studies
   Design and construction of irrigation works and farm layouts by direct labour
   Supervision of construction under contract
   Maintenance of pumps, canals, roads, drains, secondary power lines and machinery
   Provision of domestic water supplies

3. Monitoring of and control over water use, including

   River and lake gauging (to be taken over from the AVA)
   Regulation of Lake Zwai
   Dredging and maintenance of the Bulbula channel
   Flood control on the Meki Delta
   Monitoring of water composition, and control of bilharzia

4. Co-ordination of power usage and negotiation of electricity tariffs

5. Agricultural development, including:

   Provision of an advisory service to farmers
   Training of supervisory and extension staff
   Procurement of farm inputs

Certain of these responsibilities are considered in greater detail below. Though of the utmost importance, specific proposals regarding the form of land tenure and the detail of farm layouts are considered to be beyond the present project's term of reference; indeed, the project Steering Committee requested that these matters be left in abeyance pending decisions at the national level.

The structure of the proposed ZDD is shown on Figure 22. It will be seen that the simple organisation for Phase 1 is so designed that it can be expanded into the larger more complex organisation required to operate Phase 2. The subdivisions of the proposed organisation are intended to be flexible in operation, so as to maximise efficiency; for example, the construction teams could periodically be employed on maintenance and vice versa. Although it is not considered appropriate to make detailed recommendations regarding staffing at this stage, for the purposes of economic analysis (in Part 8) certain assumptions had to be made regarding staffing so that organisation overheads could be charged against the scheme; these staffing projections are listed in Table 2. It is recommended that the Area Manager who will head the organisation should have had considerable experience in the administration of a successful irrigation scheme elsewhere. If the government is unable to nominate a suitable candidate for this key post, recruitment could be considered through overseas technical assistance.

Project implementation

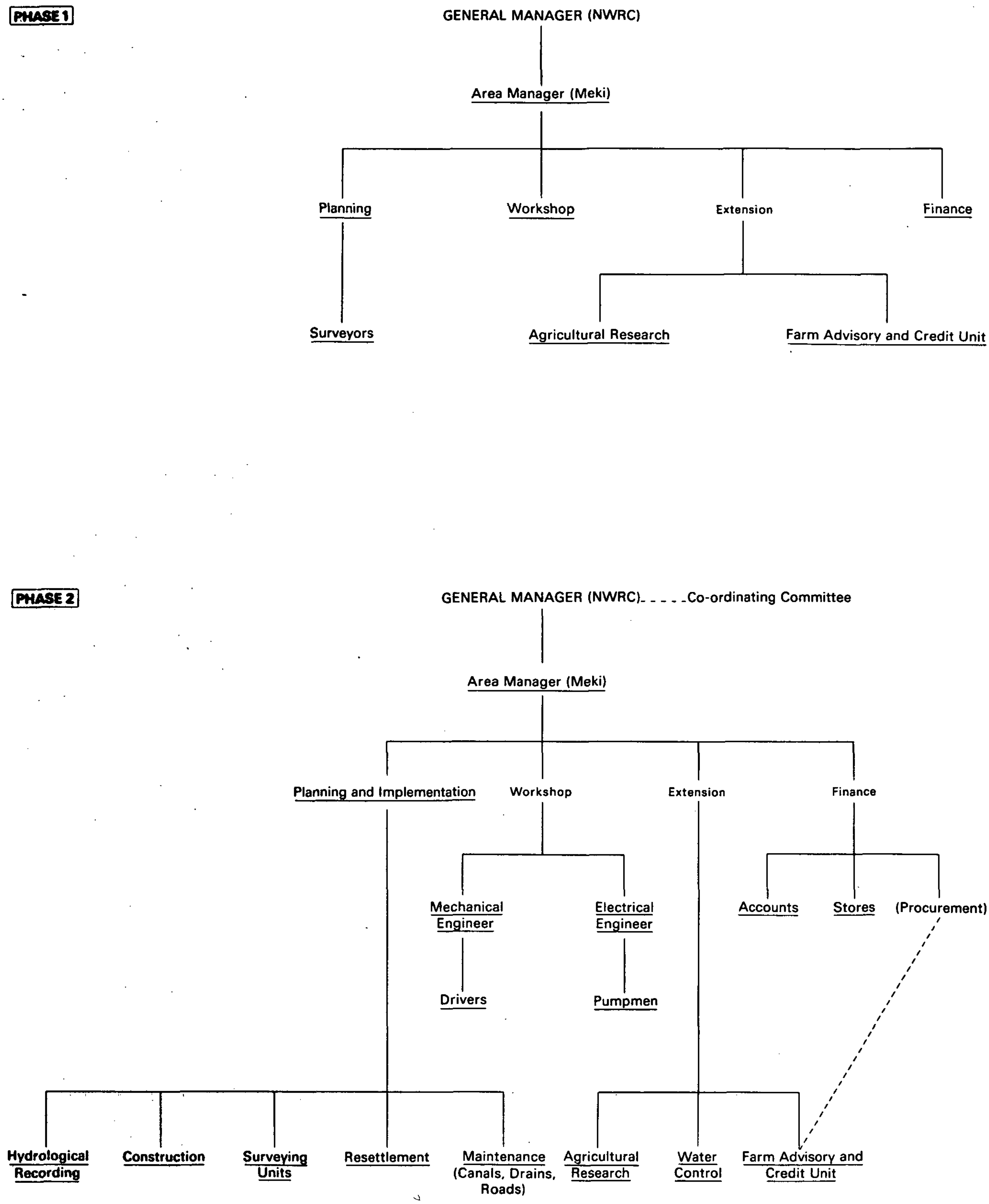
Implementation will certainly involve quite major changes in farm boundaries and in the allocation of land, including a significant element of new settlement; such changes will be facilitated by the 1975 land reform measures. Farms will have to be laid out to accord with the technical requirements of irrigation and, early in the design stage, it will be necessary for a team to visit the area from the Ministry of Land Reform to assess the full extent of the problems that will be involved in rationalising farm boundaries, resettling displaced persons and introducing irrigation on to existing holdings with a minimum of social and economic dislocation. A detailed soil and topographic survey will provide the basic information necessary for designing the irrigation and farm layouts, which will in time be modified by practical experience and by long-term experimentation with soil and water management.

Full scale development should not proceed until the 132 kV transmission line, discussed above, has been constructed as far as Zwai and Meki; The cost-benefit analysis in Part 8 has been based on the use of hydro-electric power and the project economics would be much less favourable if diesel power were substituted. The general lack of experience in irrigation, both on the part of government (other than the AVA) and a large majority of the farmers themselves, will pose a major constraint in implementation. Hence the emphasis given (below) to the need, early in the scheme, to provide technical guidance through a cadre of sufficiently numerous, well trained extension agents, coupled with a system for controlling water use by means of water guards. Multi-locational trial plots will provide the necessary agronomic information on which long-term agricultural decisions can be based.

Although the means by which the project will be executed can only be finalised when all preliminary information has been collected, it is envisaged that the following sequence of events could be followed in the implementation of Phase 1:

1. Detailed topographic survey, to provide contoured maps at a scale no smaller than 1:2 500
2. Soil survey at 1:10 000, to define the boundaries of the irrigable areas
3. Confirmation of the availability of electrical power

FIGURE 22



Units underlined to be based at Meki
- - - - - - - represents informal consultations

FIGURE 22 Proposed organisation of the Zwai Development Division,-Phases 1 and 2

4. Creation of the Zwai Development Division

5. Within the irrigable areas, cadastral survey to define current land allocation

6. Negotiation of the electricity tariff

7. Construction of power line to project area

8. Irrigation design, including canal distribution, and farm and field layouts

9. Selection of new settlers

10. Allocation and clearing of land

11. Construction of housing, through loans and provision of basic materials

12. Initiation of systems for farm-level extension and water control

13. Setting out and levelling, including development of the proposed multi-locational trial plots

14. Installation of inlet canals and local transmission lines

15. Construction of fields/canals/drains/roads

16. Installation of pumps and pipelines

17. Construction of farm boundary offtakes and tertiary canals within the holdings

18. Primary cultivations and ridging

19. Provision of seed and fertiliser on credit

20. Supervision in planting the first crops, and instruction to farmers on irrigation procedures and methods

A feature of communal irrigation will be the high degree of discipline demanded of the participants. The NWRC will need to consider the desirability of drawing up Irrigation Rules having the force of law; these Rules defining the rights and obligations of the farmer and of the ZDD. With the introduction of irrigation, the farmer would be required to bind himself to observe the Irrigation Rules; these and other provisions would be set out in a contract.

The ultimate success of an intensive irrigation scheme can depend in no small measure on maintaining a degree of control over the individual producer, and hence the ultmate sanction, after due warning, of dismissal from a scheme. In areas where farmers are settled on newly-created holdings as a result of the subdivison of existing larger farms, it is recommended that a form of life tenancy be introduced, with an automatic right of annual renewal provided the tenant has honoured his obligations. Tenants would have the right to nominate their chosen successor subject to approval by the management. On all holdings fragmentation or amalgamation should be strictly forbidden.

All schemes instituted by the ZDD should function on the basis of sound commercial principles; any rentals or charges for water and other services should be set accordingly. It is envisaged, however, that the ZDD should provide farm inputs at cost plus handling charges. Applications for credit would be channelled through the central organisation.

Responsibility for pump stations, primary and secondary canal systems, irrigation layouts and water control should rest with the management, and water allocation should be controlled by water guards. Constant liaison should be maintained between the management and the farmer by means of farm extension agents, who will have a crucial role to play. These agents should be stationed locally so as to maintain close contact with the farmers they serve. It is further suggested that the farmers could be encouraged to form a committee to maintain effective liaison with all levels of the management; the details of such a committee should be formulated by those directly concerned.

The design of a system for collecting water and other charges to be levied by the controlling authority is not regarded as falling within the terms of reference of this project. Nevertheless, the need to devise some such system is evident. It would have been ideal for charges to be collected after harvest through a cental marketing organisation, but this cannot be recommended on a scheme with several diverse products nor in an area with existing, well defined market outlets since evasion could be on a massive scale. Standard charges might instead be gathered in through the local system of tax collection, though it would be important to distinguish clearly the charges that were being recouped by the ZDD.

The ZDD will need to purhcase and maintain adequate transport for management personnel, extension agents and mechanics. Most of the irrigation works could be constructed by direct labour; for this purpose, it is suggested that the following items of equipment might be required: land plane, drag-line, back-actor, grader, dump-truck, and concrete batching and mixing plant. It should be noted however, that for the purpose of the economic analysis (Part 8), construction costs are based on 1974 unit costs of work carried out under contract (Appendix 13); consequently no allowance has been made for the purchase of construction plant. It is also proposed that a workshop be set up within the ZDD at Meki to service the Division's machinery, including pumps and irrigation structures. This workshop should be equipped to handle major repairs; in addition, mobile compressor and welding equipment should be available for use in the field.

Responsibility for the operation and maintenance of all hydro-meteoroligical stations in the Zwai Catchment (shown on Text Map 2) should be transferred to a single authority. Within this recording programme, the following specific recommendations are made:

1. The rating curves of the main rivers should be checked over as wide a range of stage as possible. For this purpose, it will be necessary for a team of observers to spend at least the whole of one wet season conducting discharge measurements

2. Lake level recording on lakes Zwai and Abiyata should be transferred entirely to the NWRC recorders, once a reasonable overlap has been obtained with the existing AVA gauges

3. A permanent observer for the staff gauge on Lake Langano should be provided urgently

4. The meteorological station at Zwai Town should be improved. The wet and dry bulb thermometers need to be replaced and the anemometer should be raised to 2 m above ground level, so that adequate Penman estimates of evaporation can be computed (see Appendix 1). It is further recommended that a thermo-hygrograph be installed

5. As development proceeds, the ZDD should establish substations in each major development area. These would evaluate variations in rainfall and evaporation and enable local irrigation requirements to be more precisely estimated

LAND PREPARATION

Measures needed to prepare land for irrigation will vary over the project area. The greatest changes will be required on the Meki Delta for the integrated scheme outlined on Text Map 7. At the other extreme, little or no preparation will be needed on farms using a nearby water source and small individual pumps for low-lift irrigation. In general, the following procedures will be necessary:

1. Land clearance, using mechanical equipment where necessary

2. Construction of major irrigation works including primary and secondary irrigation and drainage canals (tertiary canal construction would be the responsibility of the individual farmer)

3. Simultaneous demarcation of individual fields and land levelling for basin or furrow irrigation as required

4. Supervision in planting the first crops and instruction on irrigation procedures and methods

For the long term, management procedures which maintain soil fertility should be followed. There should be no degradation in chemical or physical properties and no severe increase in pests, diseases or uncontrollable weeds. Rotations will be an important aspect of land management. The importance of testing the proposed rotations to monitor the long-term effects on soil organic matter, soil alkalinity and pests has already been stressed. There will be a need for protection against soil erosion by careful levelling and the strategic use of windbreaks.

The need to monitor the soil's chemical and physical properties has also been emphasised. Since most soils have high silt contents, irrigation over a long period may result in crusting and sealing, particularly after heavy rain-storms, and care will be required to maintain surface soil structure through minimal tillage. Primary cultivations to loosen the subsoil are likely to be beneficial but inversion should be avoided; therefore subsoil tines should be used rather than deep inverting ploughs. It is also suggested that a ridge and furrow system be adopted since, apart from the convenience in demarcating rows and distributing water, this tends to reduce deterioration in soil structure and provides loose soil for prolific rooting near the soil surface. Moreover, because traffic through the crop can be confined to the furrow bottoms, less compaction will result than in flat systems of planting. Ideally, the soil organic content should be maintained by including in the rotation certain crops, such as maize, which have a large residual root system; by applying organic manure from livestock; or by growing restorative green manure crops (e.g. *Crotalaria juncea).*

Finally, field drainage must be capable of dealing with exceptional storms; the ridge and furrow system would assist in this but main drainage channels should be introduced as experience dictates. Moreover, on the Meki Delta it will be important to monitor and control the level of the watertable to avoid an accumulation of salt in the soil profile.

FARM AND IRRIGATION DESIGN

The objective of Phase 1 is an extension of the irrigated area to 1 730 ha (along the Meki, Catar and Bulbula Rivers and along the lowest parts of the Western Terraces). The second phase objective is for irrigation on a further 3 770 ha (on the Meki Delta, western lake margins, Western Terraces, east of Bulbula River, and along the Catar River). Except for the western lake margins, nearly all these areas are under cultivation (Separate Map 1). During Phase 2, a vegetable dehydration plant would need to be constructed, subject to a feasibility study. Such a plant would be supplied from a minimum of 500 ha, and it has been recommended (Part 5) that at least 400 ha should be provided by a nucleus estate operating under the control of the factory.

Because of uncertainties surrounding land tenure reform, it is not possible to predict what farm sizes will ultimately be adopted. Until 1975 farm sizes in the project area varied between 0.5 and 800 ha; over 40% of the land was cultivated by tenants and less than 10% of the land farmed in large-scale mechanised units. In the overall design of the project, farm sizes can only be tentatively prescribed.

Gross margin analysis indicates that the optimum smallholding size is about 1.5 ha. This allows for virtually full family employment and is consistent with income expectations, while not requiring excessive levels of hired casual labour. Under a system of communal farming, an average farm size of 1:5 ha could imply ten farmers on 15 ha, or 20 on 30 ha. Reference (below) to 1.5 ha as the chosen farm size is not intended therefore to discount the possibility of large communally-irrigated holdings; indeed, in this way farm operations could be communalised and pumping facilities shared. In practice, the system should be flexible and the actual irrigated area may be varied from a strict ratio of 1.5 ha per farming family, though there will need to be a degree of regularity in the design of the actual field layout. Farm units exceeding 1.5 ha would require additional hired labour (the use of hired labour under most circumstances is in fact banned by the 1975 Land Reform Proclamation). Smaller farm units (say of 1 ha), while allowing a greater density of settlement and a more intensive level of production, would tend to leave the farm family seasonally under-employed, besides reducing net farm incomes.

Selection of a suitable method for the irrigation of these small farms should take account of (a) the level of skill available, (b) topograhic and soil factors (e.g. infiltration rate, leaching requirements and groundwater control) and meteorological factors (e.g. high transpiration rates, strong winds, and relatively low rainfall), and (c) economic factors.

Current irrigation techniques involve individual pumping, direct from the water source, to the highest point in a system of gravity-fed canals supplying part of a single farm. Crops are planted on the sides of furrows up to 25 m long. During irrigation each furrow is opened by breaching the side of the supply canal. When the furrow is full the end is blocked off and the water infiltrates into the soil. No allowance is needed for draining excess water since the amount entering the furrow is carefully controlled. When irrigation has been completed, the pump is shut down. This method, known as bunded furrows, is simple and cheap, the major costs being the pump, labour and fuel; on the other hand, it cannot readily be adapted to the irrigation of larger areas covering several farms. For this, three complex factors need to be considered: (a) the distribution and allocation of water from the pumping station to the various farms, (b) the need for adequate drainage when field irrigation and pump operations cannot be fully co-ordinated and (c) the optimum dimensions of the furrows, taking into account the slopes, the infiltration rate of the soil and the timing of irrigations. In other words, a greater level of skill and experience is required than presently exists.

While methods of irrigation at farm level are expected to be similar in both phases of development, in Phase 1 water would generally be supplied from small pumps shared by up to 12 farmers. For the Phase 2 developments however, it is envisaged that irrigation would be provided on a larger scale by blocks; i.e. a communal system would be used rather than an individual supply. All communal pumping stations would be permanently sited, the pumps being bolted down to concrete plinths and protected from the weather by simple shelters constructed from close-spaced eucalyptus poles and corrugated metal roofs. These stations, though sited above maximum water level, should have as small a lift as possible, preferably less than 5 m. Centrifugal pumps would be used throughout, and multi-stage pumps would be necessary for some of the higher lifts. The capacity of each station should be divided between two or more identical pumps so that, in the event of one pump failing, the station can continue to operate. Standardisation of pump type and manufacture will reduce maintenance costs and ensure speedy repair. The pumping mains should comprise asbestos-cement pipes, which are generally both cheaper and easier to handle than other pipes, although careful site procedures are necessary to avoid breakages; some sizes (up to 200 mm diameter) are made in Ethiopia.

Since the greater part of the area is relatively flat and the level of skill is low, it is proposed that basin irrigation should be generally employed. In this system water is passed into the basin by a check gate or siphon. The basin is essentially level (gradients less than 0,02%), and surrounded by bunds up to 300 mm high which retain the water at a fixed depth. Little earth movement is required if the basins can be located according to the topography and the bunds between basins positioned along the contour. This, however, tends to give rise to irregularly shaped basins and, in practice, some land-levelling is usually required to produce a rectangular field layout more suited to farm cultivations. An idealised layout of a basic irrigation unit with 0.5 ha basins is shown in Figure 23. A single farm would comprise three adjacent basins; a communal farm could comprise any number of adjoining basins.

On steeper land (e.g. on the lake terraces and in Bulbula East), use of the basin method would require the construction of terraces. Here levelling would be more expensive and there would be a risk of erosion in the event of a bund failing; also there is a greater danger of exposing alkaline subsoil. On steeper land of up to 5% slope, it will often be preferable to employ the furrow system of irrigation, involving furrows aligned down the the slope. Water supplied from a tertiary field canal at the head of the furrow is allowed to flow downslope for a given period of time. Excess water passes into a field drain at the bottom of the slope from where it may be re-used at a lower level. For successful operation, it is necessary to relate the flow in the furrow to the varying infiltration rate along its length and the erodibility of the soil; this requires more skill than the basin method or the system of bunded furrows used at present.

Little consideration has been given to sprinkler irrigation - a system unfamiliar in the Zwai area - since the method has several disadvantages:

1. The high initial cost, as compared with the relatively minor cost of the land preparation necessary for surface irrigation; i.e.sprinkler irrigation is capital rather than labour intensive

2. The need for mechanically-skilled personnel, since sprinkler nozzles must be carefully maintained and operated at the correct pressure if uniformity of application is to be achieved

3. The need for a secondary pump system to operate the sprinkler lines, with the result that running costs will be higher than for surface irrigation; these additional costs may to some extent be offset by more efficient water use

However, against these disadvantages, must be considered the fact that under ideal operating conditions sprinkler irrigation could be expected to be more efficient. In the dry season, frequent irrigation by sprinklers would give higher yields per cubic metre of water applied. Irrigation by sprinklers might therefore be introduced gradually once considerable experience in irrigation has been acquired; the system would have obvious application on the more undulating areas of the Western Terraces.

Preliminary infiltration studies (Appendix 8) indicate slow rates of infiltration on the Western Terraces and in the Bulbula area, and relatively high rates on the Meki Delta. The permeability of the soils on the Western Terraces is considerably lower than the surface texture would suggest, due to poor structure and high subsoil alkalinity combined with a fairly high silt content. Using the very limited field data available, it has been assumed that, for developments in Phase 1, the need for canal linings to reduce conveyance losses should be limited to the Meki and Catar Deltas. The use of canal linings in Phase 2 would depend on experience gained during Phase 1.

The main irrigation networks for each of the irrigation development areas should be planned from the start. On the Meki Delta however, it would be most desirable to initiate a pilot scheme on up to 100 ha before embarking on the major engineering works; initial experience in irrigation techniques and cropping systems would prove invaluable in avoiding problems later. After the pilot scheme has operated for 2-3 years, phased development could take place on the rest of the area based on detailed topo-

FIGURE 23

Prospects for Irrigation Development around Lake Zwai

TYPICAL BASIN IRRIGATION LAYOUT

Land Resources Division, Ministry of Overseas Development | 1976

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Prepared by the Directorate of Overseas Surveys 1976

graphic survey. Throughout, the irrigation distribution and drainage works, the canals, and the basins should be constructed at a pace which ensures that newly-developed land can be immediately utilised by the farmers, under supervision from a central authority. The problems of introducing irrigation on to existing farms, taking over farms for development, and resettling displaced farmers will have to be resolved from the outset.

The farms have been designed for a relatively high labour input and the use of draught animals. Initially, the smallholder would have two draught oxen, an improved plough with attachments for ridging and lifting groundnuts, and a handsprayer. The costs of this equipment have been included in the economic analysis, but no allowance has been made for full mechanisation. Nevertheless, consideration may need to be given in the future to introducing labour-saving machinery for decorticating groundnuts and haricot beans, and for shelling maize. Whereas simple hand-operated machines exist, even these may be too expensive for a single 1.5 ha farm to purchase, although they would reduce the operations from days to hours. The possibility also exists for communal ownership of machinery; this development can be expected with encouragement from the extension agents. Advice is also needed for improved on-farm storage facilities.

It is estimated that about 700 extra farms would be created as a result of Phase 1, with an additional 1 550 following completion of the proposed Phase 2 developments. This implies that a total of some 11 000 people could gain a permanent livelihood as a result of these proposals.

With the development of irrigation, it is intended that the settlers should be housed in villages established on unirrigable land, since villages are easier to service with electricity and other utilities; with the farmers thus concentrated, the work of extension agents would also be facilitated.

RESEARCH

It must be emphasised that research and field experimentation within the project area should be undertaken from the outset. For this purpose, the ZDD should acquire land with the aim of establishing several multilocational crop trials. Each trial area should approximate to 10 ha, and the objective should be to have at least four such experimental sites operational by the middle of Phase 2. The first site, which could act as a focal point for all research activities around Zwai, should be acquired at the earliest possible opportunity; it should be located on the western shoreline of Lake Zwai, on representative Class 3 land (Soil H) and close to a year-round source of irrigation water (see Separate Maps 2 and 3). Central offices, seed storage facilities, a simple laboratory, and classrooms for training extension personnel would be sited here; also buildings to house machinery and implements and, ultimately, for post-harvest experimental work on drying, grading and packaging produce.

Later in Phase 1, a second trial site should be established on the Western Terraces on Class 5 land (Soil J) with the express purpose of performing long-term field trials to assess the suitability of these soils for irrigation. Towards the end of Phase 1, a 10 ha trial site with flood protection should be developed on drained Class 4.2 land (Soil F) on the Meki Delta; this could be gradually extended and serve as a pilot scheme for Phase 2 developments on the Delta. Finally, by the middle of Phase 2, it would be valuable if a second trial site could have been established on Class 3 land to the south of Zwai Town (Bulbula West), with the prime objective of testing new irrigation and land management techniques, in particular conserving the use of irrigation water.

Early experimentation should aim at testing the proposed cropping systems and irrigation techniques, thereby ensuring that the best possible recommendations are transmitted via the extension services to the farmer. Other research functions would include the training of extension staff, provision of improved seed, and the investigation of possibilities for introducing new farming enterprises. Experimentation should preferably be organised and supervised by the Institute of Agricultural Research (IAR), both to ensure close co-ordination with other research in Ethiopia, and to tap the available specialist expertise. An alternative approach would be association with

CADU or SORADEP; while, in the case of sugar cane or vegetables for dehydration, an investing company could undertake most of the research. Staffing is of the utmost importance and the officer-in-charge should have had prior experience in experimental field techniques and in farm and irrigation management.

The total capital cost of four research substations each of 10 ha is estimated in Table 71. In subsequent analyses, these costs have been attributed to Phase 1. Research will be organised by a senior research officer, and each substation will be managed by a research supervisor assisted by five permanent labourers. The use of machinery should reduce much of the manual labour requirement of crop and farming system trials. It is expected that the variable costs of the trials will be recovered from sales of produce. All staff salaries and housing have been included separately in the Phase 1 project operating costs (Table 82, page 200).

TABLE 71 Constituent capital costs for the proposed research substations

Item	Estimated capital cost ($ 000s)
Buildings	160.0
Farm machinery/oxen	120.0
Irrigation layout	80.0
Office and laboratory equipment	20.0
Total	380.0

Machinery purchases should include improved ox-ploughs, ox-ridgers and drills. One or two 65 hp tractors should also be obtained together with the necessary associated equipment - land levellers, disc ploughs and harrows, seed drills, tool bar and ridgers, trailers, a groundnut lifter, and threshing and harvesting equipment. A stock of hand-operated sprays, seed drills and cultivators would be required and also equipment for metering water.

The research programme

A key proposal is that research should operate alongside commercial irrigation. In this way, experience can be gained in tackling practical problems as they arise, and the bulking of tested improved seed can be implemented. Moreover, research as a whole should be made self-financing at as early a stage as possible.

Priority should be given to testing the following rotations under irrigation. If successful, the trials should be continued to determine possible long-term trends in pest, disease and weed incidence.

Rotation 1:	Year 1:	Red peppers
	Year 2:	Long-cycle maize Haricot beans
	Year 3:	Maize intercropped with groundnuts Wheat
	Year 4:	Long-cycle maize Haricot beans
	Year 5:	Maize intercropped with groundnuts
Rotation 2:	Year 1:	Maize intercropped with, and followed by, red peppers
	Year 2:	Maize intercropeed with groundnuts Haricot beans
	Year 3:	Maize intercropped with groundnuts Haricicot beans

Rotation 3:	Year 1:	Maize intercropped with, and followed by, red peppers
	Year 2:	Onions followed by haricot beans, or Haricot beans followed by onions
	Year 3:	Maize intercropped with groundnuts Haricot beans
Rotation 4:	Year 1:	Tomatoes
	Year 2:	Onions followed by haricot beans, or Haricot beans followed by onions
	Year 3:	Cabbages followed by carrots
Rotation 5:	Years 1-4 or 5:	Sugar cane
	Years 5-7 or 6-7:	Vegetable crops

Various modifications can be made to these rotations as outlined in Part 5. Experiments on cultivars, fertiliser use and irrigation application should be incorporated into the rotation trials. A suitable arrangement would be to divide a 1 ha block into three equal parts for a three-year rotation trial, and then subdivide the 1/3 ha plots to test irrigation interval, fertiliser treatment, spacing and cultivars, using standard experimental layouts which can be subjected to statistical analysis. Pest and disease control measures, such as the use of clean seed, seed dressings, applications of insecticides and fungicides as well as control through rotations, should be tested as a major part of the research programme, preferably assigned to a single research officer.

Soil management and irrigation techniques should be assessed in relation to problems of land preparation and levelling, convenience of crop management and water use efficiency. With furrow irrigation it will be necessary to determine optimum slopes, lengths of run and flow rates for different soil types. For basin irrigation the optimum size of basin should be found. Different systems may be required for different-sized farms. A long-term programme to monitor changes in soil salinity and alkalinity should also be instituted. The effect on soil exchangeable sodium and calcium of leaching with water high in bicarbonate should be studied so as to anticipate any long-term problems; associated changes in soil structure should also be investigated.

At a later stage in the research programme, investigations will be required into crop harvesting, drying and storage, with special emphasis on lifting, drying and threshing groundnuts; drying freshly picked red peppers; threshing and storing grain crops and haricot beans; and preparing vegetable crops for processing.

The potential for sugar cane, whether as a source of raw sugar or of animal feed, would justify the establishment of observation plots, including the varieties N:Co 310, Co 419, B 52298 and B 41227, to determine yield performance, ratooning periods and methods of irrigigation. A careful comparison of overhead with furrow irrigation is recommended on the coarse-textured terrace soils (Soil H). Planting dates should be selected in each of the four quarters of the year and harvesting schedules developed to give a nine-month reaping season from October to June.

Part of the trial area on the Western Terraces should be planted to a wine-grape cultivar trial, using both irrigated and rainfed treatments. Irrigation is expected to result in two crops a year but this needs confirmation. If one crop matures early in the wet season, some arrangement may be necessary to dry the grapes since the wine producers may be unwilling to accept the fruit fresh. Overhead sprinklers or travelling rainers might be particularly well suited to irrigated grape production, and could be used elsewhere during those periods when the grapes are dormant or growing on residual moisture.

Asparagus is a perennial crop with some export potential, whether fresh, dehydrated or canned. The variety 'Mary Washington' has given encouraging results at Nazareth (Jackson, 1973) and experiments should be laid down to compare yields of the male and female or of mixed selections. The timing of cutting and the length of growing intervals between successive harvests should be studied with a view to maximising the duration of the harvest period.

The profitability of livestock, especially of sheep, fed off irrigated fodders should also be assessed. In addition to the native *Cynodon plectostachyus,* the following fodders are considered suitable for irrigation in the Zwai area and it is recommended that selected varieties of each should be evaluated under both rainfed and irrigated conditions, having regard to nutritional quality as well as dry matter yield:

Grasses	- Rhodes grass *(Chloris gayana)* Guinea grass *(Panicum maximum)* Sudan grass *(Sorghum sudanense)* Sorghum X Sudan grass hybrids
Legumes	- Alfalfa *(Medicago sativa)* Berseem *(Trifolium alexandrinum)* Stylo *(Stylosanthes gracilis)*
Other fodders	- Maize or Sunflower silage Fodder Beet Sugar Cane

It would be valuable to determine the response of selected fodders to increments of fertiliser and irrigation water, and to evaluate optimum stocking rates and the prospects for zero grazing. For this, it would be important to select suitable breeds of livestock. In experiments to assess the prospects of fat lamb production for export, Blackhead Persian or derivatives therefrom (e.g. Dorper, Van Rooy, Wiltiper or Bezuidenhout Africander) may well provide crosses with the necessary characteristics. Research should concentrate on stocking rates; ability to breed throughout the year; lambing percentage; feed conversion; liveweight gain and carcass quality.

EXTENSION

The service provided by the Farm Advisory Unit will be one of the most important functions of the Zwai Development Division. New farmers will need guidance on cropping and farm management. It is proposed that extension be closely co-ordinated with research, so that experimental results can be rapidly transmitted to the farmers; similarly, there should be continuous feedback of farmers' problems so that solutions may be provided. It is envisaged that requirements for farm inputs (credit, seed, fertiliser and chemicals) would be relayed direct to the Finance Unit, which would be responsible for procurement and supply (Figure 22).

Initially, there will be a requirement of one field extension agent for 50 farmers - this relatively high raio being necessary because most farmers will have had no previous experience in irrigation. The calibre of recruits for this work will be crucial to the success of the scheme. As proficiency is gained in irrigation, each agent should gradually be made responsible for increasing numbers of farmers, with an ultimate objective of 100 farmers to one agent.

Extension workers will need to be thoroughly trained in irrigation methods and field preparation (land levelling and grading). They should be able to instill a high level of expertise in relatively unsophisticated farmers from the timethat irrigation is introduced. They should also be familiar with the cropping patterns and the problems which are likely to occur, e.g. pest and disease diagnosis and control. The Senior Extension Officer should be appointed with careful regard to personality, integrity and previous experience. His responsibilities will be onerous and of vital importance in the implementation of the proposed development. The support of CADU, and preferably their full participation at both the extension and the research level, is strongly recommended.

CREDIT

Normally, the function of credit is to enable the farmer to incur expenditure, both for consumption and for productive investment, at times when he lacks capital resources. It is proposed that, in the Zwai area, farmers should only be extended credit for productive investment. Even this will require considerable resources on the part of the Zwai Development Division (ZDD). It is not feasible at this stage to forecast the total credit requirements. Overall costs for the cultivation of irrigated crops are indicated in Appendix 10. It is likely that most initial production costs, excluding family labour, will have to be covered by credit at least until the first harvest. New settlers may also require assistance for the first year from the World Food Programme. However, the bulk of credit requirements will probably be accounted for by short-term loans for inputs such as fertiliser, seed and chemicals, and by medium-term credit to cover the costs of such capital outlays as pumps and equipment. As the project proceeds and incomes rise, the demand for credit should decline.

Table 72 gives estimates of short-term credit needed to cover the cost of essential inputs (but excluding fuel, maintenance and labour). The need for medium-term credit is more difficult to assess. From Appendix 11 it can be estimated that the credit requirement on irrigated smallholdings for implements and equipment may be of the order of $ 230/ha. Credit should be disbursed as far as possible in the form of the actual inputs needed by the farmer. It is envisaged that the extension agents would process the farm requirements, and that the Finance Unit of the Zwai Development Division would provide the inputs (or cash where necessary).

TABLE 72 **Estimated short-term credit requirements (excluding fuel, maintenance and labour) for irrigated smallholdings ($ /ha) (values derived from the direct costs in Appendix 10)**

Haricot beans	172.00
Long-cycle maize	188.60
Maize - groundnuts	294.20
Maize - peppers	382.20
Tomatoes	488.50
Onions	526.60

A system of credit collection would have to be carefully devised by the ZDD and revised in the light of experience. There may be some merit in adopting a system similar to that practised by SORADEP i.e. disbursement of credit in kind, collection of the interest charge on delivery of the input, and repayment through the extension service after harvest, with the ultimate threat of collective sanctions against an entire village in the case of default.

MARKETING

It is recommended that marketing should primarily be the concern of the farmers involved in the project. Apart from groundnuts, there are initially to be no unusual products, and it is unlikely that the quantities produced will significantly affect the market price.

In some similar schemes, the project authority controls all marketing, so as to maintain prices on behalf of the producers and ensure that loans extended are repaid. In this scheme however, it is considered that, if the marketing of project produce were to become a function of ZDD, an excessively heavy and costly workload would be added without necessarily creating any price benefit for the producer. Moreover, being so close to Addis Ababa, effective and relatively efficient marketing channels already exist. As regards loan repayments, previous experience in Ethiopia indicates that failure to repay is comparatively rare. It is proposed therefore, that the ZDD should encourage farmers to set up marketing co-operatives, and to this end be prepared to extend credit to cover marketing costs. In this way, responsibility for marketing would gradually be devolved to the level of the producer.

As the project proceeds and vegetable production for dehydration or processing becomes a significant component in the cropping pattern, it is possible that some form of control would have to be imposed by the ZDD so as to relate supply to demand, although a dehydration plant would probably assume overall control of supplies.

Part 7

Ecological implications of the proposed developments

The impact of the developments described above could in the long run be far-reaching. Acceleration in economic activity, the quickening pace of technological change and the rapid evolution of social attitudes will inevitably be accompanied by a more gradual yet fundamental disruption to the various ecosystems. Parts of the environment have already been greatly modified in recent times by human immigration and the related spread of agriculture. Much of the land area proposed for irrigation has already been cleared of its natural vegetation, and the fauna of this part of the Rift Valley have been profoundly affected to the extent of exterminating much of the large mammalian population. Around Lake Zwai, the only large wild mammals remaining are hyaena, jackal and occasional vervet monkey, and it is only through the protection afforded by the lake itself that hippopotami have survived.

Implementation of the developments outlined in Part 6 will have a variety of consequences which, although interrelated, are best considered separately:

1. The impact of lowering the level of Lake Zwai and of reducing its volume

2. The direct influence of the irrigation developments themselves

3. The effect of lake level regulation on flows in the Bulbula River

4. The significance of manipulating flows in the Bulbula for the long-term stability of Lake Abiyata, a bird sanctuary of exceptional importance

THE LOWERING OF LAKE ZWAI

Although the environs of Lake Zwai are scenically attractive and a wide variety of bird life can be found, the main economic consideration in altering the lake volume must be the impact on its very considerable potential as a freshwater fishery. With broad shallow margins fringed with swamp, dense floating vegetation and a high concentration of phytoplankton (microcystis), Lake Zwai supports the heaviest fish stocks in the area. Notable fish species include *Tilapia nilotica, Barbus gregorii* and four other *Barbus* species, together with *Discognathus makiensis* in the Meki River; catches suggest approximately equal numbers of *Tilapia* and *Barbus* (Atkins and Partners, 1965). The existing fishery operated on the concession system in return for a relatively large annual payment (currently $20 025). The 20-year concession was due to expire in 1976. Much of the fishing undertaken by the concessionaire is by seine netting mostly from small boats. Because fishing is restricted to shallow water necessary for the operation of the nets, most fish caught tend to be small, and the annual yield is low. Although fishing is currently on a small scale, Atkins and Partners estimated the potential of Lake Zwai at 3 000 tons per annum, which is equal to that of lakes Galila and Awassa combined. In view of this significant long-term potential for fisheries (to serve an expanding domestic market and also for the export of deep-frozen fillets), any effect on fish productivity cannot be ignored.

Atkins and Partners' projections of fishery potential were based on fish weight per unit of lake surface area. For Lake Zwai (with a mean surface area of 450 km^2), the annual yield was estimated at 67 kg/ha. It could be presumed therefore that a reduction would have a directly proportional effect on the fish population and hence on total fish weight, in which case the developments projected in Phases 1 and 2 could lead to a reduction in fishery potential of about 9%. This approach however, while broadly valid for deep-water lakes, may not hold for shallow lakes such as Lake Zwai, much of it less than 6 m deep. In such a shallow lake it is possible that fish population will be more closely related to lake volume than to surface area. On this basis, completion of the Phase 2 developments could result in a reduction of fish weight by up to 22% and such a reduction could have significant economic implications.

The impact on the fish population would be the most dramatic result of a lower lake level, but other more subtle effects should also be considered. The vegetation around the lake edge plays an important role in providing food and shelter for numerous organisms on which the major lake food chains are based. Whereas a rapidly fluctuating lake level could be expected to restrict the zonation of marginal vegetation, a gradual but permanent lowering of the lake as proposed in this report should allow the zones to readjust by means of natural succession. Indeed, operation of the Bulbula outlet control structure, as proposed, should have the beneficial effect of reducing the present amplitutde of lake level fluctuations. This should also help maintain the highly productive rim of marginal grassland, important in providing dry season grazing at high stocking densities.

Some species, however, are apparently extremely sensitive to even short-term disruption to their environment. Mollusc surveys in Lake Zwai have shown that the occurrence of the snail *Biomphalaria sudanica*, for example, is sporadic and almost certainly determined by the effect of seasonal lake level fluctuations on habitat maintenance (Goll and Aweitu, 1974). Collections made between 1962 and 1974 revealed the presence of a localised colony of this snail associated with floating vegetation in the south-west corner of the lake near Zwai Town. In June 1972, when the lake level was low, many empty shells were found in the same general area in *Aeschynomene* thicket. By March 1974, the lake level had fallen further and only one specimen of *B. sudanica* was located in 3½ days of sampling. In October 1974 however, following a significant rise in lake level, relatively large numbers of the snail were found at the lake edge close by Zwai Town, and also near the Bulbula outlet, near Chefe Gila and around the island of Tulu Gudo (Goll and Aweitu, 1974). The implications for the transmission of bilharzia are considered in the next section.

Reduction in lake volume could also be expected to have an effect on the ionic concentration of the water, though this is too complex to be accurately quantified. Indeed, minor seasonal changes in water chemistry already occur; between June 1972 and March 1974, the electrical conductivity (and hence the ionic concentration) increased by about 15% (Goll and Aweitu, 1974). In general, the conductivity increases with low lake levels and vice versa. Factors operating to raise the absolute level of solute in the lake following irrigation development would include:

1. Increased inflows around the lake margins of groundwater highly charged with solute

2. Seepage from the deep percolation of irrigation water applied close to the lakeshore

3. Gradual increase in the level of solute contained in the groundwater resulting from more intensive applications of fertiliser, and the introduction of chemicals for control of pests and diseases

While the influx of solute from processes 1 and 2 above would tend to raise the cationic concentration of Lake Zwai, so rendering the water more alkaline, the incursion of significant quantities of elements derived from nitrogenous and

and phosphatic fertiliser could markedly influence the population of phytoplankton and have major long-term repercussions on the entire lake ecosystem. The ultimate danger (especially in terminal Lake Abiyata) would be extreme eutrophication; i.e. the overstimulation of organic activity by fertiliser nutrients, leading to the death of all lake organisms from oxygen starvation. Balancing these factors to some extent would be the more rapid throughput of water, due to abstraction for irrigation. It is in Lake Abiyata that any net increase in ionic concentration would ultimately accumulate. Since the possible rate of increase cannot be predicted, it is essential for the proposed Zwai Development Division to institute a regular system for monitoring water quality at two locations: at the site of the Bulbula River sluice, near Adamitulu, and at a permanent site in Lake Abiyata, well away from any inflows.

BILHARZIA TRANSMISSION

The introduction of irrigation to areas hitherto devoted to rainfed agriculture will have a major long-term impact on both flora and fauna, though the specific effects are largely unpredictable. The most notable and obvious economic impact will derive from the inevitable increase in crop pests and diseases, especially those favoured by intensive irrigation (see Part 5). There may also be a significant increase in the occurrence of certain aquatic weeds in the irrigation canals, especially *Pistia stratiotes* (Nile Cabbage) and *Typha* spp. (Bulrush).

More immediate concern has been voiced regarding the possible introduction of *Schistosoma mansoni* (bilharzia), in view of the presence of its intermediate hosts, *Biomphalaria sudanica* in Lake Zwai and *B. pfeifferi* in the Meki river. Although, as alluded to above, the distribution of these molluscs tends to be sporadic, in view of their known tendency to major and rapid fluctuations in population density, the very real possibility of one or other of these species increasing under particularly favourable conditions should not be overlooked. Despite reports of schistosomiasis around Lake Zwai, prior to 1974 no infected specimen of the snail vector had ever been found. A stool survey (quoted by Aram and Goll, 1972; and carried out by the Central Laboratories and Research Institute) at Adamitulu, where the Bulbula River is used as a water supply (rather than the lake), gave a 19% prevalence of *S. mansoni* among school children. However, although suggestive, these two findings were not definitely linked; in view of the scale of recent immigration, it is not impossible that a majority, if not all, of these cases had been contracted outside the project area. A similar stool survey at Zwai gave 9 positive results for *S. mansoni* out of 190 examined (4.2% incidence), but all these except one were considered to be allochthonous cases. Nevertheless, with the vector present and with increasing human activity around the lake, there must be a considerable risk that bilharzia will spread. For this reason, the project initiated a further mollusc survey of the littorals of Lake Zwai and the upper reaches of the Bulbula River (Goll and Aweitu, 1974).

Previous surveys of the western shore of the lake had shown the presence of the following species: *Biomphalaria sudanica, Bulinus forskali, B. truncatus, Ceratophallus natalensis, Lymnaea natalensis* and *Melanoides tuberculata* (Aram and Goll, 1972). Compared with records made in earlier years the most striking result of the 1974 dry season survey was the relatively low population density of all species encountered. *B. truncatus* was present in nearly all sites where snails were found, but especially on *Nymphaea* and *Cyperus*. In contrast, by August 1974, when the water level had risen appreciably, there were flourishing juvenile populations of *C. natalensis* and *L. natalensis*. By October, however, with a further rise in lake level large numbers of *Biomphalaria sudanica* had appeared, accompanied by the two above species and *Bulinus forskali* and *B. truncatus.*

The various collections of *Biomphalaria sudanica* were examined for trematode infections. Cercariae of *Schistosoma mansoni* were found in one of 98 specimens collected near the school on the island of Tulu Gudo, an infection rate of 1%. Cercariae of other trematodes were however common, especially from the population collected near the Bulbula outlet where up to 25% infection rates were found, probably related to the high bird and fish populations in the area.

This sudden reappearance of *B. sudanica* following the rise in lake level seems almost certainly to be related to habitat limitation, apparently restricting species distribution, rather than to the associated but relatively minor changes in lake chemical composition. Regarding habitat, the species was only found in swampy areas sheltered from open water. Plant genera commonly found in association included: *Polygonum spp., Glyceria, Juncus, Kanahia, Utricularia, Cyperus, Typha* and *Eragrostis,* the first named being most frequent and considered elsewhere to be an indicator plant for *B. pfeifferi.* A favoured site appears to be provided by the lagoon effect created on the inshore side of the slightly raised ridge associated with marginal thickets of *Aeschynomene elaphroxylon.* Although this thicket was not mapped in detail, careful comparison of Separate Map 1 (Land Use) with Separate Map 4 (Physiography of Lake Zwai) seems to indicate that sites with *B. sudanica* present are associated with a relatively steep lake margin profile; this is particularly marked on Tulu Gudo. Conversely, those areas where *Aeschynomene* is absent and *B. sudanica* has not yet been found are characterised by a very gently shelving swampy margin, as on the west side of the lake north of Zwai Town. If these habitat factors do indeed describe the distribution of *B. sudanica,* then it may be possible to predict the distribution consequent upon a permanent lowering of mean lake level. By and large, the distance between the contours for 1 636.0 m and 1 634.0 m tends to be considerable, except in a few places where the profile above 1 636.0 m is already steep. It seems likely therefore that suitable habitats, and hence snail populations, will if anything tend to diminish rather than expand as a result of lake level reduction.

Although there is as yet no firm indication that *B. sudanica* aestivates or migrates to lower levels as the water recedes, aestivation seems more likely. Many of the larger snails (over 15 mm diameter) showed clear evidence of sudden interruption in growth, indicating cessation of activity consonant with aestivation. It would appear therefore that a very gradual lowering of the lake, as is generally envisaged in Part 6, should allow colonisation by *B. sudanica* of new though possibly fewer suitable habitats as these adjust to changed environmental circumstances. A more sudden lowering of the lake, even by as little as 0.5 m, might however cause a drastic (if temporary) attenuation of suitable habitats and, since migration of the snail during aestivation would be impossible, there could also be a dramatic decline in the active snail population and hence in the possible transmission of *S. mansoni.* Another factor to be considered is the role of the *Aeschynomene* thicket which currently acts as an effective barrier to human contact with the lake water, so preventing transmission cycles becoming established in areas which might otherwise be favourable, i.e. where *B. sudanica* is present. The developments envisaged in Phase 2 proposals involving lower lake levels and possible irrigation along the lake margins with increased human activity, are likely to lead to an increased transmission hazard.

One consequence of irrigation on the Meki Delta could be proliferation of suitable habitats for *B. pfeifferi.* This would depend on the permanence or otherwise of water in irrigation or drainage channels. The irrigation cycle for most cash crops would probably not encourage *B. pfeifferi,* but inevitably there will be some main supply canals which could provide suitable habitats. Much the same situation could develop along the Bulbula, though *B. sudanica* is unlikely to establish itself there. *B. pfeifferi,* which used to be abundant in the area (judging from the prolific sub-fossils in a lake terrace exposure 5 km south of Adamitulu), could become firmly re-established if chance specimens washed into the lake from the Meki or the Catar survived transit to the Bulbula outlet. It is remarkable that, despite the low ionic concentration of Lake Zwai water, *B. pfeifferi* has never been found in the lake, but only in the adjoining rivers.

The factors controlling the distribution of *B. pfeifferi* and *B. sudanica* warrant further investigation and it would be valuable to determine whether the marked fluctuations in the population of *B. sudanica* represent cyclical or merely seasonal events.

It can be concluded that outbreaks of bilharzia should not occur at the outset of irrigation development in the Zwai area, but constant vigilance is recommended (through mollusc surveys and periodic stool examinations) so that, in the likely event of the bilharzia cycle eventually becoming established, immediate control measures can be implemented. In this respect, the discovery (Lemma, 1973) at Adowa in Northern Ethiopia of an effective natural molluscicide, derived from the berries of a common highland hedge plant *(Phytolacca dodecandra - 'endod')* and already used as a soap-substitute, could represent an important advance. If *endod* can be produced cheaply and in sufficiently large quantities, it could be applied as a regular control measure to selected areas and irrigation canals, so preventing bilharzia from gaining a hold.

FLOW IN THE BULBULA RIVER

The importance of maintaining year-round flow in the Bulbula, apart from any possible effect on Lake Abiyata, relates to the need for domestic supplies of water along its entire 30 km length. The Bulbula, despite its relative inaccessibility, represents the only source of fresh water over a large area; in particular, the growing town of Bulbula is dependent on the river. During the dry seasons of 1973, 1974 and 1975, the river dried up for considerable periods, though some water could still be obtained from shallow wells dug in the river bed. It was reported from Bulbula that, prior to 1973, the river had not dried up for about 15 years. Nevertheless, it is clear that a succession of years with below-average flows can cause considerable hardship. An important side-effect of the longer-term developments would be to provide regulation of the Bulbula, such that a release of water can be maintained throughout the dry season sufficient to provide for all water requirements between lakes Zwai and Abiyata even in the driest years. Although a major social benefit, it is not one that is susceptible to quantification; it should nevertheless be considered when weighing up the benefits to be derived from the project.

CONSERVATION OF LAKE ABIYATA

Lake Abiyata is a shallow (14 m), highly productive alkaline lake whose muddy shore supports a wealth of bird life almost unequalled in Africa; as such, it is of great biological importance. The lake forms part of the Rift Valley Lakes Park, and can be expected to play an increasing role in the promotion of tourism. Despite a few patches of *Cyperus* in less alkaline water close to the inlets of the Bulbula and Gogessa rivers, the alkalinity is such that little marginal vegetation survives. Instead, food chains are based on the abundant population of phytoplankton (oocystics). The relatively high density of Lesser Flamingo is able to subsist directly off the blue-green algae in the surface waters, while many other birds are dependent on fish. Although, due to the alkalinity the fish fauna is restricted to a few species, there are heavy stocks of *Tilapia nilotica.* Although individual fish weights are generally low and commercial fishing is forbidden, some fish are taken for local consumption. It is recommended that the ban on commercial fishing be continued.

The area of the lake tends to fluctuate markedly (Text Map 6), due to annual and seasonal variations in inflow, the absence of an outlet and the relatively level northern littoral. Concern has been expressed regarding the drowning of acacia trees on the lakeshore at times of high lake level, as occurred in 1970-2, and the effect of this on the bird life (see Plates 15 and 16). In ecological terms the impact is not great, since the living trees now ringing the lake have a similar species composition to those that were killed. Indeed, the subsequent use of the dead trees by breeding colonies can be regarded as a beneficial result. Near the Bulbula inlet, for example, where the water is rather less alkaline, there are breeding colonies of darters, spoonbills and cormorants in the drowned acacias fringing the shoreline (Plate 16).

Abiyata also forms a vital feeding ground for Cape Wigeon, Abdim's Stork and Great White Pelicans, which breed in large numbers on Lake Shala, a lake which, due to alkalinity, lacks the fish necessary to support such concentrations of fish-eating birds. It is notable that the colony of Great White Pelican on Shala is one of only about a dozen on the African continent, and probably ranks as one of the largest. The Rift Valley also forms an important migration route for palaearctic birds during the northern winter and many ducks over-winter on Lake Abiyata, e.g. up to 15 000 shovellers (Brown, 1971).

PLATE 15 Shore of Lake Abiyata near the mouth of the Bulbula River (1974). Note the dead *Acacia tortilis* trees, resulting from recent high lake levels, the patches of surface alkalinity and the old staff gauge attached to a tree

PLATE 16 Lake Abiyata at the mouth of the Bulbula River (1974). Note the dead *Acacia tortilis* trees aligned along the levees of the Bulbula River, the Lesser Flamingo, Great White Pelican and the cormorants' nestings in dead trees

In its evidence to the project, the Wildlife Conservation Organisation (WCO) expressed concern regarding the possible effect of irrigation developments on the level of Lake Abiyata which, because it is a terminal lake dependent on an equilibrium between inflow and evaporation, must necessarily be highly sensitive to changes in its three major sources of inflow. Assurances have been given to the WCO that the level of Abiyata will not be reduced below the naturally-occurring lowest level. In this respect, it should be noted that regulation is only being proposed on one of the inflows - the Bulbula; the other two inflows of importance, the Gogessa and the Horakello, will be unaffected. It has been made clear in Part 4 that the project is based on maintenance of the long-term mean annual flow in the Bulbula River. This provision does not necessarily imply that individual mean monthly flows will be maintained at pre-regulation levels, nor even that the overall flow in any one year in the past could necessarily have been maintained. But it does mean that, by following Operating Rule 4 recommended in Part 4, the long-term total discharge from the Bulbula into Abiyata should not deviate from the current mean flow. Since it is unlikely that abstraction for irrigation will ever attain the maximum possible rates, there will be scope for employing different suboptimal operating rules which release Bulbula flows in such a way as to take account of fluctuations in the level of Abiyata. Construction of a flow-regulating structure on the Bulbula could therefore have the beneficial effect of allowing a measure of control over the level of Lake Abiyata, hence reducing the wide amplitude of level fluctuations which have occurred in the past following a succession of dry or wet years.

It will nevertheless be important to monitor continuously the impact of river regulation on lake level. To this end, steps should be taken to erect a new staff gauge on Lake Abiyata, and it is proposed that an automatic stage recorder be installed when the lake level has declined to a suitably low level. Continuous monitoring of the lake level should be initiated several years prior to river regulation, so that a record can be accumulated of natural fluctuations. Because of Abiyata's position as a terminal lake downstream from an area subject to increasingly intensive forms of land use, it is also imperative that a system for monitoring water quality be instituted at an early date, regardless of whether the development proposals contained in this report are implemented. Such a system should include regular microbiological analysis, as well as routine chemical analyses and measurements of dissolved oxygen levels. More complex periodic investigations may be required in the future to assess levels of stable and potentially toxic organic compounds. Pollution of the Zwai-Bulbula water could have a rapid and devastating impact on Lake Abiyata as a habitat for wildlife, and the large-scale use of toxic sprays or the disposal of chemical wastes anywhere in the Zwai-Abiyata catchment should first be subject to approval by the WCO. It is further proposed that, while responsibility for maintaining these control measures and monitoring systems should be vested in the Zwai Development Division, the Division must in these matters act in conjunction with the WCO.

Part 8

Economic analysis of the proposed developments

The fluctuating state of the international markets for many agricultural commodities and the effect of worldwide inflation make it difficult to present a definitive economic analysis of the prospects for development in the study area. Nevertheless, a preliminary analysis may help to point the general direction in which development can proceed, subject to more detailed confirmatory studies at a later date. It should therefore be emphasised that the calculations in this section are indicative only.

The analysis which follows is in two parts. First, gross margin analysis is used to estimate returns at the farm level within four defined agricultural systems. This shows how individual farmers are likely to benefit from the proposed irrigation development and from the various improvements in crop production and cropping patterns which were discussed in Part 5. Second, social cost-benefit analysis is carried out to determine whether society as a whole will benefit, after adjustments have been made to market prices and costs to correct certain distortions within the existing market system.

GROSS MARGIN ANALYSIS

Two basic categories of farm are considered - smallholdings (up to 2 ha) and large-scale farms (of 90 ha); this latter farm size was near the median size for large farms within the project area, and approximates to the optimum for machinery utilisation.

The four agricultural systems analysed are:

Smallholdings :	Agricultural System	1.	Unimproved rainfed	(2 ha)
	" "	2.	Improved rainfed	(2 ha)
	" "	3.	Improved irrigated	(1.5 ha)
Large-scale farms :	" "	4.	Improved rainfed	(90 ha)

The proposed cropping pattern for System 1 approximates to present land use in the project area in the absence of improvements. The improvements to rainfed agriculture which are recommended in Part 5 are incorporated in System 2; compared with unimproved agriculture, relatively more emphasis is given to haricot beans and peppers and less to maize. The irrigated Rotation 2 (discussed in Part 5) has been selected for use in System 3. Although it is not the most profitable of the rotations considered, it still gives a highly satisfactory return and should pose the fewest managerial problems. The cropping pattern proposed for System 4 is similar to that for System 2, except for an increased proportion of peppers at the expense of maize; on the larger farms maize is much less important as a subsistence crop.

For the purpose of gross margin analysis, labour has not been valued except when hired. It has been estimated from farm surveys that the average family has a labour availability of at least 30 man-day equivalents per month. Where crop labour requirements exceed this level, casual labour is assumed to be hired and is costed accordingly in the gross margin analysis (see Part 5; Labour Requirements). On the large-scale farms it has been assumed that all labour is hired.

Where irrigation is used, only pump fuel costs have been entered as direct costs in the gross margin analysis. Electric power has been assumed, since it is considerably cheaper than petroleum fuels. The electricity cost for an average pump lift is computed to be about $1.27 per 1 000 m^3 of water. All other costs associated with the provision of irrigation water as far as the farm boundary are considered to be the responsibility of the authority controlling irrigation development in the project area (the ZDD) and, as such, are treated as fixed costs.

Seed, fertilisers, chemicals and bags have been costed according to 1974 price levels; the rates of application are listed in Appendix 10 (Table 5). For red peppers, the cost of seed includes all inputs used in the nursery. For unimproved smallholdings, direct costs have been estimated from farm survey data; the only major input used and costed is seed. On large-scale non-irrigated farms, the direct costs of machinery use are based on fuel consumption and maintenance per hour usage (Appendix 14). Direct costs are elaborated more fully in Appendix 10.

Anticipated crop yields and prices are presented in Table 73, and crop gross margins for the four systems are summarised in Table 74.

TABLE 73 Anticipated average yields (q/ha) of crops grown under four agricultural systems (prices in $/q are shown for each crop)

System	Long-cycle maize ($15)	Tef ($30)	Wheat ($25)	Haricot beans ($50)	Groundnuts ($35)	Red peppers ($75)	Maize-groundnuts*	Maize-peppers*	Tomatoes ($6)	Onions ($6)
1.	11	7	8	7.5		10				
2.	25	10	12	14	18	16				
3.	60	12	25	22	25	30	40/20	40/20	400	300
4.	40	12	18	18	20	20				

*Maize-groundnuts and maize-peppers intercropped are priced as for single crops of maize, groundnuts and peppers

TABLE 74 Crop gross margins for different agricultural systems in $/ha (to the nearest $)

System	Maize	Tef	Wheat	Haricot beans (dry season)	Groundnuts	Red peppers	Maize-groundnuts	Maize-peppers	Tomatoes	Onions (dry season)
1.	146	189	166	321	–	671	–	–	–	–
2.	263	207	192	524	389	824	–	–	–	–
3.*	695	260	491	889	682	1898	963	1667	1705	1058
4.	302	130	216	560	301	939	–	–	–	–

*Gross margins for haricot beans and onions calculated for the dry season; wet season cropping would increase these margins

The estimates in Table 74 suggest that farmers in the traditional sector on rainfed land stand to gain considerably by adopting improved methods, and even more through the use of irrigation. This is highlighted in Table 75, which shows the gross margins and farm income estimates for each farming system, based on crop combinations and/or methods of production which promise to be more remunerative than those currently in use. The farm income data presented in Table 75 were derived by deducting fixed costs from the aggregate gross margins for each system. The fixed cost estimates used are set out in Table 76 and in Appendix 11. Irrigation costs include interest and depreciation on all capital investment, as well as maintenance and operational costs. No allowance has been made for rent or tax. The maintenance costs of oxen and equipment on farms in the traditional sector have been set at a fixed rate per hectare of crop grown, based on estimates of capital investment in the relevent items.

TABLE 75 Annual gross margin and income data for specific cropping patterns within each agricultural system

System	Farm size (ha)	Cropping pattern* (see Part 5)	Average annual gross margin ($/ha)	Average annual income per hectare ($)	Average annual income per farm ($)	Average daily income per farm ($)	Average income per day worked ($)	Average No. of labour days/ ha/year
1.	2.0	1.6 ha maize 0.2 ha peppers 0.2 ha haricot beans	216	200	400	1.10	2.30	87
2.	2.0	0.75 ha maize 0.25 ha peppers 1.0 ha haricot beans	464	424	848	2.32	4.93	86
3.	1.5	(Rotation 2) 1.0 ha maize-groundnuts 1.0 ha haricot beans 0.5 ha maize-peppers	1 791	1 281	1 922	5.27	5.59	229
4.	90.0	25 ha maize 20 ha peppers 45 ha haricot beans	573	338	30 420	–	–	–

*These cropping patterns could include a small proportion of fallow or forage crops; in which case, average annual gross margin and income data would have to be reduced accordingly.

The broad conclusion to be drawn from the data in Table 75 is that irrigated agriculture is likely to be much more profitable than rainfed agriculture, especially since the risks inherent in rainfed agriculture due to drought are not taken into account. Irrigation allows the farmer to grow high value crops without risk of failure and moreover enables him to produce more than one crop a year. Therefore the overall value of produce from irrigated agriculture is considerably greater than that from rainfed agriculture.

Large-scale mechanised farming suffers from the disadvantage of high fixed costs due to heavy investment in machinery and, in all the improved systems considered, net farm income per hectare under rainfed conditions is lower on large mechanised farms than it is on smallholdings.

SOCIAL COST-BENEFIT ANALYSIS

A cost-benefit analysis has been undertaken for the Phase 1 and 2 proposals, using the standard ODM procedure which is a simplified version of the Little and Mirrlees method (OECD, 1969). For both phases using Rotation 2, benefits exceed costs and the internal rate of return is greater than 15%. Although the analyses are only indicative, based on a range of assumptions which require further investigation, it is felt that the results are sufficiently encouraging to justify early implementation of the proposals outlined in this report. It is emphasised that all costs relate to the levels prevailing in 1974; because of inflation and the rapid changes in price levels, all economic data should be revised whenever these proposals are reviewed.

TABLE 76 Estimates of fixed costs for each agricultural system ($/ha)

System	Oxen	Farm equipment and machinery	Irrigation			Total
			Capital costs	Operational costs	Maintenance	
1.	13.20	4.00	–	–	–	17.20
2.	19.80	20.40	–	–	–	40.20
3. Phase 1	26.40	27.10	235.60	131.20	89.70	510.00
Phase 2	26.40	27.10	263.70	62.70	74.50	454.20
4.	–	235.30	–	–	–	235.30

Methodology

The social cost-benefit analysis employs the actual costs and returns which are used in financial analysis, but involves the use of discounting techniques and conversion factors to establish the national economic viability of the scheme. Imported goods are valued at border prices and non-traded goods are valued at market prices adjusted by an appropriate conversion factor. The conversion factors are designed to eliminate differences between the level of internal prices and comparable border prices. Such differences may occur as a result of tariffs, import quotas, or overstated wage costs. In the following analyses, tariffs and taxes have not been deducted from specific costs since they mainly constitute a very minor component; thus, for most traded goods, a conversion factor of unity is employed.

Daily wage rates in 1974 for unskilled labour varied between $1.00 and $2.00 per day. While $2.00 is the wage rate used in the financial analyses (i.e. for hired labour and for the derivation of fixed costs), for the purposes of social cost-benefit analysis a shadow wage rate of $1.00 per day has been used; this approximates to the marginal value product of unskilled labour in its next best alternative occupation. The conversion factor for unskilled labour is therefore 0.5. Table 5 in Appendix 13 lists the conversion factors used to modify the annual capital and operating costs.

The annual costs, thus modified by the shadow wage rate, are totalled and 15% is added for contingencies. The net value of production foregone, due to the replacement of existing rainfed agricultural production by irrigated agriculture (see Appendix 12), is added to the total annual costs for each phase to obtain the net social cost of the project.

The value of output has been aggregated by crop in Appendix 10. Since it is unlikely that relatively inexperienced farmers will immediately attain the target yields indicated in Part 5, the assumption has been made that farmers in Phase 1 will obtain 60% of target yields in the first year, only reaching 100% by Year 5 (Table 77). In Phase 2, it has been assumed that the farmers achieve the target yields by Year 4, starting from 70% in Year one.

TABLE 77 Projections of crop yields employed in the social cost-benefit analysis - Rotations 1 and 2 (q/ha)

Percentage of target yield	Maize; long-cycle	Maize; inter cropped	Red peppers	Red peppers inter cropped	Wheat	Groundnuts inter cropped	Haricot beans
60	36.0	24.0	18.0	12.0	15.0	12.0	13.2
70	42.0	28.0	21.0	14.0	17.5	14.0	15.4
80	48.0	32.0	24.0	16.0	20.0	16.0	17.6
90	54.0	36.0	27.0	18.0	22.5	18.0	19.8
100	60.0	40.0	30.0	20.0	25.0	20.0	22.0

Crop price estimates have been based on recent price levels, taking account of anticipated changes in the balance of supply and demand. The prices projected in Table 78 are therefore regarded as rough but conservative estimates of likely future price levels. Although the price adopted for maize in the analysis is high relative to the other products, the level selected was only half the 1974 world price.

TABLE 78 **Border prices (f.o.b.) for selected commodities, and prices used in the cost-benefit analysis ($/q)**

	Maize	Red peppers	Groundnuts	Haricot beans
Average price 1970-2	18.5	91.0	48.0	45.0
Average price 1973-4	n.a.	n.a.	73.5	112.5
Analysis price	15.0	75.0	35.0	50.0
Sources: CSO, 1973; EGB, 1974; Ministry of Finance, 1972				

For both phases, the cost and the benefit streams were discounted at 10% (Planning Commission recommendation) to obtain the social benefit-cost ratio and the net present value. Internal rates of return were also calculated.

Economic assumptions

The proposals for irrigation development fall into two categories (Part 6):

Phase 1: low cost pumping in areas close to sources of water, covering 1 730 ha

Phase 2: developments requiring greater investment and involving higher running costs, covering 3 770 ha

In general, the costs of irrigation increase with total pumping head due to increasing distance from, and height above, the water source.

The economics of Phases 1 and 2 have been assessed independently, in order to identify their respective costs and benefits. However, implementation of Phase 2 is dependent on the satisfactory completion of Phase 1. Although the major capital expenditure on flood protection, embankments and works on the Bulbula River will not be required until Phase 2, it has been assumed that certain items of staffing and of housing will be common to both phases; consequently a high proportion of these costs has been wholly allocated to Phase 1 (Table 82).

For the purposes of the analysis, it has been assumed that all irrigated land is to be worked by farmers each cultivating 1.5 ha. It has been further assumed that, throughout, land is developed at a rate of 300 ha per year. For Phase 1 therefore, the last farmers to join the scheme will be irrigating by Year 6, and will reach full production in Year 10. In Phase 2, irrigation developments would be completed 12 years after initiation, although full production would not be attained until Year 15. Considering the two phases together, 3 665 smallholders and their families could eventually be established on 5 500 ha, attaining full production 21 years after project inception. Although the Phase 2 developments should not take place until Phase 1 has been completed, the net social benefit is related to Year 1 for both phases. As a conservative measure, both phases have been given a project life of only 20 years, and no salvage values have been assumed in either phase.

It has further been assumed that all farmers adopt either Rotation 1 or Rotation 2 (Part 5). Although these rotations are the least profitable of those proposed, the technology involved imposes least strain on farmers new to irrigation. Moreover, if in the analyses the returns from these rotations are shown to outweigh the costs, then it can be assumed that the other rotations proposed would produce even higher net benefits. There is also the point that the more sophisticated rotations include vegetables for which prior trials are required to determine their performance. The cost-benefit analysis takes no account therefore of the possible establishment of a vegetable dehydration plant.

A number of assumptions have been made regarding the costs used in the computations; these are summarised below and elaborated in Appendixes 10 and 11.

Irrigation costs

Development costs for irrigation have been aggregated and average costs per hectare derived for each phase (Tables 79 and 80). In Phase 1, the average cost of clearing and levelling and of irrigation structures amounts to $1 957/ha; and in Phase 2, $3 428/ha. This expenditure constitutes the main project development cost. Costs in Phase 2 exceed those for Phase 1, because development will generally be farther from water. These costs do not include major capital costs.

TABLE 79 Cost-benefit analysis, Phase 1: average capital costs for irrigation construction in different localities ($/ha)

Location and area	Clearing and levelling	Inlet canals	Field canals	Drainage canals	Pumps and pump housing	Pipelines	Irrigation canal structures	Concrete canal linings	Raised earth embankments	Total	Total capital costs per locality ($000s)
Meki Delta Riverside (300 ha)	300	–	440	135	335	5	450	94	100	1 859	557.7
Catar Delta (270 ha)	300	–	440	145	335	5	675	94	–	1 994	538.4
Bulbula East (140 ha)	300	–	425	142	260	260	450	–	–	1 837	257.2
Western Terraces											
(a. 340 ha)	300	58	440	142	260	55	450	–	–	1 705	579.7
(b. 680 ha)	300	58	440	142	260	260	675	–	–	2 135	1 451.8
										Total	3 384.8

Average total capital cost = $1 957/ha. Average maintenance cost (3.0%) = $57.6/ha

TABLE 80 Cost-benefit analysis, Phase 2: average capital costs for irrigation construction in different localities ($/ha)

Location and area	Clearing and levelling	Inlet canals	Field canals	Drainage canals	Pumps and pump housing	Pipelines	Irrigation canal structures	Concrete canal linings	Raised earth embankments	Total	Total capital costs per locality ($000s)
Meki Delta (2 160 ha)	300	58	480	322	330	130	1 345	94	500	3 559	7 687.4
Western Terraces (480 ha)	300	58	450	150	940	833	1 345	94	–	4 170	2 001.6
Bulbula East											
(a. 200 ha)	300	–	450	150	340	690	1 345	94	–	3 369	673.8
(b. 100 ha)	300	–	450	150	340	780	1 345	94	–	3 459	345.9
Catar River (170 ha)	300	–	480	160	595	5	1 345	94	–	2 979	506.4
Western lake margins (660 ha)	100	58	425	425	380	–	900	–	300	2 588	1 708.1
										Total	12 923.2

Average total capital cost = $3 428/ha. Average maintenance cost (2.9%) = $99.2/ha

Capital costs

The major capital costs are summarised in Table 81, and Table 4 of Appendix 13 shows the estimated life and the annual maintenance costs of the capital items. No residual value has been attributed to any unexhausted capital item. The breakdown of the capital costs of the research substations has been set out in Table 71 (Part 6).

TABLE 81 **Cost-benefit analysis: summary of major capital cost items, ($000s). (These costs do not include replacement costs, e.g. for vehicular transport)**

Item	Phase 1	Phase 2
Irrigation construction	3 384.8	12 923.2
Staff housing	210.0	80.0
Workshops	60.0	50.0
Offices and stores	65.0	20.0
Office and workshop equipment	50.0	30.0
Transmission lines	60.0	50.0
Roads	50.0	250.0
Transport, including bicycles	100.0	120.0
Bulbula sluice	–	75.0
Bulbula channel work	1.0	130.0
Meki River dyke	50.0	–
Flood protection, Meki Delta	–	630.0
Research substations	285.0	95.0

Staff and housing

The Zwai Development Division will require a considerable staff to administer and develop irrigation. Detailed staff costs when both phases are fully operational are given in Table 82. It has been assumed that housing will not be needed for the extension agents, water guards, pumpmen, labourers etc, since most will be recruited locally. While housing costs are disbursed early in each phase, staff salaries do not reach a maximum until Year 5 in Phase 1, and Year 7 in Phase 2. The initial ratio of one extension agent to 50 farmers will be modified after Year 7 in Phase 2, so that each agent gradually becomes responsible for increasing numbers of farmers. It will be noted that staff and housing costs are greater in Phase 1 than in Phase 2. This is because, although many of the staff employed on the first phase would, after completion, start work on Phase 2, the cost of these personnel has been wholly charged against Phase 1. Thus, the salaries and housing for personnel initially employed in Phase 1 have been charged exclusively against Phase 1, even though their activities will be extended subsequently to Phase 2 operations. The soil and cadastral surveyors' salaries together with that of the draughtsman are charged against both phases, since they are only employed during the development stages; their housing is however allocated to Phase 1. The costs of mechanics, drivers, extension agents, pump men, water guards and labourers charged against Phase 2 represent additional personnel specifically recruited for Phase 2.

Power

Extension of the distribution grid to Zwai will enable electricity to be used on the project. It has been assumed that the electricity tariff would be 2.5 cents per kWh, which approximates to present costs of production at the Awash hydropower station (Jovanovic, 1972). Allowance has been made for transmission lines to cover all the irrigation areas (Table 81).

Transport

Initial expenditures of $100 000 and $120 000 have been allocated to Phase 1 and 2 respectively (Table 81) for the purchase of appropriate vehicles; these costs will recur every five years. Petrol has been estimated on the basis of $0.75 per litre, each vehicle travelling an average of 2 000 km per month.

TABLE 82 Cost-benefit analysis: staff salaries and housing costs following completion of the development of each phase ($000s)

Staff	Number	Unit annual salary	Unit house cost	Phase 1		Phase 2	
				Total annual salaries	Total housing costs	Total annual salaries	Total housing costs
Project manager	1	12.0	20.0	12.0	20.0	–	–
Asst. project manager	1	9.0	15.0	9.0	15.0	–	–
Engineer	1	9.0	15.0	–	–	9.0	15.0
Research officer	1	9.0	15.0	9.0	15.0	–	–
Research supervisors	4	4.0	10.0	16.0	40.0	–	–
Marketing officer	1	6.0	10.0	6.0	10.0	–	–
Asst. hydrologist	1	3.0	10.0		–	3.0	10.0
Accountant	1	9.0	15.0	9.0	15.0	–	–
Typist	1	3.6	–	3.6	–	–	–
Resettlement officer	1	9.0	15.0	9.0	15.0	–	–
Executive officer	1	9.0	15.0	–	–	9.0	15.0
Technical foremen	2	6.0	10.0	–	–	12.0	20.0
Surveyor	1	6.0	10.0	6.0	10.0	–	–
Asst. surveyors	2	3.0	–	6.0	–	–	–
Soil surveyor	1	6.0	10.0	6.0	10.0	6.0	–
Cadastral surveyor	1	6.0	10.0	6.0	10.0	6.0	–
Draughtsman	1	6.0	10.0	6.0	10.0	6.0	–
Mechanic	1	6.0	10.0	6.0	10.0	–	–
Electrical mechanic	1	6.0	10.0	6.0	10.0	–	–
Asst. mechanics	2	6.0	–	–	–	12.0	–
Drivers	9	3.6		10.8	–	21.6	–
Senior extension agent	1	6.0	10.0	6.0	10.0	–	–
Extension agents	59	3.6	–	82.8	–	129.6	–
Pump men	15	2.4	–	12.0	–	24.0	–
Water guards	15	1.8	–	9.0	–	18.0	–
Labourers	50	0.72	–	10.8	–	25.2	–
Additional housing for drivers and assistant mechanics	–	–	20.0	–	20.0	–	20.0
Totals	175	–	–	247.0	210.0	281.4	80.0

Farm-level costs

It has been assumed that each participating farmer will already own two working oxen. The residual value of two worked-out oxen is estimated to be $100, and the purchase cost of two young working oxen is set at $250. Thus the net capital outlay for oxen replacement is $150 per holding. The working life of an ox is reckoned to be five years. Apart from the purchase of working oxen, it is assumed for the purpose of the analysis that there are no other significant costs of or returns from livestock.

Farm implements include improved ploughs with attachments for ridging and groundnut lifting (estimated unit cost, $80). Handsprayers are priced at $120, with a life of 10 years. Operating costs at the farm level (covering such items as seed, fertiliser, chemicals and bags) have been derived from 1974 unit prices in Addis Ababa, and aggregated according to the appropriate area under each crop. Unit quantities and costs for each crop are listed in Appendix 10, while fixed costs for each farm system are presented in Appendix 11.

Results and conclusions

Full cost and value of production schedules are set out in Appendix 15 (Tables 1 and 2). The net present value, benefit-cost ratio and internal rate of return for each phase are presented in Table 83.

TABLE 83 **Cost-benefit analysis: net present values, benefit-cost ratios, and internal rates of return, for Phases 1 and 2, employing Rotations 1 and 2**

Rotation	Phase 1		Phase 2	
	1	2	1	2
Net present value ($000s)	2 353	4 183	2 359	5 343
Benefit-cost ratio	1.16	1.25	1.10	1.19
Internal rate of return %	17.3	20.4	14.1	18.4

In both phases, all three measures show high positive values, thus indicating that there would be considerable scope for either an upward revision of the cost estimates or a downward revision of revenues before a 'break-even' is reached. To test this assumption a sensitivity analysis was undertaken for Rotation 2, the internal rate of return and the net present value being separately calculated on the basis of costs increasing by up to 20% or revenues decreasing by similar proportions (Table 84). The results indicate that both development phases remain attractive if the costs are increased by 10%, or revenues decreased by 10%. Net present values and internal rates of return decrease seriously however under more adverse economic conditions, returns being more sensitive to decreasing revenues than to increasing costs. This implies that the scheme might be more seriously affected by a fall in commodity prices than by cost inflation. Nevertheless, it should be emphasised that the price and cost levels selected for use throughout this report are themselves on the conservative side.

TABLE 84 **Cost-benefit analysis: net present values and internal rates of return projected on the basis of increased costs or reduced returns for phases 1 and 2 employing Rotation 2**

	Net present value ($000s)				Internal rate of return %			
	Costs increasing by		Revenues decreasing by		Costs increasing by		Revenues decreasing by	
	10%	20%	10%	20%	10%	20%	10%	20%
Phase 1	3 161	1 905	2 090	–15	19.2	16.4	17.1	<10
Phase 2	2 582	–167	1 849	–1 239	16.7	<10	15.6	<10

It is concluded that from the assumptions made, development of irrigation in selected localities within the project area is likely to be economically viable. The analyses moreover provide justification for proceeding at an early date with the necessary additional preliminary investigations proposed elsewhere in this report, in particular the detailed surveys of soils, topography and farm boundaries, and the establishment of multilocational crop trials. Summaries of the annual costs and benefits for Rotation 2 are presented in Tables 85 and 86.

TABLE 85 Cost-benefit analysis, Phase 1: summary of costs and benefits, discounted at 10% ($000s) (See Appendix 15, Tables 1 and 5, for detailed schedules of the costs and benefits)

Year	Annual costs	Annual costs discounted at 10%	Annual benefits	Annual benefits Discounted at 10%
1	1350.7	1227.8	–	–
2	1534.1	1267.2	414.0	342.0
3	1616.0	1213.6	897.0	673.6
4	1865.5	1274.1	1449.0	989.7
5	2662.4	1650.7	2070.0	1283.4
6	2152.0	1213.7	3076.8	1735.3
7	2152.0	1104.0	3405.5	1747.0
8	2198.0	1024.3	3665.3	1708.0
9	2129.0	902.7	3856.1	1635.0
10	2169.5	835.3	3977.9	1531.5
11	2179.6	762.9	3977.9	1392.3
12	2179.6	693.1	3977.9	1265.0
13	2225.6	643.2	3977.9	1149.6
14	2156.6	567.2	3977.9	1046.2
15	2218.3	530.2	3977.9	950.7
16	2152.0	467.0	3977.9	863.2
17	2152.0	423.9	3977.9	783.6
18	2198.0	393.4	3977.9	712.0
19	2129.0	347.0	3977.9	648.4
20	2169.5	321.1	3977.9	588.7
	Total discounted costs	16 862.4	Total discounted benefits	21 045.2
	Net present value ($000s)		4 182.8	
	Benefit-cost ratio		1.25	
	Internal rate of return		20.4%	

TABLE 86 Cost-benefit analysis, Phase 2: Summary of costs and benefits, discounted at 10% ($000s). (See Appendix 15, Tables 2 and 8, for detailed schedules of the costs and benefits)

Year	Annual costs	Annual costs discounted at 10%	Annual benefits	Annual benefits discounted at 10%
1	1749.0	1589.8	–	–
2	1808.4	1493.7	483.0	399.0
3	2069.8	1554.4	1035.0	777.3
4	2346.2	1602.5	1656.0	1131.0
5	2694.6	1673.3	2346.0	1456.9
6	3033.0	1710.6	3036.0	1712.3
7	3391.1	1739.6	3726.0	1911.4
8	3686.7	1721.7	4416.0	2062.3
9	3989.0	1691.3	5106.0	2164.9
10	4305.8	1662.0	5796.0	2237.3
11	4742.2	1659.8	6486.0	2270.1
12	5683.7	1813.1	7176.0	2289.1
13	4493.0	1303.0	8138.9	2360.3
14	4458.5	1172.6	8385.0	2205.3
15	4458.5	1065.6	8561.9	2046.3
16	4545.9	991.0	8669.9	1890.0
17	4610.1	912.8	8669.9	1716.6
18	4493.0	808.7	8669.9	1560.6
19	4458.5	731.2	8669.9	1421.9
20	4458.5	664.3	8669.9	1291.8
	Total discounted costs	27 561.0	Total discounted benefits	32 904.2
	Net present value ($000s)		5 343.2	
	Benefit-cost ratio		1.19	
	Internal rate of return		18.4%	

Part 9

Possible diversion of Lake Zwai water into the Awash Valley

Several studies have been made in recent years to assess the opportunities to expand irrigation in the Awash Valley. These studies have shown that the natural river flows, even after partial regulation at Koka Dam, are insufficient for the maximum irrigation development of all potentially irrigable land in the valley. Consequently, the prospects for obtaining additional water supplies have been the subject of several investigations. Three possible approaches have been put forward:

1. Modification of the downstream release flow from Koka Dam in accordance with irrigation requirements rather than, as at present, operating for maximum energy generation

2. Construction of additional storage capacity on the main stream and tributaries

3. Diversion of additional water from adjacent catchments

Koka Dam was originally designed for storage with a view to power generation, although concurrently providing regulation sufficient to ensure that a greater area in the Awash Valley could be irrigated than would have been possible without the dam. Since the construction of Koka Dam, additional power has been provided for the grid through the commissioning of the Finchaa hydropower station in the Blue Nile Basin; consequently it is no longer necessary for Koka to operate on the basis of maximum power production. Hence there is now the possibility of significantly increasing the area under irrigation in the Awash Valley with little additional capital expenditure, simply by modifying the Koka release flows to suit irrigation requirements. Nevertheless, it has been shown by Meacham (1972) that alone this modification of Koka could not meet the irrigation demand for the entire valley and that additional water would have to be made available. The harnessing of additional supplies was first investigated by FAO (1965). Several sites for storage dams were identified and the diversion of water from the neighbouring Meki River catchment was briefly considered. Further study of this latter possibility was recommended and later taken up by Italconsult who proposed (1970) that, rather than gravity diversion from the Meki, water should be pumped out of Lake Zwai. Although more expensive, this offered two distinct advantages over the Meki diversion scheme: uniform diversion volumes throughout the year; and net production of electricity, since the power required for pumping over the watershed could be more than recouped by power generation at the lower level of Lake Galila (the reservoir behind Koka Dam).

Some consideration of the possibilities for additional storage within the Awash catchment itself is being given by two on-going investigations: The Becho Plain Reclamation Study and the feasibility study of the Lower Awash Valley. The former study, being conducted by the NWRC, is concerned with flood control on the Becho Plain, southwest of Addis Ababa. Preliminary reports (Jovanovic, 1972) suggest the need for the construction of storage reservoirs on the main river and tributaries upstream of Koka Dam. Construction of these reservoirs would, in addition to preventing flooding, contribute to the development of the Awash Valley by enabling flows to be regulated to a greater extent than is possible by operating Koka on its own, and by generating additional electric power.

The second study, which covers the Lower Awash Valley, indicates the probability that, given maximum irrigation development in the upper and middle valleys (due to lack of a sufficiently detailed overall survey, the consultants were unable to obtain precise estimates of the total development potential), there would at some stage need to be further storage and hence regulation of flow to the lower valley (Gibb, 1973). Consequently, a detailed study was made of the possibility of providing storage at the Tendaho dam site originally selected by FAO. Furthermore, since it was clear that any development in the lower valley would depend on developments upstream, the consultants undertook a computer study of the catchment hydrology, so that the result of abstraction at any point along the river and its main tributaries, and the effect of constructing new storage, could be determined. Although an allowance was made in this computer model to incorporate data on the diversion of water from Lake Zwai, significantly this facility has not yet been used. It may be inferred from this that the AVA perhaps no longer considers the diversion of water from Zwai as a feasible alternative to the provision of additional storage within the Awash catchment itself. It should also be noted that an investigation has already been made of storage and irrigation prospects on the Kessem River, a tributary of the Awash.

The only published report since the FAO study covering all aspects of the water resources within the Awash catchment is that by Meacham (1972). However, this was prepared before much work had been undertaken on the two studies discussed above, and hence before the case for Tendaho and the needs of the lower valley had been determined. In drawing up a schedule of water for irrigation requirements, Meacham only considered two possible developments: the modification of Koka releases, and the diversion of water from Lake Zwai. On this basis, he suggested that given a rapid rate of irrigation development of 5 000 ha/year the Koka releases would have to be modified as early as 1975, but not until 1985 if the rate of development were only 2 000 ha/year. Thereafter, as a second source of supply, diversion from Lake Zwai might be initiated as early as 1978, or not until 1995 depending on the rate of development.

Although the rate of irrigation development in the Awash Valley has, under the stimulus of high cotton prices, exceeded 5 000 ha per year, a substantial proportion of recent settlement has been illegal. The total net area under irrigation in December 1974 was assessed at about 63 700 ha. With falling cotton prices and other institutional problems, however, it is considered that the rate of irrigation development is likely to decline. As yet, the Koka Dam release flows have not been officially modified, although some cognisance is taken of irrigation requirements. The optimum operation of Koka must await a formal agreement between the AVA and EELPA since, under the present arrangement, EELPA has full control over Koka.

The first priority for the development of water resources in the Awash Valley should be modification of the Koka release flows. Thereafter, the AVA 1974-89 Master Plan envisages:

1. Commencing in 1980, construction of Tendaho Dam to increase the net irrigable area to 134 000 ha (including full development of the lower plains)

2. Commencing in 1985, construction of storage on the Kessem tributary to irrigate 7 000 ha additional to that possible from run-of-river flows

3, Commencing in 1986, diversion of water from Lake Zwai to irrigate 13 000 ha

In evaluating the proposal to divert water from Lake Zwai to the Awash, Italconsult (1970) estimated that up to 205 mcm of water could be pumped out annually at a minimum capital cost of $23.8 million. This cost estimate, however, merely covers the necessary structures, the pumps and the proposed power station; it does not take into account running costs, nor does it include any of the costs associated with irrigation at the farm level. Assuming that the diverted water were used to irrigate 13 000 ha in the Awash Valley, the investment cost would be equivalent to $1 831/ha. When this cost is depreciated and discounted over a project life of 30 years, it represents an annual capital charge of $194/ha. Although these figures do not allow for the possible generation of electricity on route, they are nonetheless indicative of the level of deduction which would have to be made from the gross value of the benefits to be derived from this additional 13 000 ha of irrigation. Estimates for on-farm investment in irrigation works and structures in the Awash Valley are about $2 700/ha (Gibb, 1973). Thus, the incremental investment costs for the provision and utilisation of irrigation water in the Awash Valley, as a consequence of diverting water from Lake Zwai, would exceed $4 530/ha, equivalent to an annual capital charge of about $480/ha; this excludes project overheads, administration and maintenance. It is considered most unlikely that any cropping system presently used in the Awash Valley could support such high capital costs over and above the normal variable costs of irrigation.

Nevertheless, it is recommended that the cost of the Lake Zwai diversion scheme be revised when the final outcome of the studies on Tendaho Dam and Becho Plain Reclamation is known. Since it appears likely that the economic feasibility of further capital-intensive development projects within the Awash Valley itself will be proved, the relative benefits attributable to the supplementary Lake Zwai diversion scheme are likely to have been overstated. It is concluded that, on present evidence, it is unlikely that the diversion of water from Lake Zwai to the Awash will emerge as a viable scheme either now or in the future.

In this report an alternative use for Lake Zwai water has been considered, i.e. irrigation by pumping onto land in close proximity to the lake. Although the total development envisaged around Zwai at the conclusion of Phase 2 requires only 65 mcm of water annually to irrigate the 5 500 ha (as compared with an irrigation potential in the Awash Valley of 13 000 ha using 205 mcm per year of Lake Zwai water), the use around Zwai of any significant amount of water would necessarily reduce the water available for diversion to the Awash, thereby causing the capital cost per additional hectare irrigated in the Awash Valley to become prohibitively high. Since several farmers have already started irrigating around Zwai and more are likely to follow suit, it is essential that the government should decide at an early date which scheme should go ahead. This report has shown that irrigation around Lake Zwai could be a profitable option, especially if it were linked with investment in a vegetable dehydration plant and nucleus estate but, if in the face of these indications it were decided that Lake Zwai water should be reserved for use in the Awash Valley, it is clear that the current irrigation developments around Lake Zwai should be halted. If however these developments are allowed to proceed and a decision were made in favour of diversion at some later date, less water would be available with the consequence that any financial analysis of a diversion project would be even less favourable than has been indicated above.

Part 10

Conclusions and recommendations

This report contains the findings of a pre-feasibility study of the land and surface water resources of the Lake Zwai area. This investigation evaluated the prospects for irrigation development on up to 750 km^2 around Lake Zwai and a further 25 km^2 in the middle Meki Valley.

HYDROLOGY

In Part 4, analysis of the hydrological characteristics of the Zwai catchment led to the conclusions that:

1. Reliable dry season flow in the Meki River is extremely low, limiting run-of-river irrigation to a maximum of 300 ha. A preliminary investigation of the storage prospects in the upper catchment concluded that, despite a relatively low projected cost of stored water at Dam Site 1 (Table 19), the initial capital investment could well render the scheme uneconomic. Nevertheless, proposals are advanced for a preliminary topographic survey of Dam Site 1 on the Meki River near Bui.

2. The magnitude of possible floods, from which protection would be required on the Meki Delta, is such that flood control works should be designed on the basis of a discharge of 200 m^3/s, assuming that there is no regulation in the upper catchment.

3. The technical feasibility of lowering the lake level is confirmed. The reduced surface area would so decrease evaporation loss as to make available an increased volume of water for abstraction.

4. In view of the critical position of Lake Abiyata as a terminal lake sensitive to any flow variation within the catchment, the Bulbula outflow from Lake Zwai to Lake Abiyata should not be allowed to deviate over the long term from the average naturally-occurring flow. As development proceeds this will necessitate eventual control of the outflow by means of a sluice (Figure 21), associated with deepening of the channel upstream to maintain the necessary flow at lower lake levels. The amount of dredging would depend on the desired level of irrigation abstraction.

5. Given regulation of the outflow, a volume of water exceeding the total irrigation potential around Lake Zwai could be abstracted from the lake without affecting the long-term average flow into Lake Abiyata.

PROPOSED IRRIGATION DEVELOPMENTS

In Part 6, it is shown that irrigation development (limited by topography, soil and/or uneconomic pump lift, rather than by water availability) is not possible in the middle Meki Valley, in Abernosa, or on land to the west and south of Adamitulu; moreover, the irrigation potential along the Catar is seriously restricted by unfavourable topography and inaccessibility. Nor can irrigation be developed to the south and east of Lake Zwai, with the exception of minor areas around the Catar Delta (520 ha in all) and along the Bulbula (510 ha to the east of the river). Consequently, the main areas envisaged for irrigation development are confined to the Meki Delta (2 890 ha); the Western Lake Terraces; land to the west of the Bulbula (1 770 ha); and, after the lake has receded, the Western Lake Margins (770 ha) (see Table 68 and Text Map 8).

Because the source of irrigation on each of these sites lies below the proposed irrigation area, development will be based on pumping. With the imminent construction of a 132 kV transmission line from the Awash hydropower stations to Adamitulu, and thence to Zwai and Meki, it is proposed that the pumps be electrically driven and that inexpensive electricity tariffs be negotiated. Indeed, it is urged that government adopt a policy of cheap power for agricultural purposes, to boost rural development and maximise the use of hydro-electricity. The possibility of generating electricity locally on the Bulbula cannot be recommended due to the seasonal nature of the projected releases from Lake Zwai.

Meki Delta

Development beyond the 300 ha of low-lift pumping from run-of-river flow must await flood control measures based on river and lake level regulation. Control of the Meki River will necessitate construction of a flood release channel and overflow control structures (see Figure 18) and of flood control dykes on the lower delta, and the straightening and dredging of the Meki outlet channel to allow for lower lake levels (total estimated capital cost $680 000). The development of basin irrigation should be based on pumping water from Lake Zwai to the top of raised canals, and running the water inland by gravity to irrigate suitable areas below the 1 640.2 m contour. Water would be fed from the raised primary canal, which would also act as a flood control embankment, to secondary feeder canals via chutes. A complementary system of drains would be essential to control the groundwater level, which it is proposed should be monitored regularly. The suggested system of 0.5 ha basins is illustrated in Figure 23; an idealised production unit of 1.5 ha would comprise three such basins in series. Following detailed topographic survey and prior to embarking on development, initiation of a pilot scheme on up to 100 ha is recommended; in this way, unforeseen problems can be resolved and the irrigation network can be planned on the basis of practical experience.

Western Terraces

Irrigation here would have to be based exclusively on direct pumping and the generally undulating topography may require the use of furrow irrigation. While some farms could be irrigated by small pumps, it should prove more economic for groups of farmers or communal farms to co-operate in sharing larger pumps, or even banks of pumps. Pumps would be sited at the edge of the lowest terrace and would extract lake water from canals excavated inland. On the more level terraces, where difficulties in distribution are anticipated, it will be necessary to undertake especially detailed topographic surveys (at a contour interval of 0.1 m) prior to designing the layout.

Lake Zwai margins

Here development will be more problematic and dependent on the prior lowering and regulation of the lake level. If all the immediate development options were taken up, some 5 500 ha of lake bed and margins could be reclaimed. However, due to unsuitable soil and/or inaccessibility the actual irrigable area is unlikely to exceed 660 ha. It is recommended that reclamation and development be preceded by simple crop trials on a higher-lying site, such trials to include asparagus, fodder grasses and sugar cane.

IRRIGATION DESIGN

In Part 5, consideration was given to the prospects for raising agricultural production by irrigation. Despite high levels of bicarbonate, the water of Lake Zwai and of the rivers flowing into the lake is suitable for irrigation. The altitude of the project area confers a climatic advantage in the production of several crops, including beans, tomatoes, onions and sugar cane. A review of the market prospects and agronomic requirements of these and other crops concluded that development should be based on intensification through both intercropping and double-cropping, using haricot beans, wheat, peppers, onions, and maize intercropped with red peppers or groundnuts. However, due to severe subsoil alkalinity, the land is less than ideal. Nevertheless, following careful analysis of all the relevant physico-chemical factors, it was concluded that the more permeable coarser-textured soils covering 27% of the project area can be regarded as suitable for irrigation. The finer-textured land with alkaline subsoil (30% of the project area) in which the feasibility of continued leaching must be problematical has however been classified as unsuitable for irrigation, pending results from proposed irrigation trials. Poor topography, shallow soil, surface salt and alkali, or urban development render 12% of the project area wholly unsuited to irrigation; and a further 18%, on the Meki Delta, should not be developed until river and lake level regulation has eliminated the risk of flooding. A total of 12 800 ha are regarded as being physically suited to irrigation and a further 5 600 ha could be developed following flood control (irrigation suitability is summarised in Table 38; Part 5).

Implementation will involve major changes in farm boundaries and in the allocation of land, including a significant element of new settlement; such changes will be facilitated by the 1975 land reform measures. Farms will have to be laid out to accord with the technical requirements of irrigation and, early in the design stage, it will be necessary for a team to visit the area from the Ministry of Land Reform to assess the full extent of the problems that will be involved in rationalising farm boundaries, resettling displaced persons and introducing irrigation onto existing holdings with a minimum of social and economic dislocation.

Within each development area a preliminary cadastral survey will be essential to determine holding boundaries. Moreover, the variability of the land is such that all developments will need to be preceded by detailed soil survey, at a scale of not less than 1: 10 000 and sampling regularly at depths down to 2 m. Developments should also be preceded by appropriately detailed topographic surveys in each area, to enable optimum irrigation layouts to be designed and the necessary amount of land preparation to be determined. It is recommended that spot levels be taken on a 25 m grid, from which contours at 0.1 or 0.2 m interval can be interpolated.

Proposals have been based on formalised farms of 1.5 ha, regarded as the smallest economic unit consistent with the production of subsistence requirements and a target annual cash income of not less than $1 000. These farm units are designed to maximise the use of family labour and draught animals, with minimal mechanisation.

Full-scale development should not proceed until the 132 kV transmission line has been constructed as far as Zwai and Meki. The cost-benefit analysis in Part 8 has been based on the use of hydro-electric power; the project economics would be much less favourable if diesel power were substituted. The general lack of experience in irrigation, both on the part of government and a large majority of the farmers themselves, will pose a major constraint in implementation. Hence the emphasis given to the need, early in the scheme, to provide technical guidance through a cadre of sufficiently numerous, well trained extension agents. Multilocational trial plots will provide the necessary agronomic information on which long-term agricultural decisions can be based.

Five basic crop rotations have been proposed for trial. Though intensive, these rotations are largely confined to crops which are already commonly grown in the Zwai area; in this way farmers' experience can be utilised and initial marketing problems avoided. The implications of introducing these rotations, in respect of labour and irrigation requirements, pest and disease control, and cultivation and harvesting, have been considered in some detail in Part 5.

AGRONOMIC INVESTIGATIONS

Because of the lack of definite information regarding crop performance and the need to confirm the viability of the proposed rotations, the Zwai Development Division should acquire land with the aim of establishing several multilocational crop trials. Each trial area should approximate to 10 ha. The first site, which could act as a focal point for all research activities around Zwai, should be acquired at the earliest possible opportunity; it should be located on the western shoreline of Lake Zwai, on representative Class 3 land (Soil H) and close to a year-round source of irrigation water (see Separate Maps 2 and 3). Here would be sited central offices, seed storage facilities, a simple laboratory, and classrooms for training extension personnel. A second trial site should be established on the Western Terraces on Class 5 land (Soil J) with the express purpose of performing long-term field trials to assess the suitability of these soils for irrigation. Other 10 ha trials should be developed on Class 4.2 land on the Meki Delta, where the site could be extended and so serve as a pilot scheme for later developments, and on Class 3 land to the south of Zwai Town (Bulbula West), with the aim of testing new irrigation and land management techniques.

Agronomic investigations in the Zwai area should have the following major objectives:

1. Identification of optimum cropping systems, soil management and irrigation techniques, and pest and disease control measures, priority being given to Rotations 1-3

2. Investigation into the feasibility of introducing new farming systems and crops

3. Testing of ox-drawn equipment, with special emphasis on harvesting

4. Monitoring changes in soil alkalinity and physical structure resulting from irrigation

5. Bulking, grading, storing and distributing to farmers stocks of improved seed

6. Training extension staff in irrigation techniques

Details of the proposed research programme are given in Part 6.

PROCESSING

Opportunities for raising product value by means of local processing have been considered. The production of hardboard or livestock feed from sugar, of wine from grapes, of paste from tomatoes, and the dehydration of vegetables (especially onion, capsicums and carrots) have been reviewed in Part 5. Vegetable dehydration appears especially promising. The design for a nucleus vegetable estate on the Meki Delta is outlined in Part 6 and shown on Text Map 7. Preliminary field trials are essential to identify the optimum varieties and dates of planting, and to project the yields and costs of production. Should these trials prove promising, it is recommended that a feasibility study be undertaken to assess the likely profitability of dehydrated vegetable production. Consideration should be given to establishing a plant on the Meki Delta with a minimum daily processing capacity of 50 tons of fresh produce (estimated capital cost: $2.25 million), with a nucleus estate to ensure continuity of supply.

DEVELOPMENT STRATEGY

Proposed irrigation developments around Lake Zwai (Table 68) have been phased according to priority for development based on costs, as follows:

Phase One

Development within the five years, 1977-81, comprising an extension of existing low-lift pump irrigation. The total area to be irrigated in this phase would be 1 730 ha. For this development the discounted benefit: cost ratio is projected to be of the order of 1.25, with a total capital cost (excluding farm-level investment in equipment, oxen etc.) over five years of $4 419 800 (i.e. $2 556/ha) and a high internal rate of return of about 20%.

Phase Two

Expansion of the irrigated area to 5 500 ha would necessitate prior lake level regulation by constructing a control sluice on the Bulbula (capital cost $75 000), with associated dredging and rock blasting (total estimated capital cost $130 000). In addition, developments on the Meki Delta would necessitate overall expenditure of $630 000 on flood control. Total expenditure of some $835 000 is therefore essential for the implementation of Phase 2. As this work develops, the increasing amounts of water extracted will require the lake to be regulated at lower average levels. The anticipated benefit: cost ratio is about 1.19, with total capital expenditure over 20 years of $14 718 200 (i.e. $3 914/ha) and an internal rate of return on capital of about 18%.

Overall capital costs may therefore work out at around $3 480/ha. More economic data are provided in Appendixes 10-15 and in Part 8 where it is concluded that irrigation developments are likely to be economically viable, provided that the assumptions upon which the projections are based remain valid.

It is proposed that irrigation development should be founded on the following premises:

1. Development to be based on sound commercial principles, with charges for water and other services set accordingly

2. A degree of discipline necessary for the effective operation of an irrigation scheme to be imposed on the participants, including the ultimate sanction of dismissal from the scheme through the enactment (as in Kenya) of Irrigation Rules: these and other provisions to be set out in a legally binding contract

3. Prolonged absenteeism and the fragmentation or amalgamation of holdings to be forbidden

4. Responsibility for pumping stations, canal and drain construction and maintenance, irrigation layouts and overall water control to be vested in the controlling authority

5. Farm extension agents to be decentralised throughout the scheme where they should play a crucial role

While some of the expertise necessary to establish the proposed scheme already exists within Ethiopia, there would be scope for an irrigation agronomist or engineer, recruited on technical assistance, to supervise the initiation of developments.

In the event of a decision being made not to implement irrigation around Lake Zwai, it should be noted that major additional benefits could be derived from the promotion of existing systems of rainfed agriculture, through the provision of necessary inputs (especially credit, seed and fertilisers) and, perhaps above all, by the improved cultivation techniques outlined in Part 5. All this could be achieved for a relatively small investment in farm-level extension backed by simple crop trials. Ideally, since CADU has already assumed responsibility for extension, marketing etc. around the eastern and southern margins of Lake Zwai, it would seem rational for this unit to be encouraged to extend its services to cover the entire Lake Zwai area. If for administrative or other reasons this proves impossible, it is suggested that EPID could establish a separate extension centre based at Meki.

The particularly advantageous features of the irrigation proposals outlines herein can be summarised as follows:

1. Development can proceed gradually as resources (financial and otherwise) become available, as technical expertise increases and as the results of crop trials become apparent

2. The development requirements are relatively straightforward and implementation should be within the capacity of the government

3, There is a relatively low capital requirement. Consequently, it is not envisaged that significant long-term overseas assistance, either financial or technical, will be needed at any stage in development, until it is decided to embark on the development of a dehydrated vegetable plant and associated nucleus estate

4. The main capital sums to be invested need not be committed until a decision has been taken to proceed with Phase 2, i.e. until after experience has been gained in operating Phase 1

5. The benefits will largely accrue to local farmers, and hence to the local economy

6. The project involves a substantial proportion of new settlement. Up to 20 000 people could benefit from the introduction of irrigation, about 11 000 of whom would be settled from outside the area

Part 11

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Appendixes 1 - 15

Appendix 1

Meteorological records

This appendix contains:

1. Monthly and annual rainfall records for selected stations in the Meki River, Catar River and Lake Zwai catchments
2. Other meteorological records for Zwai Town
3. Annual rainfall totals for Addis Ababa
4. Evaporation data for Zwai

1. MONTHLY AND ANNUAL RAINFALL RECORDS (mm)

Station: Adamitulu — Lat. N: 7° 55′ — Elevation: 1 650 m
Catchment: Lake Zwai — Long. E: 38° 45′ — Year: 1914–40, 1956–69

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1914	69.1	46.8	75.8	83.6	43.0	10.2	89.4	96.4	149.2	104.2	0.6	7.6	775.9
1915	1.7	2.4	27.4	57.8	45.7	81.6	104.2	43.0	80.4	11.2	0.6	0.0	456.0
1916	32,2	19.4	42.8	68.4	46.3	104.2	70.0	77.8	118.3	31.6	0.6	9.2	620.8
1917	24.8	26.6	20.6	92.8	175.5	79.2	113.4	176.4	145.2	5.5	0.4	0.0	860.4
1918	0.0	42.9	53.1	123.8	42.0	52.0	105.2	74.0	54.2	0.0	3.3	0.8	551.3
1919	6.4	28.6	72.0	53.4	56.0	20.8	174.6	157.8	13.0	0.0	0.0	0.0	582.6
1920	39.6	13.6	70.8	59.2	19.6	20.0	117.0	28.6	88.8	11.2	0.0	0.0	468.4
1921	3.7	0.0	0.0	1.9	72.6	43.4	139.4	54.3	70.0	11.6	9.4	0.0	406.3
1922	0.0	8.6	52.4	2.8	30.3	57.6	65.0	155.0	88.6	14.8	0.0	0.0	475.1
1923	0.0	42.8	8.2	58.6	89.1	52.0	132.3		46.0	3.6	17.8	0.0	589.9
1924	1.0	20.2	36.5	198.2	15.0	4.6	63.0	124.7	80.4	0.0	0.0	0.0	543.6
1925	0.0	38.3	0.0	4.0	36.8	43.8	80.3	113.7	53.4	13.4	63.2	14.6	461.5
1926	9.2	21.0	51.6	108.6	39.0	80.6	103.8	150.8	106.8	20.6	88.6	0.0	880.6
1927	0.0	45.6	7.6	12.5	27.9	3.6	83.8	130.1	126.5	0.1	4.5	0.0	442.2
1928	13.4	0.0	0.4	127.0	86.3	41.5	129.2	27.6	40.6	21.4	11.1	0.0	498.5
1929	0.2	10.3	2.2	32.8	136.3	53.0	81.0	59.8	145.4	4.8	0.0	23.1	548.9
1930	42.9	48.0	82.0	76.1	31.3	125.1	119.9	87.5	52.5	32.9	0.0	157.1	855.3
1931	24.2	64.6	41.9	29.0	15.9	36.4	177.2	68.0	101.0	39.3	0.0	0.0	597.5
1932	0.0	7.9	52.5	23.7	40.2	62.5	74.8	30.0	75.8	0.6	0.0	19.6	387.6
1933	0.0	1.2	14.9	26.3	21.2	13.3	105.2	125.6	54.8	18.2	2.5	0.0	383.2
1934	0.0	0.0	31.0	44.0	53.0	121.0	121.0	116.0	89.0	2.0	2.0	0.0	579.0
1935	0.0	0.0	1.0	40.0	259.0	122.0	150.0	42.0	42.0	10.0	0.0	36.0	702.0
1936	0.0	70.0	62.0	66.0	44.3	52.0	105.2	91.9	80.4	11.2	0.6	0.0	588.6
1937	–	–	–	–	–	–	87.8	77.3	29.7	1.1	19.7	0.7	–
1938	92.3	0.0	0.0	0.0	84.3	73.0	108.1	86.8	119.9	0.0	0.0	0.0	564.4
1939	0.0	0.0	26.6	87.1	25.0	29.3	108.9	118.1	55.4	0.0	0.0	0.0	450.4
1940	14.4	70.2	173.1	–	–	–	–	–	–	–	–	–	–
Mean	14.4	24.2	38.7	59.1	65.4	55.3	108.1	94.3	81.0	14.2	8.6	10.3	573.6
1956	–	–	–	–	–	–	–	97.7	143.3	83.2	–	–	–
1957	–	–	–	–	–	–	–	–	–	–	–	–	–
1958	0.0	49.7	11.6	33.7	1.8	100.7	187.6	154.1	127.2	41.0	0.7	12.2	720.3
1959	21.1	2.7	22.1	29.0	49.5	31.3	67.4	58.6	103.9	21.0	0.3	0.0	406.9
1960	0.6	0.2	51.9	11.3	117.6	52.9	98.7	97.4	140.6	–	–	–	–
1961	0.0	2.6	92.8	106.2	41.4	75.8	69.0	108.9	167.0	31.5	24.0	0.0	719.2
1962	0.3	0.4	56.7	38.6	17.7	34.1	127.0	84.3	149.9	41.4	31.3	43.0	624.7
1963	0.5	5.0	8.8	26.8	71.2	22.6	180.4	113.8	15.1	0.0	2.6	10.2	527.0
1964	0.6	1.5	13.2	86.4	112.5	70.7	–	–	–	–	–	–	–
1965	–	0.0	30.0	27.9	24.0	22.1	119.3	154.3	74.9	55.8	2.2	0.0	–
1966	0.0	118.3	35.4	147.8	19.1	–	212.2	234.5	108.1	65.3	0.0	0.0	–
1967	0.0	1.1	33.9	68.3	134.2	39.4	98.7	73.0	61.6	99.8	83.0	0.0	693.0
1968	0.0	112.3	11.0	216.1	5.9	45.1	77.5	86.1	100.6	0.6	2.0	0.0	657.2
1969	27.7	197.4	61.1	64.6	41.9	43.5	150.4	58.1	–	5.4	4.2	0.0	–
Mean	4.7	40.9	35.7	77.2	53.1	48.9	126.2	110.9	108.4	40.5	16.0	6.5	668.4

Sources: 1914–40, Fantoli (1966). 1956–69, CAA

Station: Asella (Mission)
Catchment: Catar River

Lat. N: 7° 55′
Long. E: 39° 05′

Elevation: 2 370 m
Years: 1954–62
1966–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1954	–	–	–	–	–	–	214.1	285.0	268.5	55.0	–	–	–
1955	–	–	–	–	–	–	–	–	189.9	–	–	–	–
1956	–	–	–	–	–	–	–	–	–	–	–	16.1	–
1957	–	–	–	–	–	–	–	–	–	–	–	–	–
1958	–	–	56.4	60.4	71.0	223.5	–	550.7	211.6	91.0	49.2	21.2	–
1959	81.6	–	105.1	53.0	50.5	–	–	–	–	–	–	25.0	–
1960	1.0	20.7	156.0	21.8	224.0	90.4	182.5	263.1	–	–	–	–	–
1961	–	–	–	–	–	155.2	157.5	401.0	235.0	123.5	–	–	–
1962	0.0	3.0	62.0	38.5	31.0	72.5	–	–	–	–	–	–	–
Mean	27.5	11.8	94.9	43.4	94.1	135.4	184.7	374.9	226.2	89.8	49.2	20.8	1 352.7
1966	28.0	191.0	86.0	186.0	27.0	146.0	232.0	222.0	139.0	82.0	2.0	0.0	1 341 0
1967	3.0	0.0	90.0	71.0	180.0	112.0	366.0	282.0	211.0	191.0	100.0	0.0	1 606.0
1968	10.0	125.5	50.0	278.5	101.0	199.0	213.0	267.5	267.5	20.0	15.0	17.0	1 564.0
1969	46.0	131.0	134.0	74.0	84.0	149.0	248.5	247.0	182.0	39.0	14.0	5.0	1 353.5
1970	112.0	35.0	275.0	72.0	77.0	92.0	285.0	225.5	167.0	65.0	0.0	0.0	1 425.5
1971	29.0	2.0	98.0	153.0	185.0	164.0	191.0	200.0	171.0	38.5	25.5	27.0	1 284.0
1972	23.0	43.0	88.5	256.0	75.5	134.0	160.5	341.0	117.0	2.0	6.5	9.0	1 256.0
1973	2.0	0.0	1.0	40.5	194.5	177.3	155.2	168.5	135.0	53.0	0.0	0.0	927.0
Mean	31.6	65.9	102.8	141.4	115.5	146.7	231.4	183.8	176.2	61.3	20.4	7.2	1 284.2

Source: CAA

Station: Bokoji
Catchment: Catar River

Lat. N: 7° 35′
Long. E: 39° 20′

Elevation: 2 720 m
Years: 1963–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1963	–	–	–	–	–	–	283.3	291.3	–	–	–	–	–
1964	–	–	–	50.0	108.8	74.6	–	–	–	–	–	–	–
1965	–	–	–	84.8	1.8	39.4	156.5	228.4	76.7	126.5	3.2	0.0	–
1966	10.3	116.7	21.6	119.4	52.8	–	–	198.1	73.0	88.7	12.8	–	–
1967	0.0	3.8	65.1	–	–	–	–	–	–	2.5	114.5	1.0	–
1968	2.5	171.4	164.7	265.0	115.0	84.3	92.4	113.8	89.7	0.0	2.9	6.4	1 108.1
1969	98.8	52.4	87.6	65.5	44.2	99.5	165.6	200.8	72.5	18.5	10.6	0.7	916.7
1970	109.1	140.7	174.1	138.4	48.4	78.3	188.7	131.5	103.7	69.0	2.5	3.5	1 187.9
1971	18.4	0.0	31.5	90.6	82.7	158.5	164.4	249.2	59.3	89.4	22.3	12.7	979.0
1972	18.3	204.9	80.8	225.2	69.8	109.2	239.1	135.0	64.9	9.4	13.6	16.0	1 186.2
1973	0.0	0.9	0.0	114.3	90.7	83.3	221.3	209.0	81.3	123.2	1.5	29.7	955.2
Mean	32.2	86.4	78.2	128.2	68.2	90.9	188.9	195.2	77.6	58.6	23.8	8.8	1 037.0

Sources: 1963–7, CAA, 1968–73, AVA

Station: Butajira | Lat. N: 8° 10′ | Elevation: 2 100 m
Catchment: Meki River | Long. E: 38° 20′ | Years: 1956–60 1972–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1955	120.1	3.0	90.0	52.3	164.0	345.0	116.0	–	51.0	0.5	0.0	0.0	–
1956	0.0	0.0	27.0	198.0	17.0	241.0	52.0	–	–	–	–	–	–
1957	0.0	12.5	284.5	242.0	184.0	161.0	29.0	–	–	–	–	–	–
1958	0.0	57.0	115.0	0.0	16.0	341.0	125.0	–	–	–	–	–	–
1959	–	–	–	–	–	–	–	–	–	–	–	–	–
1960	–	–	111.0	–	72.0	–	183.0	152.0	–	–	–	–	–
Mean	30.0	17.6	125.5	125.1	90.6	272.0	101.0	152.0	51.0	0.5	0.0	0.0	965.3
1972	–	217.6	103.4	157.3	90.8	135.2	109.7	217.7	81.9	1.4	0.0	0.0	–
1973	0.0	0.2	0.0	27.0	90.2	123.2	144.9	122.3	78.1	75.2	0.0	40.9	702.0
Mean	0.0	108.9	51.7	92.2	90.5	129.2	127.3	170.0	88.0	38.3	0.0	20.5	916.6

Sources: 1955–60, CAA.1972–3, NWRC

Station: Egerssa | Lat. N: 8° 15′ | Elevation: 1 800 m
Catchment: Meki River | Long. E: 38° 45′ | Years: 1967–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1967	–	–	–	–	–	–	–	–	–	49.6	105.6	0.0	–
1968	0.0	169.3	48.1	151.8	28.0	80.1	156.8	176.4	87.7	1.0	2.0	3.0	904.2
1969	35.3	59.3	79.5	52.0	22.2	110.8	227.5	117.0	73.8	0.0	0.0	0.0	777.4
1970	84.0	16.4	136.4	28.0	50.1	29.6	256.0	155.8	168.6	0.0	0.0	0.0	924.9
1971	0.0	0.0	34.0	43.0	137.4	134.0	199.9	215.8	132.2	0.0	12.0	28.7	937.0
1972	4.0	137.0	70.4	129.4	83.1	71.1	175.3	178.0	58.0	0.0	0.0	0.0	906.3
1973	0.0	0.0	0.0	10.1	86.7	68.8	172.3	166.9	156.2	–	–	–	–
Mean	20.6	63.7	61.4	69.1	67.9	82.4	198.0	168.3	112.8	8.4	19.9	5.3	877.5

Source: AVA

Station: Kersa (Police Station) | Lat. 7° 35′ | Elevation: 2 680 m
Catchment: Catar River | Long. E: 38° 55′ | Years: 1967–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	2.0	120.2	51.0	186.8	163.5	95.0	49.7	80.0	66.0	43.0	14.0	11.0	282.2
1969	65.0	97.0	129.0	41.0	49.0	41.0	115.0	149.0	102.0	10.0	3.0	0.0	801.0
1970	39.0	33.0	170.0	76.0	48.0	66.0	108.0	85.0	99.0	37.0	0.0	0.0	761.0
1971	3.0	2.0	24.0	87.0	87.0	56.0	37.0	79.0	101.0	85.2	107.0	23.0	691.2
1972	22.0	113.0	35.9	191.0	41.0	45.1	71.0	64.0	72.1	37.3	2.0	0.0	694.1
Mean	26.8	54.2	48.3	113.0	100.2	73.5	94.6	101.0	97.7	51.0	18.1	4.9	783.3

Source: AVA (This station is poorly run and the recorded rainfall is probably underestimated)

Station: Lemu (Mission) Lat. 7° 40′ Elevation: 2 520 m
Catchment: Catar River Long. E: 39° 15′ Years: 1956–61, 1965–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1956	–	–	30.0	225.5	53.0	120.5	221.0	273.5	295.5	231.5	12.0	9.5	–
1957	19.5	28.0	238.0	257.2	–	–	–	–	–	–	–	–	–
1958	–	–	–	–	–	–	–	–	–	–	–	–	–
1959	77.0	132.9	108.3	93.9	130.0	88.0	181.2	113.2	181.9	101.1	19.8	6.7	1 233.8
1960	32.4	26.0	233.6	80.7	159.7	125.1	167.0	145.8	154.7	2.4	13.5	70.2	1 211.1
1961	1.0	32.7	136.7	312.7	114.7	107.9	155.2	230.2	163.7	–	–	–	–
Mean	32.5	54.9	149.3	194.0	114.4	125.4	181.1	190.6	199.0	111.7	15.1	28.8	1 396.8
1965	–	–	–	–	–	–	–	–	–	–	–	0.0	–
1966	25.0	140.5	51.5	142.8	53.5	156.2	246.5	354.5	151.3	76.0	0.0	0.0	1 397.8
1967	9.5	7.0	57.5	121.5	212.8	117.0	240.8	294.8	214.6	74.1	217.1	0.0	1 566.7
1968	0.0	191.8	46.0	306.5	110.5	–	258.5	265.0	118.8	–	6.5	49.2	–
1969	113.0	112.8	157.0	133.5	133.0	161.5	388.5	251.3	159.8	39.5	0.0	0.0	1 649.9
1970	115.0	74.0	141.5	106.0	97.0	62.5	264.5	206.0	185.0	92.5	0.0	0.0	1 344.0
1971	14.5	0.0	57.5	71.0	204.0	300.6	65.0	–	116.0	49.0	36.0	45.5	–
1972	26.0	89.0	68.0	172.0	58.5	–	320.0	–	59.5	0.0	18.5	0.0	–
1973	0.0	0.0	0.0	0.0	151.5	187.5	406.5	378.0	135.0	83.5	0.0	0.0	1 342.0
Mean	37.9	76.9	72.4	131.7	127.6	164.2	273.8	291.6	142.5	59.2	34.8	10.5	1 423.3

Source: CAA (1965–9 record erroneously published as rainfall at Bokoji Mission).

Station: Meki Lat. N: 8° 10′ Elevation: 1 680 m
Catchment: Lake Zwai Long. E: 38° 54′ Years: 1965–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1965	–	–	–	–	–	–	–	–	151.2	70.3	45.1	4.5	–
1966	12.7	108.5	23.7	44.0	35.2	63.4	156.6	268.2	135.2	36.1	0.0	0.0	883.6
1967	0.0	1.2	62.5	46.3	59.4	82.8	244.1	80.2	95.2	68.2	117.3	0.0	857.2
1968	0.0	50.1	27.2	147.1	8.6	86.8	122.6	138.7	118.3	3.2	1.6	0.0	704.2
1969	9.5	84.6	55.0	30.8	22.9	35.1	153.6	113.9	79.9	0.0	3.8	0.0	589.1
1970	112.5	30.4	50.2	4.9	59.4	20.2	104.9	159.5	128.8	15.7	0.0	0.0	694.3
1971	0.4	0.0	21.8	17.4	62.8	117.1	113.3	195.6	119.8	0.0	11.3	7.0	666.5
1972	30.8	30.7	42.3	167.3	37.4	112.6	115.2	167.6	60.0	0.0	0.0	0.0	763.9
1973	0.0	0.0	0.0	1.6	111.3	77.2	167.2	161.6	223.9	85.9	0.1	0.0	828.8
1974	0.0	18.7	150.8	2.7	139.3	74.0	195.8	154.9	187.5	25.7	0.0	0.0	949.4
Mean	18.4	36.0	48.2	51.3	59.6	74.3	152.6	160.0	130.0	30.5	17.9	1.1	779.9

Source: AVA

Station: Ogelcho Lat. N: 8° 10′ Elevation: 1 700 m
Catchment: Lake Zwai Long. E: 39° 00′ Years: 1967–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1967	–	–	–	–	–	–	–	–	132.3	59.2	73.0	0.0	–
1968	0.0	75.0	10.0	190.5	23.8	105.1	145.1	112.0	100.0	0.0	0.5	0.0	762.0
1969	3.0	172.0	95.5	64.0	40.0	94.0	174.0	76.0	91.5	11.0	0.0	14.5	835.5
1970	68.1	3.8	88.1	2.1	36.2	8.3	127.8	88.4	110.6	4.2	0.0	0.0	537.6
1971	0.0	2.5	42.2	27.8	35.2	87.9	94.1	104.0	20.3	0.0	5.4	26.0	445.4
1972	0.0	25.8	25.2	194.6	27.2	60.3	71.9	115.9	73.9	17.0	0.0	0.0	611.8
1973	0.0	1.0	0.0	30.9	72.9	74.2	176.6	208.5	95.9	133.6	0.0	0.0	739.6
1974	8.5	31.7	102.9	0.8	38.9	106.6	171.7	95.9	97.7	5.8	0.0	0.0	660.5
Mean	11.0	44.5	52.0	73.0	39.2	76.6	137.3	114.4	90.3	28.8	9.9	5.1	682.1

Source: AVA (Abura)

Station: Sagure
Catchment: Catar River

Lat. N: 7° 45′
Long. E: 39° 10′

Elevation: 2 460 m
Years: 1967–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1967	–	–	–	–	–	–	–	45.0	151.6	54.5	77.6	1.4	–
1968	0.0	117.7	17.3	157.7	39.8	178.0	263.9	201.1	142.0	6.1	103.8	24.8	1 252.2
1969	49.9	43.3	113.3	48.2	58.5	192.9	179.7	114.8	102.4	25.3	7.2	2.3	936.8
1970	58.5	74.6	130.8	11.9	74.3	143.5	382.3	137.4	147.4	21.0	0.0	0.0	1 181.7
1971	0.5	0.2	62.7	83.1	93.7	167.3	112.9	76.9	51.5	17.9	11.6	10.9	689.2
1972	1.7	32.1	51.2	81.6	53.0	184.6	111.8	112.0	71.6	14.7	3.2	2.5	720.0
1973	2.4	0.0	1.3	77.0	192.8	92.7	236.3	169.4	103.4	49.7	–	–	–
Mean	18.8	44.7	62.8	76.6	85.4	160.0	214.5	122.4	110.0	27.0	33.9	7.0	973.1

Sources 1967–72, AVA.1973, NWRC

Station: Silte (Mission)
Catchment: Meki River

Lat. N: 8° 00′
Long. E: 38° 20′

Elevation: 2 100 m
Years: 1953–64
1973

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1953	–	–	–	–	–	–	131.8	125.4	140.5	0.0	29.0	15.5	–
1954	–	–	–	14.1	39.0	126.2	92.2	198.3	186.4	39.6	0.0	–	–
1955	–	–	1.0	75.4	35.2	108.1	136.8	148.3	223.8	36.1	0.0	5.0	–
1956	60.1	13.1	24.2	281.9	30.2	138.6	153.6	173.1	209.9	158.7	0.0	34.0	1 276.5
1957	2.4	83.1	317.1	104.4	147.4	84.3	100.0	135.8	109.0	13.6	7.9	0.0	1 105.0
1958	196.7	131.6	42.5	59.4	17.5	106.1	242.1	183.0	154.5	37.6	0.0	6.0	1 177.0
1959	41.4	64.5	208.4	55.7	64.2	64.3	139.2	108.2	127.5	67.5	26.0	74.2	1 041.1
1960	0.0	13.6	219.5	42.0	234.0	80.3	129.3	147.5	200.3	0.0	0.0	51.5	1 118.0
1961	–	2.7	5.5	154.8	93.5	89.8	157.5	156.5	170.7	51.8	67.0	0.0	–
1962	0.0	3.5	142.7	–	52.1	86.6	169.0	151.3	86.4	30.0	16.5	34.5	–
1963	8.5	32.5	4.0	305.3	199.0	66.6	181.5	106.3	114.7	0.0	0.4	58.5	1 077.3
1964	13.5	0.0	27.3	–	135.5	–	151.0	47.5	–	–	–	–	–
Mean	40.3	38.3	99.2	121.4	95.2	95.1	148.7	140.1	156.7	39.5	13.3	27.9	1 015.7
1973	–	0.3	0.0	18.0	66.5	107.0	216.0	212.1	215.4	0.0	0.0	–	–

Sources: 1953–64, CAA 1973, NWRC

Station: Zwai Town
Catchment: Lake Zwai

Lat. N: 8° 00′
Long. E: 38° 45′

Elevation: 1 640 m
Years: 1968–73

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	–	–	–	–	–	–	6.6	89.2	99.6	2.0	1.6	1.6	–
1969	46.2	63.0	85.6	24.4	25.4	50.4	156.8	55.2	99.2	5.8	–	–	–
1970	66.5	–	70.2	43.7	–	–	–	–	93.7	–	0.0	0.0	–
1971	6.8	1.0	30.4	100.8	73.4	143.6	116.2	114.4	29.6	0.0	3.4	1.6	621.2
1972	0.0	22.4	3.2	85.8	18.2	2.4	113.2	134.2	66.2	30.6	0.2	0.0	479.2
1973	0.0	0.0	0.0	5.4	131.2	85.9	158.9	121.2	121.7	31.8	0.0	0.0	656.1
1974	3.6	5.5	152.4	1.2	67.6	62.6	114.2	217.9	214.2	0.0	0.0	0.0	838.2
Mean	20.5	18.4	57.0	43.5	63.2	69.0	111.0	122.0	103.5	11.7	0.9	50.5	621.2

Source: AVA

2. MONTHLY METEOROLOGICAL RECORDS FOR ZWAI TOWN

(a) Mean maximum temperature (^{o}C)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1968	–	–	–	–	–	–	–	24.2	26.3	26.1	25.6	26.1
1969	26.2	24.8	25.8	26.8	28.8	27.5	25.0	25.6	26.4	27.6	26.9	–
1970	–	27.3	26.4	27.4	–	32.3	31.2	26.2	25.4	26.9	25.6	27.6
1971	25.4	27.8	28.5	28.5	27.7	25.5	24.1	23.9	24.8	26.7	25.6	–
1972	–	–	27.9	26.5	28.2	28.0	25.7	25.5	26.9	27.0	27.1	27.2
1973	27.5	29.1	30.8	31.4	29.1	28.1	24.4	24.8	26.1	26.5	27.1	25.2
1974	26.8	27.9	26.7	28.9	27.4	27.8	24.8	25.8	25.1	26.5	25.6	25.5
Mean	26.5	27.4	27.7	27.9	28.2	28.1	25.9	25.1	25.9	26.8	26.2	26.3

(b) Mean minimum temperature (^{o}C)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1968	–	–	–	–	–	–	–	14.8	13.1	11.2	11.0	10.0
1969	13.2	13.6	14.8	14.4	14.1	14.5	–	–	–	–	–	–
1970	–	15.1	14.8	15.3	–	15.4	15.1	14.5	9.8	9.4	10.8	10.6
1971	8.6	9.4	6.8	6.2	5.8	5.7	–	12.3	12.7	12.6	12.9	–
1972	–	–	6.3	9.2	8.8	10.0	11.4	11.7	10.8	11.6	11.7	9.8
1973	11.8	11.5	13.5	12.9	14.1	14.0	13.5	13.5	13.2	10.8	11.5	8.8
1974	10.9	11.6	13.6	11.8	13.6	13.2	12.6	13.8	12.5	10.3	9.4	9.5
Mean	11.1	12.2	11.6	11.6	11.3	12.1	13.2	13.4	12.0	11.0	11.2	9.7

(c) Mean temperature (^{o}C)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1968	–	–	–	–	–	–	–	19.5	19.7	18.6	18.2	18.0
1969	19.7	19.1	20.3	20.6	21.4	20.8	–	–	–	–	–	–
1970	–	21.2	20.6	21.4	–	23.8	23.1	20.3	17.6	18.1	18.2	19.1
1971	17.0	18.6	17.6	17.3	16.7	15.6	–	18.1	18.8	19.7	19.2	–
1972	–	–	17.1	17.8	18.5	19.0	18.5	18.6	18.8	19.3	19.4	18.5
1973	19.6	20.3	22.1	22.1	21.6	21.0	18.9	19.1	19.6	18.6	19.3	17.0
1974	18.9	19.7	20.1	20.3	20.5	20.1	18.7	19.8	18.8	18.4	17.5	17.5
Mean	18.8	19.8	19.6	19.9	19.7	20.0	19.8	19.1	18.9	18.8	18.6	18.0

(d) Mean relative humidity (%)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1968	–	–	–	–	–	–	–	–	82	73	69	63
1969	61	71	75	77	69	67	72	70	70	55	–	–
1970	–	55	55	55	–	61	69	78	80	65	64	44
1971	74	58	63	63	76	–	83	80	–	–	72	–
1972	56	65	55	62	62	63	70	75	76	75	70	73
Mean	63.6	62.2	62.0	64.2	69.0	63.6	73.5	75.7	77.0	67.0	68.7	60.0

(e) Mean wind speed (m/s) at 1 m above ground level

Year	J	F	M	A	M	J	J	A	S	O	N	D
1968	–	–	–	–	–	–	–	1.05	0.83	1.08	1.41	1.24
1969	1.25	1.25	0.95	0.82	0.92	1.51	1.25	0.86	0.73	1.09	–	–
1970	–	0.72	1.15	0.72	–	1.72	0.37	1.20	0.66	0.76	1.92	0.86
1971	2.16	1.24	1.18	1.05	0.75	–	–	–	–	–	1.18	–
1972	1.56	1.41	1.25	1.02	1.16	1.54	1.56	1.12	0.94	1.59	1.70	1.82
1974	1.70	1.80	1.50	1.40	1.60	1.60	1.60	1.60	1.10	1.20	1.68	1.83
Mean	1.67	1.28	1.21	1.00	1.11	1.59	1.20	1.17	0.85	1.14	1.58	1.44

(f) Class 'A' pan evaporation (mm)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1969	–	–	–	–	235.6	180.0	136.4	136.4	159.0	195.3	–	–
1970	–	166.0	174.2	186.7	–	–	–	–	–	–	–	–
1971	–	–	–	–	–	–	190.2	110.4	157.6	174.0	118.9	–
1972	–	–	–	–	130.9	102.9	121.3	175.5	124.5	178.1	175.6	165.8
1974	192.4	189.8	169.3	198.0	134.8	168.3	167.7	132.7	144.1	175.1	193.7	228.1

Sources: Italconsult (1970). AVA (1972a). AVA (1972b). AVA (1973). 1973 data taken direct from observers records. 1974 data direct from AVA.

3. ANNUAL RAINFALL TOTALS (mm) AT ADDIS ARABA, 1900–73

Year	Rain	Year	Rain	Year	Rain	Year	Rain	Year	Rain	Year	Rain	Year	Rain	Year	Rain
1900	1 164.7	1910	1 268.8	1920	1 076.3	1930	1 460.7	1940	936.7	1950	957.6	1960	1 043.0	1970	1 421.6
1901	1 241.0	1911	1 075.8	1921	1 039.0	1931	1 021.7	1941	–	1951	936.7	1961	1 365.4	1971	1 181.3
1902	984.9	1912	1 161.4	1922	1 060.5	1932	975.0	1942	–	1952	1 095.2	1962	906.8	1972	941.0
1903	1 432.6	1913	1 175.4	1923	1 321.3	1933	–	1943	–	1953	918.2	1963	1 017.5	1973	1 269.0
1904	1 106.9	1914	1 438.9	1924	1 905.0	1934	1 027.0	1944	–	1954	1 188.2	1964	1 233.8		
1905	1 104.9	1915	1 900.0	1925	1 476.5	1935	1 283.0	1945	–	1955	1 288.9	1965	965.1		
1906	1 543.4	1916	1 729.9	1926	1 754.8	1936	1 419.0	1946	1 362.5	1956	1.022.8	1966	1 201.6		
1907	1 047.5	1917	1 590.8	1927	1 271.0	1937	1 134.4	1947	1 936.7	1957	1 345.9	1967	1 225.6		
1908	1 132.0	1918	959.9	1928	1 342.5	1938	1 053.4	1948	1 612.2	1958	1 270.1	1968	1 208.6		
1909	1 263.5	1919	991.7	1929	1 244.1	1939	1 133.3	1949	1 351.3	1959	1 037.3	1969	1 308.2		

Sources: 1900–40, Fantoli (1966). 1946–73, CAA

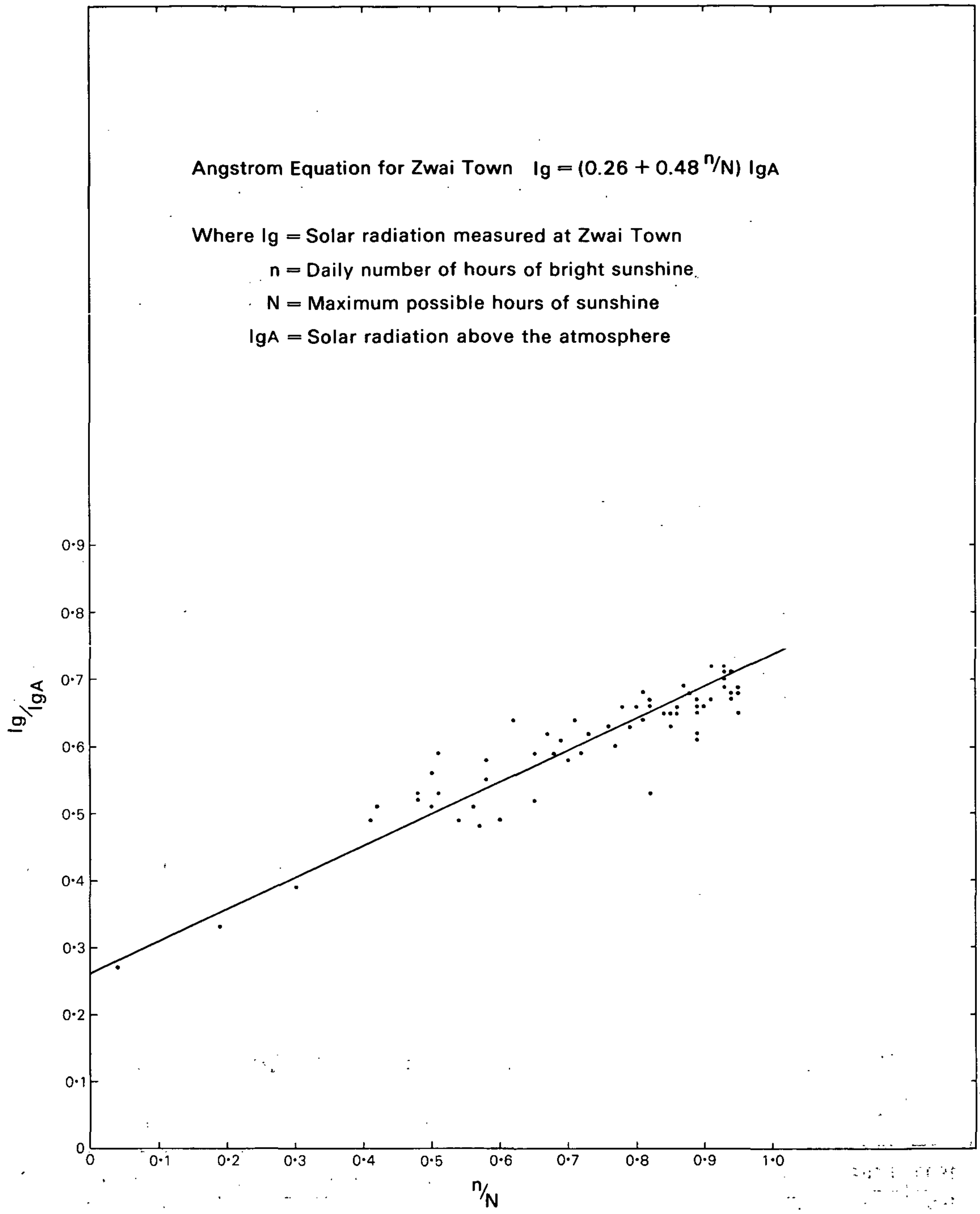

FIGURE 24 Relationship between daily solar radiation and hours of bright sunshine at Zwai Town

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4. EVAPORATION DATA FOR ZWAI

Between February and May 1974, a bimetallic actinograph (with daily charts) was installed at the Zwai meteorological station and during this period readings were made of both short wave radiation and daily hours of bright sunshine. The actinograph was subsequently removed, though records of sunshine will continue to be kept using the Campbell-Stokes instrument intalled by this project. The concurrent records of sunshine and radiation are plotted on Figure 24 as proportions of the maximum possible sunshine and radiation. From the regression line, values for the constants in the Angstrom equation were determined, and hence the relationship between sunshine hours and radiation (the Angstrom equation) at Zwai is $Ig = (0.26 + 0.48 \frac{n}{N})\, Ig\,A$.

where Ig is the solar radiation measured at Zwai

IgA is the solar radiation above the atmosphere

n is the daily number of hours of bright sunshine

N is the maximum possible hours of sunshine

The above relationship enables radiation estimates (Ig) to be determined from records of sunshine (n). Table 1 gives 10-day average values of N and IgA for Zwai.

TABLE 1 Ten-day values of maximum possible hours of daily sunshine (N) and of solar radiation above the atmosphere (IgA) at Zwai (latitude 8°N)

Month	Ten-day period	N	IgA	
			cal/cm^2/day	mm water/day
January	1	11.7	764	12.73
	2	11.7	776	12.93
	3	11.8	794	13.23
February	1	11.8	815	13.58
	2	11.9	836	13.93
	3	11.9	853	14.22
March	1	12.0	868	14.47
	2	12.1	880	14.67
	3	12.2	889	14.82
April	1	12.2	892	14.87
	2	12.2	892	14.87
	3	12.3	888	14.80
May	1	12.4	881	14.68
	2	12.5	874	14.57
	3	12.5	868	14.47
June	1	12.6	862	14.37
	2	12.6	858	14.30
	3	12.6	857	14.28
July	1	12.6	859	14.32
	2	12.6	863	14.38
	3	12.5	867	14.45
August	1	12.4	872	14.53
	2	12.4	877	14.62
	3	12.3	880	14.67
September	1	12.3	880	14.67
	2	12.2	877	14.62
	3	12.1	871	14.52
October	1	12.0	860	14.33
	2	11.9	846	14.10
	3	11.9	830	13.83
November	1	11.9	810	13.50
	2	11.8	790	13.17
	3	11.7	775	12.92
December	1	11.7	763	12.72
	2	11.6	756	12.60
	3	11.6	757	12.62

It is recommended that, in future, regular estimates of open water evaporation be made using Penman's Method. In addition to sunshine data, records of air temperature, relative humidity and wind speed are required in the form of mean values for the period under consideration. This period should be at most a month and preferably only 10 days. To provide adequate data, it will be necessary to modify the existing station at Zwai so that wind speed is measured at 2 m above ground level, and the wet and dry bulb thermometers should be renewed. Furthermore, humidity measurements should be taken at selected hours during the day, such that the average of all daily values approximates to the actual daily mean humidity determined from readings on a thermohygrograph.

The Penman formula for evaporation is:

$$E_o = \frac{\Delta/\gamma \; R + Ae}{\Delta/\gamma \; + 1} \qquad -(1)$$

where E_o is the energy used in evaporation (potential or open water evaporation)

Δ/γ is the slope of the saturated vapour pressure-temperature curve divided by the psychrometric constant

R is net radiation

Ae is the aerodynamic energy available for evaporation

In practical terms, the constituent parts of the formula may be written as:

1. $R = 0.95\ Ig - IgB \qquad -(2)$

   where Ig is determined from the Angstrom equation as presented above and given in Table 2.

IgB is the back (long-wave) radiation and is estimated from the following equation:

$$IgB = \sigma T^4 \,(0.56 - 0.092 \sqrt{e})\,(0.10 + 0.90\ ^n/N) \qquad -(3)$$

where e is the vapour pressure of the air in millimeters of mercury calculated by multiplying the relative humidity by the saturated vapour pressure of the are (e_s): Values of e_s in terms of air temperature are given in Table 3. Values of the expressions $(0.56 - 0.092\ \sqrt{e})$ and $(0.10 + 0.90\ ^n/N)$ are given in Tables 4 and 5 respectively.

σT^4 is the energy that would be radiated from the earth in the absence of an atmosphere; values for σT^4 are given in Table 6.

2. $Ae = 0.35\ \dfrac{(0.5 + 5u)\ (e_s - e)}{800} \qquad -(4)$

where u is the wind speed in km/day

3. Values for Δ/γ are given in Table 7.

Provided regular records are compiled of the four input variables, air temperature, relative humidity, wind speed and sunshine, estimates of open water evaporation can readily be computed using Tables 1 to 7.

TABLE 2 Values of Ig/IgA (Angstrom equation) for Zwai, in terms of the proportion of actual to possible hours of bright sunshine ($^n/N$)

$^n/N$	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.10	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.35
0.20	0.36	0.36	0.37	0.37	0.38	0.38	0.38	0.39	0.39	0.40
0.30	0.40	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.44	0.45
0.40	0.45	0.46	0.46	0.47	0.47	0.48	0.48	0.49	0.49	0.50
0.50	0.50	0.51	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.54
0.60	0.55	0.55	0.56	0.56	0.57	0.57	0.58	0.58	0.59	0.59
0.70	0.60	0.60	0.61	0.61	0.62	0.62	0.62	0.63	0.63	0.64
0.80	0.64	0.65	0.65	0.66	0.66	0.67	0.67	0.68	0.68	0.69
0.90	0.69	0.70	0.70	0.71	0.71	0.72	0.72	0.73	0.73	0.74

TABLE 3 Values of the saturated vapour pressure (e_s) in mm of mercury, expressed in terms of air temperature

Air temp. ^oC	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
16	13.63	13.71	13.80	13.90	13.99	14.08	14.17	14.26	14.35	14.44
17	14.53	14.62	14.71	14.80	14.90	14.99	15.09	15.17	15.27	15.38
18	15.46	15.56	15.66	15.76	15.96	15.96	16.06	16.16	16.26	16.36
19	16.46	16.57	16.68	16.79	16.90	17.00	17.10	17.21	17.32	17.43
20	17.53	17.64	17.75	17.86	17.97	18.08	18.20	18.31	18.43	18.54
21	18.65	18.77	18.88	19.00	19.11	19.23	19.35	19.46	19.58	19.70
22	19.82	19.94	20.06	20.19	20.31	20.43	20.58	20.69	20.80	20.93
23	21.05	21.19	21.32	21.45	21.58	21.71	21.84	21.97	22.10	22.23
24	22.37	22.50	22.63	22.76	22.91	23.05	23.19	23.31	23.45	23.60
25	23.75	23.90	24.03	24.20	24.35	24.49	24.64	24.79	24.94	25.08

TABLE 4 Values of the function $(0.56 - 0.092\sqrt{e})$, in terms of the actual vapour pressure of the air (e) expressed in mm of mercury

e	Function	e	Function	e	Function	e	Function
4.0	0.38	10.0	0.27	15.0	0.20	20.0	0.15
4.5	0.37	10.5	0.26	15.5	0.20	20.5	0.14
5.0	0.35	11.0	0.25	16.0	0.19	21.0	0.14
5.5	0.34	11.5	0.25	16.5	0.19	21.5	0.13
6.0	0.33	12.0	0.24	17.0	0.18	22.0	0.13
6.5	0.33	12.5	0.23	17.5	0.18	22.5	0.12
7.0	0.32	13.0	0.23	18.0	0.17	23.0	0.12
7.5	0.31	13.5	0.22	18.5	0.16	23.5	0.11
8.0	0.30	14.0	0.22	19.0	0.16	24.0	0.11
8.5	0.29	14.5	0.21	19.5	0.15	24.5	0.10
9.0	0.28						
9.5	0.28						

TABLE 5 Values of the cloudiness function $(0.10 + 0.90\ ^n/N)$, in terms of the proportion of actual to possible hours of bright sunshine $(^n/N)$

$^n/N$	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.10	0.19	0.20	0.21	0.22	0.23	0.24	0.24	0.25	0.26	0.27
0.20	0.28	0.29	0.30	0.31	0.32	0.32	0.33	0.34	0.35	0.36
0.30	0.37	0.38	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45
0.40	0.46	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54
0.50	0.55	0.56	0.57	0.58	0.59	0.60	0.60	0.61	0.62	0.63
0.60	0.64	0.65	0.66	0.67	0.68	0.68	0.69	0.70	0.71	0.72
0.70	0.73	0.74	0.75	0.76	0.77	0.78	0.78	0.79	0.80	0.81
0.80	0.82	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.89	0.90
0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.96	0.97	0.98	0.99

TABLE 6 Energy radiated back from the earth in the absence of any atmosphere (σT^4) expressed in mm of water per day, as a function of air temperature

Air temp. °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
16	13.84	13.86	13.88	13.90	13.92	13.94	13.95	13.97	13.99	14.01
17	14.03	14.05	14.07	14.09	14.11	14.13	14.15	14.17	14.19	14.21
18	14.23	14.25	14.27	14.29	14.31	14.33	14.35	14.37	14.39	14.41
19	14.43	14.45	14.47	14.49	14.51	14.53	14.54	14.56	14.58	14.60
20	14.62	14.64	14.66	14.68	14.70	14.73	14.75	14.77	14.79	14.81
21	14.83	14.85	14.87	14.89	14.91	14.93	14.95	14.97	14.99	15.01
22	15.03	15.05	15.07	15.09	15.11	15.13	15.15	15.17	15.19	15.21
23	15.23	15.25	15.27	15.29	15.31	15.34	15.36	15.38	15.40	15.42
24	15.44	15.46	15.48	15.50	15.52	15.55	15.57	15.59	15.61	15.63
25	15.65	15.67	15.69	15.71	15.73	15.76	15.78	15.80	15.82	15.84

TABLE 7 Ratio of the slope of the saturated vapour pressure – temperature curve to the psychrometric constant (Δ / γ), as a function of air temperature

Air temp. °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
16	1.759	1.769	1.779	1.789	1.799	1.810	1.820	1.830	1.840	1.850
17	1.860	1.871	1.881	1.891	1.902	1.913	1.924	1.934	1.945	1.955
18	1.966	1.977	1.988	1.999	2.010	2.022	2.033	2.044	2.055	2.066
19	2.077	2.089	2.100	2.112	2.124	2.136	2.147	2.159	2.171	2.182
20	2.194	2.206	2.218	2.230	2.242	2.255	2.267	2.279	2.291	2.303
21	2.315	2.328	2.340	2.353	2.366	2.379	2.391	2.404	2.417	2.429
22	2.442	2.455	2.469	2.482	2.496	2.509	2.522	2.536	2.549	2.563
23	2.576	2.590	2.604	2.618	2.632	2.646	2.659	2.673	2.687	2.701
24	2.715	2.730	2.744	2.759	2.773	2.788	2.802	2.817	2.831	2.846
25	2.860	2.875	2.890	2.906	2.921	2.936	2.951	2.966	2.982	2.997

To illustrate the method of estimating evaporation at Zwai using the Penman formula and Tables 1 to 7, a detailed example follows:

Calculation of open water evaporation at Zwai for the ten-day period 1—10 March 1974

Mean air temperature	20.0°C
Mean relative humidity (estimated from poor data)	68%
Mean wind speed (adjusted to 2 m above ground level)	131 km/day
Mean duration of bright sunshine	8.1 hours

(a) Calculation of R — Net Radiation

From Table 1 — $N = 12.0$ hours
therefore $^n/N = 0.67$
and $IgA = 14.47$ mm of water/day

From Table 2 — $\frac{Ig}{IgA} = 0.58$
therefore $Ig = 14.47 \times 0.58 = 8.39$ mm of water/day

From Table 3 — $e_s = 17.53$
and $e = 0.68$ (relative humidity) $\times 17.53 = 11.92$)

From Table 4 — $(0.56 - 0.092\ \sqrt{e}) = 0.24$

From Table 5 — $(0.10 + 0.90\ ^n/N) = 0.70$

From Table 6 — $\sigma T^4 = 14.62$

Therefore from Equation (3) $IgB = 14.62 \times 0.24 \times 0.70 = 2.46$ mm of water/day

and from Equation (2)

$$R = 0.95\ Ig - IgB$$
$$= 0.95 \times 8.39 - 2.46$$
$$= 5.51 \text{ mm of water/day}$$

(b) Calculation of Ae — Aerodynamic Energy
$u = 131$ km/day : hence $5u/800 = 0.82$
$e_s - e = 17.53 - 11.92 = 5.61$

From Equation (4) $Ae = 0.35\ (0.5 + \frac{5u}{800})\ (e_s - e)$

$$= 0.35\ (0.5 + 0.82)\ 5.61$$

$$= 2.59 \text{ mm of water/day}$$

(c) Calculation of E_o — Open Water Evaporation

From Table 7 — $^\Delta/_\gamma = 2.19$

From Equation (1) $E = \frac{^\Delta/_\gamma\ R + Ae}{^\Delta/_\gamma + 1}$

$$= \frac{(2.19 \times 5.51) + 2.59}{3.19} = 4.59 \text{ mm of water/day}$$

Appendix 2

Irrigation requirements

This appendix explains the methods used to determine irrigation requirements for components of the cropping systems proposed in Part 5. The major factors considered are:

1. Rainfall, consumptive use and evapotranspiration
2. Methods of application, field application efficiency and leaching requirement
3. Distribution network efficiency and conveyance losses
4. Total water requirement at source and peak demand

CONSUMPTIVE USE AND EVAPOTRANSPIRATION

Although some water is required for incorporation into plant tissue, by far the greatest proportion of the water consumed is evaporated from soil and leaf surfaces in the process known as evapotranspiration. Consumptive use and evapotranspiration can therefore be considered as almost equivalent in quantitative terms.

Evapotranspiration (E_t) is assumed to depend on the same climatic factors as open water evaporation (E_o), so that $E_t = fE_o$, where f is a crop coefficient taking account of the stage of crop development, amount of leaf cover, and the configuration of the crop canopy. If the crop is liberally supplied with water and covers an extended area, the actual evapotranspiration (E_a) equals the calculated evapotranspiration E_t. In practice, however, the rate at which water can be transmitted from soil to leaf may be limited by a shortage in soil moisture between irrigations, by limited root development or by intense evaporative demand. A water availability coefficient (p) is therefore also introduced so that $E_a = pE_t$, p having a maximum value of 1. The crop irrigation requirement is the proportion of the consumptive use that must be supplied by irrigation after allowing for rainfall.

Tables 1 to 6 show the estimated irrigation requirements for several cropping systems. The column headed E_o lists open water evaporation estimates for 10-day periods at Zwai, derived from monthly Penman Estimates for Wonji in the Awash Valley (30 km to the north of the project area), where relevant meteorological data have been recorded since 1954. Adjustments were made to take account of altitude differences between Zwai and Wonji (McKerchar and Douglas, 1974). The crop coefficients (f) were based on lysimeter and water balance studies in various parts of the world (e.g. Hagan, Haise and Edminster, 1967). The coefficient for bare moist soil following a pre-plant irrigation is taken as 0.4 and, as the crop grows, the values increase, sometimes equalling or exceeding unity at full leaf cover but normally decreasing towards harvest as the crop matures. The water availability coefficients (p) are applied where intervals between successive irrigations or rainfall, or other factors mentioned above, could be expected to limit evapotranspiration. It is assumed that certain economies in water use may be possible without significantly affecting yield. The rainfall estimates in Tables 1 to 6 are based on the daily records of rainfall stations around Lake Zwai.

TABLE 1 Determination of irrigation requirements and schedule of proposed surface applications: Maize intercropped with red peppers

10-day period beginning	Operation	E_o (mm)	f	E_t (mm)	p	E_a (mm)	Rainfall (mm)	Irrigation schedule	(mm)
May 21	Pre-plant irrigation	65	0.40	26	1.00	26	20		75
31	Plant maize	60	0.42	25	1.00	25	18		
June 10		60	0.46	28	1.00	28	18		
20		60	0.57	34	0.90	31	18		
30	Interplant red peppers	50	0.74	37	0.90	33	18		50
July 10		50	0.86	43	0.90	39	38		
20		50	0.91	46	0.90	41	38		
30		50	1.00	50	0.90	45	38		50
Aug. 9		50	1.00	50	0.90	45	33		
19		50	1.00	50	0.90	45	33		
29		47	1.00	47	0.90	42	33		
Sept. 8		47	0.96	45	0.90	40	30		
18		47	0.90	42	0.85	36	30		50
28		56	0.90	50	0.85	42	7		
Oct. 8	Harvest maize	56	0.90	50	0.85	42	7		
18		56	0.90	50	0.85	42	7	Oct. 18	50
28	Peppers first harvest	53	0.90	48	0.85	41	5	Nov. 1	50
Nov. 7		53	0.90	48	0.85	41	4	7	50
								14	50
17		53	0.90	48	0.85	41	4		
								21	50
27		51	0.90	46	0.85	39	4		
								28	50
								Dec. 5	50
Dec. 7		51	0.90	46	0.85	39	3		
								15	50
17		51	0.90	46	0.85	39	3		
								20	50
21	Peppers second harvest	52	0.90	47	0.85	40	4		
								Jan. 2	50
Jan. 6		52	0.90	47	0.85	40	4		
								9	50
16		52	0.90	47	0.85	40	4	16	50
								23	50
26		52	0.70	36	0.70	25	4		
								30	50
Feb. 5		53	0.50	26	0.60	16	10		
								Feb. 6	50
								13	50
15		53	0.40	21	0.50	10	10		
								20	50
25	Peppers third harvest	53					10		
Mar. 7		62					13		
17		62					13		
27		62					13		
April 6		60					21		
16		60					21		
26		60					21		
May 6		65					20		
16		65					20		
Totals						1 013			1 075

See text for definition of symbols

TABLE 2 **Determination of irrigation requirements and schedule of proposed surface applications: Maize intercropped with groundnuts, and followed by haricot beans**

10-day period beginning	Operation	E_o (mm)	f	E_t (mm)	p	E_a (mm)	Rainfall (mm)	Irrigation schedule (mm)
May 21	Pre-plant irrigation	65	0.40	26	1.00	26	20	75
31	Plant maize and groundnuts	60	0.42	25	1.00	26	18	
June 10		60	0.46	28	1.00	26	18	
20		60	0.57	34	0.90	31	18	
30		50	0.74	37	0.90	33	18	50
July 10		50	0.86	43	0.90	39	38	
20		50	0.91	46	0.90	41	38	
30		50	1.00	50	0.90	45	38	50
Aug. 9		50	1.00	50	0.90	45	33	
19		50	1.00	50	0.90	45	33	
29		47	1.00	47	0.90	42	33	50
Sept. 8		47	0.96	45	0.85	38	30	
18		47	0.90	42	0.85	36	30	
28		56	0.70	39	0.80	31	7	
Oct. 8	Harvest maize	56	0.60	34	0.60	20	7	
18	and groundnuts	56					7	
28		53					5	
Nov. 7		53					4	
17		53					4	
27		51					4	
Dec. 7		51					3	
17		51					3	
27		51					4	
Jan. 6	Pre-plant irrigation	52	0.40	21	1.00	21	4	50
16	Plant beans	52	0.45	23	1.00	23	4	
26		52	0.70	36	1.00	36	4	50
Feb. 5		53	0.80	42	0.90	38	10	50
15		53	0.95	50	0.85	42	10	50
25		53	1.00	53	0.85	45	10	50
Mar. 7		62	1.00	62	0.85	53	13	50
17		62	1.00	62	0.90	56	13	50
27		62	1.00	62	0.90	56	13	50
April 6		60	0.90	54	0.85	46	21	
16		60	0.60	36	0.85	31	21	
26	Harvest beans	60					21	
May 6		65					20	
16		65					20	
16-21		65					10	
Totals						971		725

See text for definition of symbols

TABLE 3 Schedule of irrigation applications for Rotation 2

Irrigation periods beginning		Year 1 Maize intercropped with red peppers (mm)	Year 2 Maize intercropped with groundnuts; haricot beans (mm)	Year 3 Maize intercropped with groundnuts; haricot beans (mm)	Average monthly requirements (m^3/ha)
May	21	75	75	75	750
	31				
June	10				
	20				
	30	50	50	50	500
July	10				
	20				
	30	50	50	50	500
Aug.	9				
	19				
	29		50	50	333
Sept.	8	50			
	18				
	28				167
Oct.	8				
	18	50			
	28				167
Nov.	1	50			
	7	50			
	14	50			
	21	50			
	28	50			833
Dec.	5	50			
	15	50			
	20	50			500
Jan.	2	50			
	6		50	50	
	9	50			
	16	50			
	23	50			
	26		50	50	1 500
	30	50			
Feb.	5		50	50	
	6	50			
	13	50			
	15		50	50	
	20	50	50	50	
	25		50	50	1 833
Mar.	7		50	50	
	17		50	50	
	27		100*	100*	1 333
Annual total		1 075	725	725	8 416

* Comprises two irrigation applications each of 50 mm

TABLE 4 **Determination of irrigation requirements and schedule of proposed surface applications: Phased onion production* in the wet season, followed by haricot beans in the dry season (substitute for Year 2 in Rotation 2)**

Period beginning		Operation	E_o (mm)	f				E_t (mm)				p				E_a (mm)				Rainfall (mm)	Irrigation schedule (mm)			
				1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		1	2	3	4
May	21	Pre-plant irrigation	65	0.45				29				1.00				29				20	50			
	26	Onion Crop 1 planted																			50			
	31		60	0.50				30				1.00				30				18	50	50		
June	10	Pre-plant irrigation	60	0.60	0.45			36	27			0.90	1.00			32	27			18		50		
	15	Onion Crop 2 planted																			50	50		
	20		60	0.70	0.50			42	30			0.90	1.00			38	30			18	50			
	25																				50	50		
	30		50	0.80	0.60			40	30			0.90	0.90			36	27			18				
July	5																					50		
	10	Pre-plant irrigation	50	0.80	0.70	0.45		40	35	22		0.90	0.90	1.00		36	31	22		38			50	
	15	Onion Crop 3 planted																				50	50	
	20		50	0.85	0.80	0.50		42	40	25		0.90	0.90	1.00		38	36	25		38			50	
	30		50	0.85	0.80	0.60		42	40	30		0.90	0.90	0.90		38	36	27		38				
Aug..	9	Pre-plant irrigation	50	0.85	0.85	0.70	0.45	42	42	35	22	0.90	0.90	0.90	1.00	38	38	31	22	33	50		50	50
		Onion Crop 4 planted																						50
	19		50	0.85	0.85	0.80	0.50	42	42	40	25	0.90	0.90	0.90	1.00	38	38	36	25	33		50		50
	29		47	0.85	0.86	0.80	0.60	40	40	38	28	0.90	0.90	0.90	0.90	36	36	34	25	33			50	
Sept.	8		47	0.85	0.85	0.85	0.70	40	40	40	33	0.90	0.90	0.90	0.90	36	36	36	30	30				
	18		47	0.60	0.85	0.85	0.80	28	40	40	38	0.90	0.90	0.90	0.90	25	36	36	34	30				
	28		56	0.40	0.85	0.85	0.80	22	48	48	45	0.90	0.90	0.90	0.90	19	43	43	40	7		50	50	50
Oct.	3	Harvest Crop 1																				50	50	50
	8		56	0.60	0.60	0.85	0.85		34	48	48		0.90	0.90	0.90		31	43	43	7			50	50
	18		56		0.40	0.85	0.85		22	48	48		0.90	0.90	0.90		19	43	43	7			50	50
	23	Harvest Crop 2																					50	50
	28		53			0.85	0.85			45	45			0.90	0.90			40	40	5			50	50
Nov.	2																						50	50
	7		53			0.60	0.85			32	45			0.90	0.90			29	40	4			50	50
	12																							50
	17		53			0.40	0.85			21	45			0.90	0.90			19	40	4			50	50
	22	Harvest Crop 3																						50
	27		51				0.85				43				0.90				29	4				50
Dec.	2																							50
	7		51				0.60				31				0.90				28	3				50
	17		51				0.40				20				0.90				18	3				50
	27	Harvest Crop 4	52																	4				
Subtotal																469	464	464	457		350	450	650	900
Mean of the subtotal																463					587			
Jan.	6	Pre-plant irrigation	52	0.40				21				1.00				21				4	50			
	16	Beans planted	52	0.45				23				1.00				23				4				
	26		52	0.70				36				1.00				36				4				
	31																				50			
Feb.	5		53	0.80				42				0.90				38				10	50			
	15		53	0.95				50				0.85				42				10				
	20																				50			
	25		53	1.00				53				0.85				45				10				
Mar.	2																				50			
	7		62	1.00				62				0.85				53				13	50			
	12																				50			
	17		62	1.00				62				0.90				56				13	50			
	22																				50			
	27		62	1.00				62				0.90				56				13	50			
April	6		60	0.90				54				0.85				46				21				
	16		60	0.60				36				0.85				31				21				
	26	Harvest beans																						
Subtotal																447					500			
Total†																910					1 087			

* Numeral headings refer to onion crops planted on four dates, crops 1, 2, 3 and 4 respectively
Evaporation and rainfall estimates all refer to 10-day periods beginning on the given date
E_a totals are only given for periods of crop growth (fallow periods excluded)
See text for definition of symbols
† This total is the mean of the subtotal values for the onion crops added to the subtotal for the bean crop

TABLE 4 **Determination of irrigation requirements and schedule of proposed surface applications: Phased onion production* in the wet season, followed by haricot beans in the dry season (substitute for Year 2 in Rotation 2)**

Period beginning	Operation	E_o (mm)	f				E_t (mm)				p				E_a (mm)				Rainfall (mm)	Irrigation schedule (mm)			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		1	2	3	4
May 21	Pre-plant irrigation	65	0.45				29				1.00				29				20	50			
26	Onion Crop 1 planted																			50			
31		60	0.50				30				1.00				30				18	50	50		
June 10	Pre-plant irrigation	60	0.60	0.45			36	27			0.90	1.00			32	27			18		50		
15	Onion Crop 2 planted																			50	50		
20		60	0.70	0.50			42	30			0.90	1.00			38	30			18	50			
25																				50	50		
30		50	0.80	0.60			40	30			0.90	0.90			36	27			18				
July 5																					50		
10	Pre-plant irrigation	50	0.80	0.70	0.45		40	35	22		0.90	0.90	1.00		36	31	22		38			50	
15	Onion Crop 3 planted																				50	50	
20		50	0.85	0.80	0.50		42	40	25		0.90	0.90	1.00		38	36	25		38			50	
30		50	0.85	0.80	0.60		42	40	30		0.90	0.90	0.90		38	36	27		38				
Aug. 9	Pre-plant irrigation	50	0.85	0.85	0.70	0.45	42	42	35	22	0.90	0.90	0.90	1.00	38	38	31	22	33	50		50	50
	Onion Crop 4 planted																						50
19		50	0.85	0.85	0.80	0.50	42	42	40	25	0.90	0.90	0.90	1.00	38	38	36	25	33		50		50
29		47	0.85	0.86	0.80	0.60	40	40	38	28	0.90	0.90	0.90	0.90	36	36	34	25	33			50	
Sept. 8		47	0.85	0.85	0.85	0.70	40	40	40	33	0.90	0.90	0.90	0.90	36	36	36	30	30				
18		47	0.60	0.85	0.85	0.80	28	40	40	38	0.90	0.90	0.90	0.90	25	36	36	34	30				
28		56	0.40	0.85	0.85	0.80	22	48	48	45	0.90	0.90	0.90	0.90	19	43	43	40	7		50	50	50
Oct. 3	Harvest Crop 1																				50	50	50
8		56	0.60	0.60	0.85	0.85		34	48	48		0.90	0.90	0.90		31	43	43	7			50	50
18		56		0.40	0.85	0.85		22	48	48		0.90	0.90	0.90		19	43	43	7			50	50
23	Harvest Crop 2																					50	50
28		53			0.85	0.85			45	45			0.90	0.90			40	40	5			50	50
Nov. 2																						50	50
7		53			0.60	0.85			32	45			0.90	0.90			29	40	4			50	50
12																							50
17		53			0.40	0.85			21	45			0.90	0.90			19	40	4			50	50
22	Harvest Crop 3																						50
27		51				0.85				43				0.90				29	4				50
Dec. 2																							50
7		51				0.60				31				0.90				28	3				50
17		51				0.40				20				0.90				18	3				50
27	Harvest Crop 4	52																	4				
Subtotal															469	464	464	457		350	450	650	900
Mean of the subtotal															463					587			
Jan. 6	Pre-plant irrigation	52	0.40				21				1.00				21				4	50			
16	Beans planted	52	0.45				23				1.00				23				4				
26		52	0.70				36				1.00				36				4				
31																				50			
Feb. 5		53	0.80				42				0.90				38				10	50			
15		53	0.95				50				0.85				42				10				
20																				50			
25		53	1.00				53				0.85				45				10				
Mar. 2																				50			
7		62	1.00				62				0.85				53				13	50			
12																				50			
17		62	1.00				62				0.90				56				13	50			
22																				50			
27		62	1.00				62				0.90				56				13	50			
April 6		60	0.90				54				0.85				46				21				
16		60	0.60				36				0.85				31				21				
26	Harvest beans																						
Subtotal															447					500			
Total†															910					1 087			

* Numeral headings refer to onion crops planted on four dates, crops 1, 2, 3 and 4 respectively
Evaporation and rainfall estimates all refer to 10-day periods beginning on the given date
E_a totals are only given for periods of crop growth (fallow periods excluded)
See text for definition of symbols
† This total is the mean of the subtotal values for the onion crops added to the subtotal for the bean crop

TABLE 5 Determination of irrigation requirements and schedule of proposed surface applications: haricot beans in the wet season, followed by phased onion production in the dry season (substitute for Year 2 in Rotation 2)

Period beginning	Operation	E_o (mm)	f				E_t (mm)				p (mm)				E_a (mm)				Rainfall	Irrigation requirements (mm)			
June 20	Pre-plant irrigation	50	0.40				24				1.00				24				18	50			
30	Beans planted	50	0.45				22				1.00				22				18				
July 10		50	0.70				35				1.00				35				38				
20		50	0.80				40				0.90				36				38	50			
30		50	0.95				47				0.85				40				38				
Aug. 9		50	1.00				50				0.85				42				33	50			
19		50	1.00				50				0.85				43				33				
29		47	1.00				47				0.90				42				33				
Sept. 8		47	1.00				47				0.90				42				30	50			
18		47	0.90				42				0.85				36				30				
28		56	0.60				34				0.85				29				7				
Oct. 3	Harvest beans																						
Subtotal															391					200			
			5*	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8		5	6	7	8
Oct. 8	Pre-plant irrigation	56	0.40				22				1.00				22				7	50			
18	Onion Crop 5 planted	56	0.45				25				1.00				25				7	50			
28		53	0.50				26				0.90				23				5	50			
Nov. 2																				50			
7		53	0.60	0.40			32	21			0.90	1.00			29	21			4				
12	Pre-plant irrigation																			50	50		
17	Onion Crop 6 planted	53	0.70	0.45			37	24			0.90	1.00			33	24			4	50			
22																				50	50		
27		51	0.80	0.50			41	25			0.90	0.90			37	22			4		50		
Dec. 2																				50	50		
7		51	0.80	0.60	0.40		41	31	20		0.90	0.90	1.00		37	28	20		3	50			
12	Pre-plant irrigation																			50	50	50	
17	Onion Crop 7 planted	51	0.85	0.70	0.45		43	36	23		0.90	0.90	1.00		39	32	23		3		50		
22																				50	50	50	
27		52	0.85	0.80	0.50		44	42	26		0.90	0.90	0.90		40	38	23		4	50		50	
Jan. 1																				50	50	50	
6		52	0.85	0.80	0.60	0.40	44	43	31	21	0.90	0.90	0.90	1.00	40	38	28	21	4		50		
11	Pre-plant irrigation																			50	50	50	50
16	Onion Crop 8 planted	52	0.85	0.85	0.70	0.45	44	44	36	23	0.90	0.90	0.90	1.00	40	40	32	23	4	50		50	
21																				50	50	50	50
26		52	0.85	0.85	0.80	0.50	44	44	42	26	0.90	0.90	0.90	0.90	40	40	38	23	4		50		
31																				50	50	50	50
Feb. 5		53	0.85	0.85	0.80	0.60	45	45	42	32	0.90	0.90	0.90	0.90	41	41	38	29	10	50		50	
10																				50	50	50	50
15		53	0.60	0.85	0.85	0.70	32	45	45	37	0.90	0.90	0.90	0.90	29	41	41	33	10		50		50
20																				50	50	50	50
25		53	0.40	0.85	0.85	0.80	21	45	45	42	0.90	0.90	0.90	0.90	19	41	41	38	10			50	
Mar. 2	Harvest Crop 5																				50	50	50
7		62		0.85	0.85	0.80		53	53	50		0.90	0.90	0.90		48	48	45	13		50		50
12																					50	50	50
17		62		0.60	0.85	0.85		37	53	53		0.90	0.90	0.90		33	48	48	13			50	
22																					50	50	50
27		60		0.40	0.85	0.85		25	53	53		0.90	0.90	0.90		22	48	48	13				50
April 1	Harvest Crop 6																					50	50
6		60			0.85	0.85			51	51			0.90	0.90			46	46	21			50	
11																						50	50
16		60			0.60	0.85			36	51			0.90	0.90			32	46	21				50
21																						50	50
26		65			0.40	0.85			24	51			0.90	0.90			22	46	21				
May 1	Harvest Crop 7																						50
6		65				0.85				55				0.90				50	20				50
11																							50
16		65				0.60				39				0.90					35				
21																							50
26						0.40				26				0.90				23	20				
June 5	Harvest Crop 8																						
Subtotal															494	509	528	554		1000	1000	1000	1000
Mean of the subtotal															521					1000			
Total†															912					1200			

* Numeral headings refer to onion crops planted on four dates, crops 5, 6, 7 and 8 respectively
Evaporation and rainfall estimates all refer to 10-day periods beginning on the given date
E_a totals are only given for periods of crop growth (fallow periods excluded)
See text for definition of symbols
† This total is the mean of the subtotal values for the onion crops added to the subtotal for the bean crop

TABLE 6 **Determination of irrigation requirements and schedule of proposed surface applications: tomatoes (possible substitute for Year 1 in Rotation 2)**

Periods beginning	Operation	E_o (mm)	f	E_t (mm)	p	E_a (mm)	Rainfall (mm)	Irrigation schedule (mm)
Aug. 9		50					33	
14	Pre-plant irrigation							50
19	Plant tomatoes	50	0.40	20	1.00	20	33	50
29		47	0.42	20	1.00	20	33	50
Sept. 3								50
8		47	0.46	22	1.00	22	30	50
18		47	0.57	27	1.00	27	30	50
23								50
28		56	0.74	41	0.90	37	7	50
Oct. 8		56	0.86	48	0.90	43	7	50
13								50
18		56	0.95	53	0.90	48	7	50
28		53	1.10	58	0.86	50	5	50
Nov. 2								50
7		53	1.10	58	0.86	50	4	50
17		53	1.10	58	0.86	50	4	50
22								50
27	Start picking	51	1.10	56	0.86	48	4	50
Dec. 2								50
7		51	1.10	56	0.86	48	3	50
12								50
17		51	1.10	56	0.86	48	3	50
22								50
27		52	1.10	57	0.86	49	4	50
Jan. 1								50
6		52	1.10	57	0.86	49	4	50
11								50
16		52	1.10	57	0.86	49	4	50
21								50
26		52	1.10	57	0.86	49	4	50
31								50
Feb. 5		53	1.10	58	0.86	50	10	50
10								50
15		53	1.10	58	0.86	50	10	50
20								50
25		53	1.10	58	0.86	50	10	50
Mar. 2								50
7		62	1.10	68	0.86	58	13	50
17		62	1.10	68	0.86	58	13	50
27	Finish picking							
Total						973		1 900

Annual evapotranspiration estimates (E_a) for the various cropping systems are summarised in Table 7.

TABLE 7 **Estimated annual crop evapotranspiration (E_a) for certain cropping systems**

Cropping system	E_a (mm)
1. Maize intercropped with and followed by red peppers	1 013
2. Maize intercropped with groundnuts; Haricot beans in the dry season	971
3. Onions in the wet season; Haricot beans in the dry season	910
4. Haricot beans in the wet season; Onions in the dry season	912
5. Tomatoes	973

IRRIGATION PRACTICE

In Tables 1-6 the amount of water allowed for each irrigation application is 50 mm. This figure is based on present practice in the project area, where tomato growers using furrow irrigation find it impractical to apply and distribute less than 500 m^3 of water over 1 ha. By improving land grading, furrow slopes and furrow lengths, it may prove possible to use less water, but allowance must be made for operational inefficiences. In any case it is not possible to supply the precise evapotranspiration needs of a crop, since wastage inevitably occurs as surface run-off or as seepage. Indeed, sufficient seepage must be allowed, so as to maintain a favourable salt balance in the soil.

Basin irrigation is proposed for the Meki Delta and for other areas with slopes generally less than 1%. Land grading will be necessary to ensure that undulations within the basins are kept within about 5 cm of the mean level. Furrows can be used within the basins to assist drainage during heavy rainfall. Application efficiency in these basins will depend in part on the relationship between size of basin and water infiltration rate. Large basins are suitable for soils with low intake rates, but small basins are necessary on soils with high intake rates. It is suggested that 0.5 ha basins would be suitable on the Meki Delta (see Part 6).

Furrow irrigation is also appropriate in much of the project area. Furrows are convenient for management, facilitating plant spacing, intercropping and groundnut harvesting; moreover, crops planted on ridges are not subject to flooding around their stems. With careful grading, furrows can be formed on land with up to 5% slope. Field application efficiency depends on the number and shape of the furrows, on the proportion of land area wetted, on the rates of flow into the furrows and on slope and furrow length. Considerable skill will be needed in diverting water from feeder channels to the correct number of furrows. Optimum field layouts will have to be determined by experiments on contrasting soil types.

Overhead irrigation by sprinklers, rainguns, travelling rainers, etc., could be used on land with uneven topography (e.g. on the lake terraces) thus eliminating the need for levelling. In theory, the amount of water applied can be more easily controlled by the farmer, though in practice considerable skill is required to ensure efficient operation. Efficient distribution may be adversely affected by wind, such that surplus water has to be applied to certain areas (e.g. close to sprinklers) to ensure that other areas have adequate water.

The number of irrigations judged to be necessary for each crop throughout the year (assuming surface irrigation is adopted) is shown in Tables 1-6. Pre-planting irrigations to bring the soil to field capacity have been taken into account, and the number and approximate timing of applications have been chosen in relation to rainfall, evapotranspiration and soil moisture retention characteristics (Appendix 7). Although, in the wet season, the timing and number of irrigations will have to be adjusted according to rainfall, two or three applications have been scheduled on the basis of the analysis of dry periods in the wet season (Tables 29 and 30, and Figure 16; Part 5).) The timing of irrigation applications in the dry season takes into account the relatively small amounts of water held in most of the soils between field capacity and 2 bars (2 atmospheres) water tension, and hence the relatively steep decline in growth rate which can be anticipated during the irrigation interval. The shortest irrigation interval recommended is 5 days for onions and tomatoes, the yields of which are sensitive to small moisture deficits. Table 8 summarises the proposed irrigation applications for several cropping systems.

TABLE 8 **Summary of field applications for surface irrigation**

	Number of applications		Irrigation water quantity	
	Pre-plant	Post-plant	(mm)	(mm/year)
1. Maize intercropped with and	1	2	175	
followed by – Red Peppers		18	900	1 075
2. Maize intercropped with groundnuts	1	3	225	
Dry season haricot beans	1	9	500	725
3. Wet season onions	1	6-17*	350-900*	
Dry season haricot beans	1	9	500	850-1 400*
4. Wet season haricot beans	1	3	200	
Dry season onions	1	19	1 000	1 200
5. Tomatoes	1	37	1 900	1 900

(*Depends on date of planting)

A comparison can now be made between the evapotranspiration estimates in Table 7 and the irrigation applications given in Table 8. Assuming equal amounts of water are retained by the soil before and after cropping, water added as rainfall or irrigation which is not used in evapotranspiration must either run off the soil surface or drain through the root zone. Soil infiltration characteristics are such that most of the losses can be attributed to internal drainage (the validity of this assumption for certain soils should be borne in mind in what follows). The depth of drainage water assuming no runoff occurs is given in Table 9; also given is the leaching fraction, which is defined as the ratio of drainage water to rainfall plus irrigation water.

TABLE 9 **Estimated depth of drainage water and leaching fraction for Rotation 2, assuming no runoff**

	Year 1	Year 2	Year 3	Annual average
	Maize, red peppers (mm)	Maize, groundnuts, haricot beans (mm)	Maize, groundnuts, haricot beans (mm)	(mm)
Mean annual rainfall	607	607	607	607
Surface irrigation	1 075	725	725	842
Total water additions	1 682	1 332	1 332	1 449
Actual crop evapotranspiration, E_a	1 013	971	971	985
Evaporation during fallow periods	114	125	125	121
Total annual evapotranspiration	1 127	1 096	1 096	1 106
Depth of drainage water	555	236	236	342
Leaching fraction %	33	18	18	23

The average leaching fraction (Table 9) is 23% of the water added to the soil, assuming no runoff occurs. The question as to whether this leaching fraction is adequate to maintain the soil profile relatively free of salinity, and indeed whether the physico-chemical state and the profile permeability are such that leaching at these rates can be sustained over a long period, is highly complex and not susceptible to solution other than by field experimentation. This problem has nevertheless been considered in detail from several standpoints within the main body of this report (Part 5), where it was concluded that a leaching fraction of 23% should be sustainable in both the more permeable and the non-alkaline soil types and that this flow should maintain a favourable salt balance in the soil.

DISTRIBUTION NETWORK EFFICIENCY

Conveyance losses between source and field must be taken into account in determining water requirements at source. Seepage from primary canals may be controlled by concrete linings; sometimes linings can also be justified for secondaries. Most of the seepage can be expected to occur from the tertiaries, but it is not possible to assess distribution network efficiency at a pre-feasibility stage since the systems have not been designed in detail. As an estimate of conveyance losses, a figure of 40% of field irrigation requirement has been used; with small-scale pumping from a source close to irrigation the loss may well be much less. It should be noted that the estimated conveyance loss (40% of irrigation requirement in the field) represents about 28% of the water actually abstracted from source.

Total irrigation demand

The average irrigation requirements for 1 000 ha of irrigated land cropped with a typical three-year rotation (Rotation 2) is calculated as follows:

Average annual irrigation requirement in the field	8 420 m^3/ha
Plus 40% for losses in the distribution network	3 370 "
Total irrigation requirement	11 790 "
Irrigation requirement for 1 000 ha	11.8×10^6 m^3/year

The peak demand is in the month of February, but on occasions might also be expected in January or March, when it may also be necessary to apply 50 mm/week (i.e. 500 m^3/ha). A maximum weekly demand of 500 + 40% = 700 m^3/ha is therefore estimated; i.e. each 1 000 ha of irrigated land would require a maximum allocation of 700 000 m^3/week or 2 700 l/s, assuming an irrigation period of 12 hours per day and six days a week. With an individual pump capacity of 400 l/s, seven pumps would be required to meet the peak demand on 1 000 ha of irrigated land cropped as proposed.

Appendix 3

Hydrological records

This appendix contains:

1. Monthly and annual discharges in the Meki, Catar, Bulbula, Horakello and Gogessa rivers
2. Monthly and annual average levels of lakes Zwai, Abiyata and Langano.

1. MONTHLY AND ANNUAL RIVER DISCHARGES (mcm)

a. Meki River at Meki Town

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1963*	–	–	–	–	75.17	11.14	56.42	75.57	42.95	7.24	0.94	1.18	–
1964*	1.54	0.65	0.78	3.32	4.24	10.05	39.31	70.45	62.11	39.13	4.98	2.95	239.51
1965*	1.79	1.33	1.98	1.84	0.94	0.78	11.60	37.71	32.35	26.46	3.76	0.99	121.53
1966*	0.75	12.77	12.45	23.22	12.05	4.80	22.12	70.17	74.52	23.57	5.00	1.50	262.92
1967*	1.04	0.57	0.86	6.39	46.53	12.01	58.08	72.18	34.07	45.15	48.88	10.34	336.10
1968*	2.42	12.18	10.15	84.44	68.44	13.14	28.92	70.51	57.25	16.52	2.57	1.68	368.22
1969+	3.55	26.71	58.31	26.94	37.03	21.81	75.95	119.62	64.82	11.08	3.18	2.36	451.37
1970+	12.42	6.63	52.92	74.95	8.08	5.93	87.11	153.39	58.17	17.30	5.46	4.04	486.40
1971+	3.61	2.66	3.13	7.03	14.58	50.22	102.15	142.14	80.58	18.44	10.67	8.39	443.60
1972+	8.39	23.40	42.50	49.54	40.04	21.21	56.74	107.66	53.25	19.91	9.29	5.25	437.13
1973†	6.69	5.23	1.17	1.07	8.33	10.39	72.67	99.77	87.91	52.34	11.99	6.86	362.42
Mean	4.22	9.21	18.42	27.87	28.67	14.68	55.55	92.65	58.91	25.19	9.70	4.14	349.21

Sources: * Italconsult (1970). + AVA (1972). † Unpublished. Derived from gauge height records and AVA rating curve.

b. Catar River at Ogelcho (Abura)

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968*	–	–	–	–	–	–	–	137.91	53.78	38.25	7.28	5.20	–
1969*	7.23	15.22	45.16	17.96	23.41	11.56	76.50	164.72	117.00	18.64	7.69	6.01	511.10
1970*	9.58	5.21	36.14	30.95	22.82	7.11	66.70	251.31	129.81	42.87	9.20	6.37	618.07
1971*	5.40	4.19	4.54	6.63	10.95	28.43	76.48	106.09	72.95	33.70	10.56	7.03	366.95
1972*	6.23	8.04	8.27	19.34	18.89	8.71	60.38	100.33	48.12	16.28	8.05	5.90	308.54
1973+	5.03	3.96	4.03	3.90	5.68	5.74	30.80	104.19	82.99	38.84	6.94	5.04	297.14
1974†	5.09	4.11	9.38	11.16	6.78	9.45	32.67	87.69	67.86	16.70	5.67	5.07	261.63
Mean	6.43	6.79	17.92	14.99	14.75	11.83	57.25	136.03	81.99	29.33	7.91	5.80	390.82

Sources: * AVA (1973). + Unpublished. Derived from gauge height records and AVA rating table. † Private communication, AVA.

c. Bulbula River at Bulbula

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968*	–	–	–	–	–	–	–	30.27	42.25	45.53	32.14	21.96	–
1969*	14.20	10.40	14.20	13.48	12.59	8.55	14.20	42.59	69.21	60.53	38.20	27.40	325.55
1970*	23.59	17.49	18.73	13.31	7.28	5.18	5.67	31.44	69.47	72.75	44.72	28.31	337.94
1971*	18.34	10.55	6.75	5.45	5.53	4.94	9.99	24.00	49.29	44.30	28.07	18.32	225.53
1972*	12.16	8.36	9.33	8.55	9.63	8.35	9.45	21.56	31.89	27.79	16.71	10.33	174.11
1973+	6.63	3.80	1.78	0.00	0.45	0.00	1.08	0.57	9.34	12.76	8.78	4.93	50.12
1974†	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	5.79	8.87	4.52	1.49	21.09
Mean	12.49	8.43	8.46	6.80	5.91	4.50	6.73	21.55	39.61	38.93	19.82	12.58	189.06

Sources: * AVA (1973) + Unpublished. Derived from gauge height records and AVA rating table.
† Private communication, AVA

d. Horakello River near Bulbula

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1969*	4.68	2.78	3.08	2.72	2.68	2.07	2.01	9.37	30.33	29.46	16.33	14.46	119.97
1970*	10.98	7.52	4.02	2.85	2.01	1.17	1.34	9.37	19.44	29.90	14.51	4.02	107.13
1971*	2.01	1.21	0.96	0.73	0.62	0.57	0.99	3.21	6.03	8.30	2.85	1.61	29.09
1972*	0.94	0.75	0.67	0.52	0.67	0.65	0.94	2.01	7.39	8.70	2.20	1.02	26.46
1973+	0.67	0.41	0.35	0.26	0.16	0.08	0.03	0.05	0.52	1.34	1.04	0.67	5.58
Mean	3.86	2.53	1.82	1.42	1.23	0.91	1.06	4.80	12.74	15.54	7.39	4.36	57.66

Discharges computed from level data for Lake Langano using the relationship in Figure 26 – Appendix 5
Sources of data for Lake Langano: * AVA (1973) + Unpublished gauge height records

e. Gogessa River

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1969*	0.36	1.30	3.64	0.69	1.76	2.27	4.73	5.51	6.13	0.44	1.89	0.00	28.72
1970*	0.54	0.32	2.02	0.45	0.34	0.16	2.14	5.71	2.48	1.03	1.62	2.09	19.90
1971*	1.41	0.92	0.64	0.48	0.58	0.62	0.91	0.81	0.75	1.21	1.34	1.21	10.88
1972*	0.94	0.85	0.71	0.82	0.65	0.29	0.79	3.01	1.93	1.15	0.99	0.73	12.86
1973†	0.22	0.00	0.00	0.00	0.28	0.42	2.20	2.00	1.20	0.24	0.00	0.00	6.56
1974†	0.00	0.00	0.15	0.05	0.02	0.09	0.14	0.12	0.54	0.04	0.00	0.00	1.15
Mean	0.57	0.56	1.19	0.41	0.60	0.64	1.82	2.86	2.17	0.68	0.97	0.67	13.14

Sources: * AVA (1973) † Private communication, AVA

2. MONTHLY AND ANNUAL AVERAGE LAKE LEVELS (m)

a. Lake Zwai at Zwai Town

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1967*	–	–	–	–	–	–	–	1.06	1.48	1.69	1.63	1.57	–
1968*	1.40	1.26	1.21	1.25	1.35	1.31	1.36	1.62	1.81	1.79	1.55	1.36	1.44
1969*	1.22	1.14	1.26	1.25	1.22	1.14	1.25	1.52	1.99	2.20	2.12	(1.80)	(1.51)
1970+	1.39	1.18	1.12	1.15	1.03	0.90	0.89	1.39	1.92	2.04	1.80	1.46	1.36
1971†	1.21	0.99	0.82	0.70	0.73	0.73	0.97	1.39	1.67	1.64	1.44	1.21	1.12
1972ɸ	0.98	0.88	0.81	0.80	0.84	0.79	0.84	1.11	1.30	1.26	1.08	0.98	0.97
1973x	0.88	0.74	0.64	0.46	(0.36)	(0.26)	(0.30)	0.80	1.02	1.18	1.06	0.87	(0.71)
1974xx	0.74	0.61	0.49	0.52	0.23	0.38	0.39	0.58	0.98	1.13	0.95	0.78	0.65

All levels refer to the AVA staff gauge at Zwai town. Staff gauge zero = 1 635.1 m (a.s.l.). Figures in brackets are estimates from incomplete data of average lake level.

Sources: * Italconsult (1970) + AVA (1972a) † AVA (1972b) ɸ AVA (1973)
x Unpublished gauge height records
xx Private communication, AVA

b. Lake Abiyata near Bulbula

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1968*	–	–	–	–	–	–	–	–	(0.30)	(0.44)	(0.65)	0.88	–
1969*	(0.90)	(0.96)	1.06	1.15	1.18	1.16	1.19	1.42	1.90	2.42	(2.61)	2.62	1.54
1970+	2.69	2.71	2.74	2.77	2.67	2.45	2.38	2.49	2.81	2.64	2.80	2.70	2.65
1971†	2.59	2.38	2.20	2.41	2.27	2.34	2.38	2.45	2.74	2.87	2.98	2.90	2.54
1972ɸ	2.82	2.75	2.75	2.62	2.53	2.50	2.46	2.53	2.78	2.80	2.78	2.74	2.44
1973x	2.56	2.40	2.24	(1.93)	(1.93)	1.78	1.84	1.92	1.95	1.93	(1.81)	(1.55)	1.99
1974xx	1.44	1.34	1.25	1.15	1.05	0.97	0.89	0.83	0.85	0.81	0.63	0.48	0.97

All levels refer to the AVA staff gauge near Bulbula. Staff gauge zero = 1 576.4 m (a.s.l .) (Italconsult, 1970). Figures in brackets are estimates from incomplete data of average lake level.

Sources: * Italconsult (1970) + AVA (1972a) † AVA (1972b) ɸ AVA (1973)
x Unpublished gauge height records
xx Private communication, AVA

c. Lake Langano near Bekele Mola Hotel

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1968*	–	–	–	–	–	–	–	–	(2.03)	2.01	1.79	(1.68)	–
1969*	1.60	(1.54)	(1.54)	1.52	(1.51)	1.46	1.45	1.69	(2.14)	(2.10)	(1.85)	(1.80)	(1.68)
1970+	(1.73)	(1.66)	(1.59)	(1.52)	(1.44)	1.32	1.35	1.69	1.91	2.01	1.81	1.59	(1.63)
1971†	(1.45)	(1.35)	(1.26)	(1.18)	(1.10)	1.09	1.27	1.54	1.67	1.67	1.53	1.39	(1.37)
1972ɸ	1.26	1.18	1.10	1.05	1.12	1.12	1.24	1.45	1.66	1.68	1.47	1.27	(1.30)
1973x	1.13	1.00	0.92	0.85	0.75	0.60	0.47	0.55	1.05	1.35	1.28	1.14	(0.92)

All levels refer to the AVA staff gauge near Hotel. Staff gauge zero = 1 582.1 m (a.s.l.). Figures in brackets are estimates from incomplete data of average lake level.

Sources: * Italconsult (1970) + AVA (1972a) † AVA (1972b) ɸ AVA (1973)
x Unpublished gauges height records

Appendix 4
The Lake Zwai water balance model; and simulation of hydrological records for 1954 - 73

THE WATER BALANCE MODEL FOR LAKE ZWAI

The water balance of Lake Zwai can be summarised as:

> [Meki flow + Catar flow + rain on lake] — [evaporation + Bulbula flow + change in storage] = 0

Considering, the terms in the equation:

1. Flows in the Meki, Catar and Bulbula rivers have been gauged (see Appendix 3)
2. Rainfall on Lake Zwai is assumed to be the average of the gauged rainfall at Ogelcho, Meki, Zwai and Adamitulu (or whichever are available) (Appendix 1). Conversion of gauged rainfall to volume of water entering the lake is by multiplication with lake area (Figure 4, Page 26)
3. Evaporation estimates have been derived from data for Wonji and adjusted for the difference in elevation (Table 20, Part 4). These can be converted to volumes of water lost from the Lake surface using Figure 4
4. Storage changes can be computed from lake level data using Figure 4

From a knowledge of the inflow to the lake and the change in lake level it was possible to predict the Bulbula flows. These were then compared with the recorded Bulbula flows to calibrate the model. Furthermore, by combining the data on Figures 4 and 11, a relationship between Bulbula flow and lake volume was derived, such that changes in volume, and hence in Lake Level could also be predicted. Monthly data for 1969-72 were used in the calibration. A model efficiency (defined as $(Fo^2 - F^2)/Fo^2$, where F^2 is the sum of squares of differences between observed and derived Bulbula flows, and Fo^2 is the sum of squares of differences between observed flows and their arithmetic means) of 97.2% was achieved when the following values of model parameters were used:

1. A time delay of 0.422 months
2. An annual total evaporation of 2 017 mm
3. An initial lake storage volume of 1 487 mcm (January 1969)
4. An increase of 4.4% over recorded Meki flows
5. An increase of 0.3% over recorded Catar flows

SIMULATION OF HYDROLOGICAL RECORDS FOR 1954-73

With the exception of the Meki River, hydrological data for the Lake Zwai catchments only cover the period since 1969, and this is known to have been untypical of long-term average conditions. It was therefore necessary to extend the data series to cover a longer period (20 years) so that reliable estimates could be made of the average flow in the Bulbula river and hence the water available for abstraction for irrigation.

In order to use the water balance model for the determination of Bulbula flows, it was first necessary to derive 20-year sequences of Meki River flows, Catar River flows and of rainfall on Lake Zwai and in the catchments of the tributary rivers.

The evaporation data presented in Table 20 (Part 4) were assumed to be valid throughout the period 1954-73.

It should be noted that the only data extending back over the full 20-year period were rainfall records at Adamitulu and Addis Ababa.

Extension of Meki flows

Although a long rainfall record was available for Adamitulu, this was not used principally because Adamitulu lies in an area which is wholly unrepresentative of the Meki catchment. The rainfall pattern at Addis Ababa, on the other hand, shows marked similarities with that in the upper reaches of the Meki catchment although the gauge is sited some distance beyond the catchment boundary, and rainfall data from this station were found to correlate fairly well with Meki flows during the period for which records of both variables were available. From this correlation, Meki flows could be estimated for the earlier period during which only rainfall records were available.

Statistics of monthly rainfall at Addis Ababa for the period 1948-71 are presented in Table 1. Similarities to the Meki flow data (Table 15, Part 4) are exhibited by the strong seasonality in the means and standard deviations.

TABLE 1 **Statistics of monthly rainfalls at Addis Ababa 1948-71**

Month		Mean (mm)	Standard deviation (mm)	Skewness coefficient	Month-to-month correlation	Coefficient of variation
Jan.	1	18.66	22.86	1.48	– 0.11	1.225
Feb.	2	27.79	36.65	1.71	0.08	1.319
Mar.	3	71.85	64.56	1.34	0.19	0.899
April	4	87.46	51.76	1.05	– 0.05	0.592
May	5	68.27	59.51	1.06	– 0.12	0.872
June	6	116.87	41.43	0.48	0.29	0.354
July	7	253.38	58.55	0.19	0.33	0.231
Aug.	8	270.90	63.45	– 0.09	0.30	0.234
Sept.	9	180.14	54.20	0.17	0.19	0.301
Oct.	10	40.05	45.18	1.10	0.27	1.128
Nov.	11	9.65	17.16	2.36	0.09	1.779
Dec.	12	11.59	18.87	2.00	– 0.25	1.628

Annual mean = 1 157 mm
Annual standard deviation = 167 mm
No. of years observations = 24

The seasonal effect of monthly rainfall means $\overline{P}_j$ and standard deviations S_j were removed from the monthly rainfall values by the transformation:

$$\chi_t = (P_t - \overline{P}j)/S_j$$

where χ_t is the standardised rainfall value for any month t; P_j the observed rainfall for that month; $\overline{P}j$ the mean monthly rainfall for month j where j = 1 .... 12 (column 2 in Table 1); and S_j is the standard deviation for month j (column 3 in Table 1).

Likewise the monthly flows were standardised by the transformation:

$$y_t = (Q_t - \bar{Q}j)\ \sigma_j$$

where y_t is the standardised flow value; Q_t the observed flows; $\bar{Q}_j$ the mean monthly flow (column 2 in Table 15, Part 4); σ_j the standard deviation of the flow series for month j (column 3 in Table 15).

Contiguous sequences of standardised flows (y_t) and rainfalls (χ_t) cover the period May 1963 - December 1971 (a total of 104 months); the cross-correlation between the series is 0.399. To extend the monthly flows, a simple relationship was postulated of the form:

$$\text{Meki flow}_t = \bar{y} + a\ (\text{Meki flow}_{t-l} - \bar{y}) + b\ (\text{rainfall}_t - \bar{\chi})$$

where t = any month between May 1963 and December 1971; and t-l the month previous to t; a and b are constants whose values were determined as 0.469 and 0.381; $\bar{y}$ is the mean river flow and $\bar{\chi}$ the mean rainfall. Using this relationship a sequence of standardised flows $\{y_t\}$ was calculated, corresponding to the longer sequence of standardised rainfall $\{\chi_t\}$. Finally, the extended y_t was re-scaled by the appropriate Q_j and σ_j to give the extended flow sequence.

Extension of Catar flows

Because of poor rainfall correlations and the very short flow records, the Catar flows could not be extended by the technique used for the Meki. A method was therefore developed which conceived the catchment as a simple reservoir. Flow was predicted to occur when the reservoir overflowed. Rainfall was added to the reservoir contents and any overflow (assumed to be the Catar flow) was abstracted. An additional loss from the reservoir was taken as representing evaporation. This was of 60 mm/month reducing to 30 mm/month when the reservoir was more than 65 mm below capacity. These figures were selected by trial and error. The overflows were converted to volumes according to the equation: Outflow = 0.05 (storage contents) $^{1.5}$, i.e. using a non-linear reservoir function.

The flows calculated from this conceptual model compare reasonably with recorded flows (Figure 25). The estimated flows from 1954 onwards were obtained using the model and a synthetic sequence of rainfall as derived below.

Extension of rainfall records

Rainfall data collection in the Meki catchment began with one gauge in 1953 (Silte) while the record from the Catar catchment dates from 1954 (Asella). In both catchments, rainfall records tend to be fragmentary until the middle 1960's. Rainfall near the lake is available from 1956 from the gauge at Adamitulu. Before flows could be generated from the rainfall sequences, therefore, considerable reconstruction and infilling of the sequences was required. The method adopted was to assume that operational gauges could in any month be used as index gauges, even if they lay outside the catchment under consideration (e.g. Addis Ababa). The mean monthly rainfall at each gauge was calculated by summing all the observed monthly totals recorded by it, and dividing by the number of months present. Catchment mean monthly rainfalls were then obtained for the Catar basin, the Meki basin and the lake hinterland, by finding the average of the mean monthly rainfalls of gauges within each area. Weighting factors for each gauge relative to the Catar and Lake Zwai catchments, were calculated by expressing catchment mean monthly rainfalls as a proportion of individual gauge mean monthly rainfalls; these are summarised in Table 2.

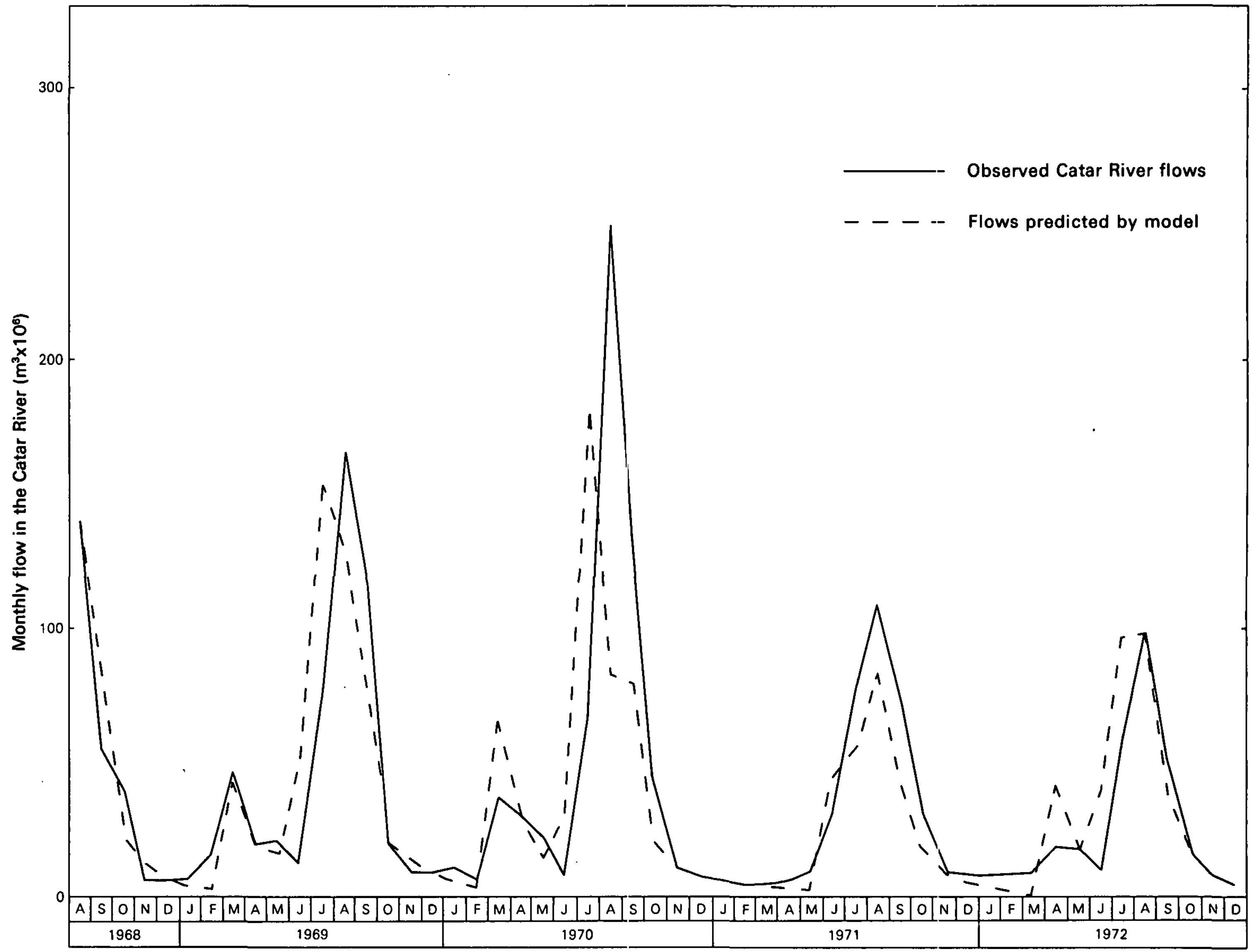

FIGURE 25 Predicted and observed flows in the Catar River

FIGURE 25

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TABLE 2 **Summary of rainfall data used to extend hydrological records**

Catchment	Raingauge station	Number of monthly readings	Mean monthly rainfall (mm)	Weighting factor relative to the Catar	Weighting factor relative to Lake Zwai
Meki River	Silte	128	87.5	1.11	0.67
	Butajira	84	93.2	1.04	0.63
	Egerssa	72	73.1	1.33	0.80
	Addis Ababa	216	97.5	1.00	0.60
	Average for catchment	-	87.8	-	-
Lake Zwai	Ogelcho	76	55.9	1.74	1.05
	Adamitulu	131	58.2	1.67	1.01
	Meki	101	61.9	1.57	0.95
	Average for catchment	-	58.7	-	-
Catar River	Asella	135	116.1	0.84	0.51
	Lemu	119	121.6	0.80	0.48
	Sagure	74	81.0	1.20	0.72
	Kersa	84	66.8	1.46	0.88
	Bokoji	121	101.1	0.96	0.58
	Average for catchment	-	97.3	-	-

Before generating a synthetic series of rainfall totals for any of the catchments, all gauge rainfalls were weighted using the appropriate weighting factor. Operational gauges within the catchment were first considered; if there were two or more operational gauges, the mean of these 'in-catchment' gauges was used as the catchment rainfall. If one or no gauge was operational within the catchment, then a mean of all operational gauge rainfalls was used, the 'in-catchment' rainfall (if any) being given double weighting.

In this way, rainfall on Lake Zwai and on the Catar catchment was estimated for the 20-year period. Rainfall on the Meki catchment was not calculated in this manner since a reasonable correlation of Meki flows with Addis Ababa rainfall records had already been found.

EXTENDED DATA SERIES

Table 3 compares the generated 20-year data, derived by the methods outlined above, with those of the shorter term gauged data.

TABLE 3 **Means and standard deviations (shown in brackets) of generated and gauged hydrological data for the Meki River, Catar River and rainfall on Lake Zwai**

Hydrological element	Mean annual values			
	Generated data (1954-73)		Gauged data (1969-72)	
Meki River flow (m^3/sec)	333.6	(86.7)	349.6	(114.5)
Catar River flow (m^3/sec)	505.8	(143.9)	449.4	(119.0)
Rainfall on Lake Zwai (mm)	638.0	(92.1)	598.6	(62.5)

Using the calibrated water balance model and the 20-year derived input data, it was possible to compute similar sequences of flows in the Bulbula river and variations in lake level. The results are presented in Table 4 and the hydrograph of predicted lake levels is shown as Figure 12 (page 65). Figure 10 shows the reduction in evaporation losses resulting from the lowering of the level of lake, and compares the results of the derived 20-year data series with the short (1969-72) series.

When reviewing the results of the data extension exercise, the uncertainties implicit in the derivation of the input data need to be borne in mind. There are two sources of error:

1. Error in the original Meki and Catar flow records. Large errors may exist in the Catar records due to the poorly defined rating curve for the gauging station. Only a few gaugings have been made, and none at particularly high or low stages. The Meki rating curve is better documented with over 100 gaugings, but most of these were made in the early years of the station, and there have been no recent measurements at very high or low stages despite shifts in the control of the gauging section. The few recent measurements that are available suggest that low flows in particular may have been considerably overestimated by using the old rating curve. Comparison of recorded flows at this station with contemporary flows at Meki 1 gauging station just 5 km upstream also indicate that there could be significant error at the top end of the rating curve.

2. Error in the estimation of catchment rainfall. Since there are no very long homogeneous rainfall records available within the catchment, this is probably the largest source of error.

It is evident that errors in original rainfall data will lead to errors in derived streamflows and that these are likely to be greater in the data extension exercise than in the short-term analysis using 1969-72 records only. The longer series is likely however, to be the better indicator of average conditions.

TABLE 4 Water balance of Lake Zwai using 20 years of generated input data (1954-73)

Year	Lake area (km^2)	Lake level (m)	Volume of water in lake (mcm)	Meki flow (mcm)	Catar flow (mcm)	Rainfall (mcm)	Evaporation (mcm)	Bulbula flow (mcm)
1954	468.63	0.84	1 428.41	315.2	477.1	259.4	943.8	155.6
1955	474.76	0.99	1 475.25	358.6	553.6	305.9	958.8	231.4
1956	475.14	0.99	1 534.07	277.5	622.7	320.8	957.2	216.4
1957	487.68	1.37	1 471.19	414.6	568.2	330.9	983.4	415.9
1958	477.11	1.06	1 516.21	352.4	579.0	340.6	960.7	281.6
1959	471.67	0.89	1 368.15	284.1	387.2	252.9	950.6	140.0
1960	464.83	0.72	1 310.93	290.7	395.2	272.3	936.4	94.0
1961	466.17	0.80	1 467.10	390.4	528.0	316.2	938.3	155.2
1962	464.61	0.72	1 300.08	245.8	353.6	247.7	936.5	93.4
1963	466.44	0.78	1 339.53	327.9	501.1	258.6	939.1	124.3
1964	458.00	0.59	1 323.58	239.4	454.3	277.0	921.7	77.1
1965	446.42	0.36	1 148.82	121.6	425.9	211.1	899.0	42.9
1966	451.26	0.52	1 362.71	262.8	551.6	389.8	907.5	93.4
1967	475.47	1.06	1 674.95	336.2	940.2	338.7	956.4	346.3
1968	491.97	1.51	1 542.17	368.1	683.0	327.1	991.7	549.0
1969	485.46	1.30	1 501.48	451.4	511.1	309.2	978.5	357.2
1970	483.35	1.23	1 539.36	486.4	618.1	232.4	974.0	346.4
1971	476.26	1.02	1 454.09	443.6	366.9	253.9	959.2	214.8
1972	475.40	0.98	1 373.37	437.2	308.5	273.6	958.3	164.1
1973	458.43	0.62	1 351.61	362.5	269.5	341.4	922.7	89.6

Average lake level is 0.917 m on Zwai staff. Average annual Bulbula flow = 210 mcm.
Assumed initial content of lake (Jan. 1954) = 1 460.0 mcm

Appendix 5

Lake Abiyata water balance

Table 1 shows the computation of the water balance of Lake Abiyata by months from January 1969 to December 1973. Horakello flows have been estimated from a correlation with the levels of Lake Langano, derived from a curve by Italconsult (1970) and extended by project measurements (Figure 26). Gaps in the lake level record were determined by linear interpolation. The published data for the Horakello River (AVA, 1972 and 1973) were found to contain considerable inconsistencies and could not be used. Bulbula and Gogessa flows were as published. Rainfall on the lake was estimated at 450 mm per year (see Text Map 2) distributed between the months March to September (approximately in accordance with the rainfall distribution at Zwai town); while a figure of 2 000 mm was used as an estimate for annual lake evaporation and the total distributed in the same monthly proportions as for Lake Zwai. Rainfall and evaporation estimates were converted to volumes using the lake level/area relationship shown on Text Map 6; this was also used to derive a level/volume of water relationship, which enabled the effect of monthly storage variations to be converted to lake levels.

The computed gauge heights are plotted in Figure 15 together with observed lake levels. The latter set of levels are not shown exactly as published since the record contained several obvious discontinuities which, in the absence of other information, had to be removed subjectively. The result is a good fit between observed and computed lake levels, and this would suggest that (a) it is reasonable to derive Horakello flows from records of the level of Lake Langano using Figure 26 and (b) evaporation from the lake surface is of the order of 2 000 mm per annum. In view of the adoption of a higher value for evaporation at Zwai, the selection of 2 000 mm at Abiyata could be contentious, particularly as Abiyata is at a lower altitude than Zwai and is slightly drier. However, an initial water balance calculation assuming annual evaporation at 2 200 mm gave predictions of lake levels consistently lower than the recorded values during the 5-year period. If evaporation is shown to be of the order of 2 200 mm (there are no local estimates of evaporation to use as a guide), then either:

1. Rainfall is greater than 450 mm
2. There is a significant ungauged inflow into the lake
3. The interpolation of discontinuities in the lake level record is incorrect, or
4. The lake level/area relationship is inaccurate

Alternatively, the figure for Lake Zwai evaporation could be an overestimate, particularly since no local measurements are available. Certainly, an open water evaporation rate of 2 012 mm per annum at the altitude of Zwai (1 637 m) is well above the anticipated rate, compared with other locations in Ethiopia and in East Africa generally.

TABLE 1 **Lake Abiyata water balance by months (1969–73)**

Month	Horakello river (mcm)	Bulbula river (mcm)	Gogessa river (mcm)	Evaporation-precipitation (mcm)	Storage change (mcm)	Gauge height (m)
1969						1.40
J	4.7	14.2	0.4	27.2	–7.9	1.35
F	2.8	10.4	1.3	25.5	–11.0	1.29
M	3.1	14.2	3.6	30.4	–9.5	1.23
A	2.7	13.5	0.7	22.0	–5.1	1.17
M	2.7	12.6	1.8	23.7	–6.6	1.13
J	2.1	8.6	2.3	16.8	–3.8	1.10
J	2.0	14.2	4.7	8.3	12.6	1.19
A	9.4	42.6	5.5	11.8	45.7	1.49
S	30.3	69.2	6.1	11.9	93.7	2.06
O	29.5	60.5	0.4	31.5	58.9	2.42
N	16.3	38.2	1.9	28.5	27.9	2.60
D	14.5	27.4	0.0	28.6	13.3	2.68
1970						
J	11.0	23.6	0.5	28.6	6.5	2.71
F	7.5	17.5	0.3	26.8	–1.5	2.70
M	4.0	18.7	2.0	32.2	–7.5	2.66
A	2.8	13.3	0.4	23.3	–6.8	2.62
M	2.0	7.3	0.3	24.9	–15.3	2.51
J	1.2	5.2	0.2	17.8	–11.2	2.45
J	1.3	5.7	2.1	8.8	0.3	2.45
A	9.4	31.4	5.7	12.4	34.1	2.66
S	19.4	69.5	2.5	12.5	78.9	3.15
O	29.9	72.8	1.0	32.8	70.9	3.58
N	14.5	44.7	1.6	29.8	31.0	3.78
D	4.0	28.3	2.1	29.9	4.5	3.80
1971						
J	2.0	18.3	1.4	29.9	–8.2	3.75
F	1.2	10.6	0.9	28.0	–15.3	3.66
M	1.0	6.8	0.6	33.5	–25.1	3.50
A	0.7	5.4	0.5	23.9	–17.3	3.40
M	0.6	5.5	0.6	25.6	–18.9	3.30
J	0.6	4.9	0.6	18.2	–12.2	3.21
J	1.0	10.0	0.9	9.1	2.8	3.23
A	3.2	24.0	0.8	12.8	15.2	3.32
S	6.0	49.3	0.8	12.8	43.3	3.60
O	8.3	44.3	1.2	33.3	20.5	3.70
N	2.8	28.1	1.3	29.8	2.4	3.73
D	1.6	18.3	1.2	29.8	8.5	3.78
1972						
J	0.9	12.2	0.9	29.8	–15.8	3.68
F	0.8	8.4	0.8	27.8	–17.8	3.57
M	0.7	9.3	0.7	33.1	–22.4	3.45
A	0.5	8.6	0.8	23.8	–13.9	3.35
M	0.7	9.6	0.6	25.6	–14.7	3.26
J	0.6	8.4	0.3	18.2	–8.9	3.20
J	0.9	9.4	0.8	9.1	2.0	3.22
A	2.0	21.6	3.0	12.7	13.9	3.31
S	7.4	31.9	1.9	12.7	28.5	3.48
O	8.7	27.8	1.2	32.9	4.8	3.50
N	2.2	16.7	1.0	29.3	–9.4	3.45
D	1.0	10.3	0.7	29.3	–17.3	3.32
1973						
J	0.7	6.6	0.2	29.1	–21.6	3.20
F	0.4	3.8	0.0	27.3	–23.1	3.07
M	0.3	1.9	0.0	32.6	–30.4	2.90
A	0.3	0.0	0.0	23.4	–23.1	2.71
M	0.2	0.5	0.3	24.9	–23.9	2.59
J	0.1	0.0	0.4	17.8	–17.3	2.49
J	0.0	1.2	2.2	8.8	–5.4	2.46
A	0.0	0.7	2.0	12.3	–9.6	2.40
S	0.5	9.3	1.2	12.3	–1.3	2.39
O	1.3	13.2	0.2	31.7	–17.0	2.29
N	1.0	8.8	0.0	28.0	–18.2	2.16
D	0.7	4.9	0.0	27.8	–22.2	2.02

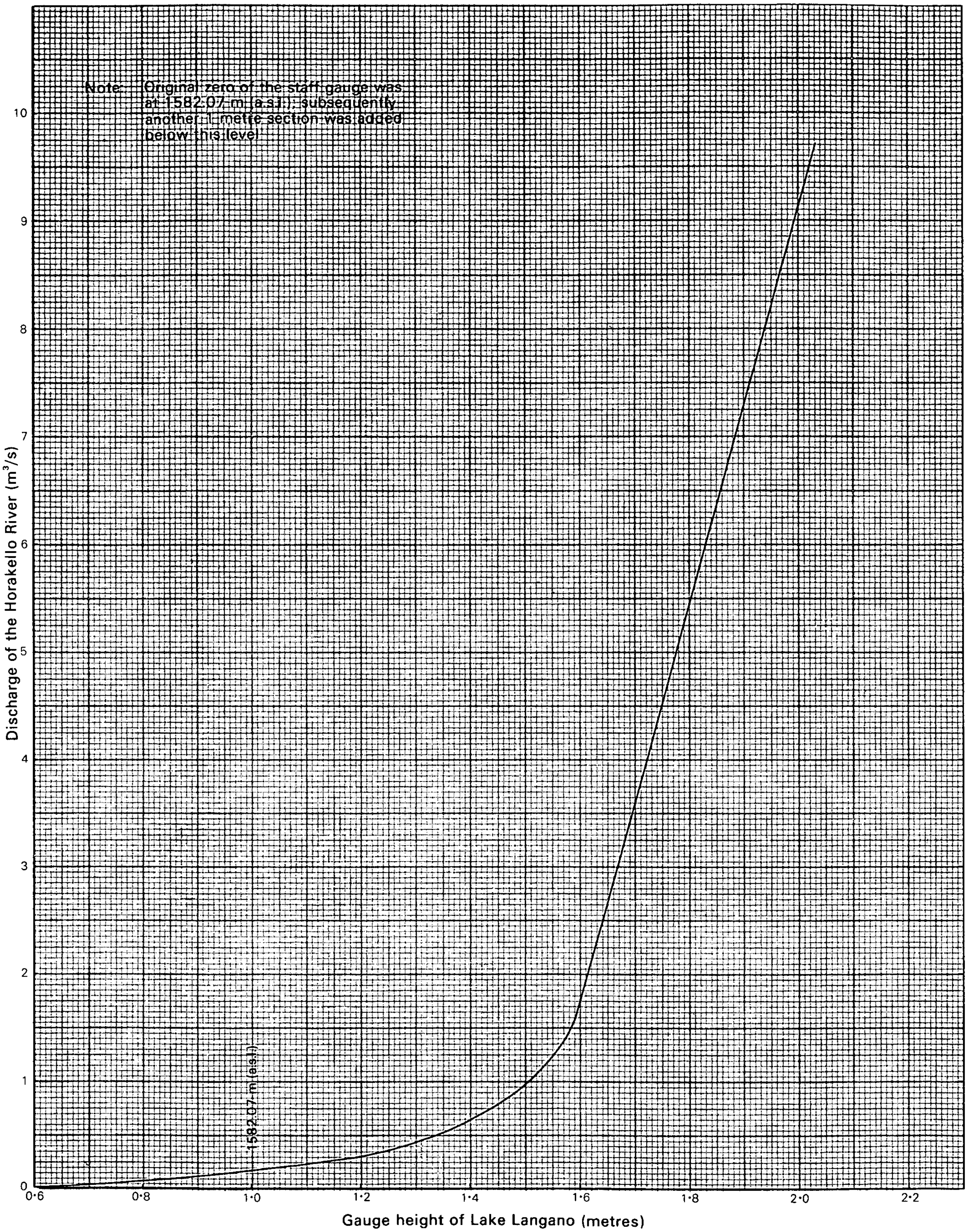

FIGURE 26 Relationship between the level of Lake Langano and outflow in the Horakello River

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Appendix 6

Soil profile descriptions and analyses

This section contains profile descriptions and analysis data for representative profiles of the main soil types. Additional analyses, undertaken to help determine the irrigation suitability of the alkaline terrace soils, are also included.

All terms used in soil descriptions are those defined by Carroll and Hill (1968). Colour names and notations are derived from the Munsell Soil Colour Chart.

A. SOILS ON THE MEKI RIVER LEVÉE

Distribution	Along the Meki River, except in the lower part of the Delta
Location	Meki Delta, on irrigated farm 3 km from Meki – left bank of Meki River
Landform	Recent levee, less than 1% slope. Aspect N E
Land use	Previously under tomatoes
Horizon (depth in cm)	**Description**
0-25	Brown (10YR 5/3). Clay loam with some silty lenses. Cloddy hard consistence. Common small roots. Gradual wavy lower boundary
25-65	Dark grey-brown (10YR 4/2). Clay loam. Moderate subangular blocky structure. Hard consistence. Common fine tubular pores. Moderately developed thick cutans along large pores and root channels. Common small roots. Clear smooth lower boundary
65-175	Brown (10YR 5/3). Few distinct yellowish-brown lenses. Silty clay with lenses of sandy material. Weak subangular blocky structure. Hard consistence. Common fine tubular pores. Common small roots. Gradual smooth lower boundary.
175+	Dark brown (10YR 4/3). Common distinct brown mottles. Clay loam with sand lenses. Weak platey structure. Firm consistence. Few soft irregular blotches of decayed organic matter. Few small roots.
Associated soils	Basin clays occur on flat low-lying sites flanking present-day levee. Towards the lower delta Soil A gives way to sandy and clay soils on old levee material.
Variations	Topsoil textures vary from sandy clay loam to silty clay; subsoils from silty clay loam to clay. Indistinct buried clay topsoils may or may not be present. Thin sand layers of depth less than 15 cm may be present below 10 cm.

Characteristic	Horizon (depth in cm)				
	0-10	10-25	25-65	65-175	175+
Bulk density g/ml	0.9	0.92	0.88	0.87	0.86
Gravel % > 2 mm	0	1	4	0	0
Sand % 2 mm – 0.05 mm	23	17	5	27	37
Silt % 0.05 mm – 0.002 mm	41	42	52	39	33
Clay % <0.002 mm	34	41	43	34	30
Organic matter %	3.4	3.4	1.8	1.4	1.1
Total N %	0.25	0.23	0.13	0.10	0.07
pH (1:5)	7.3	7.4	7.3	6.9	6.7
Conductivity (1:5 at 25°) μmhos/cm	200.0	170.0	120.0	120.0	90.0
Carbonate %	0	0	0	0	0
Soluble sodium meq %	0	0	0	0	0
TEB meq %	36.0	36.6	34.7	32.7	26.8
CEC meq %	35.2	37.1	36.7	35.5	30.1
Base saturation %	100	99	95	92	89
Exch. Na meq %	0.3	0.5	0.9	0.3	0.5
Exch. K meq %	3.4	3.3	3.5	1.8	1.3
Exch. Mg meq %	6.6	6.8	7.7	9.0	7.3
Exch. Ca meq %	25.7	26.0	22.6	21.6	17.7
Exch. Na % (ESP)	<1	1	2	<1	1
Available P (Olsen) ppm	45	23	4	10	6
Total P ppm	1 090	600	440	450	510
Total K ppm	6 400	6 550	7 300	6 700	4 650
Total Mg ppm	5 850	6 100	6 500	6 800	6 150
Copper ppm	30	30	30	30	40
Manganese ppm	1 690	1 790	1 780	1 800	2 170
Zinc ppm	150	166	160	160	140

B. SANDY SOILS ON OLD LEVEE MATERIAL

Distribution	Widespread in the central parts of the Meki Delta on old levee ridges
Location	5 km S E of Meki Town
Landform	Old levee, level
Land use	Previously under maize

Horizon (depth in cm)	**Description**
0-12	Brown (10YR 5/3). Clay loam. Cloddy hard consistence. Common small roots. Gradual smooth lower boundary.
12-25	Greyish-brown (10YR 5/2). Few small faint brown sandy mottles. Clay loam. Moderate medium subangular blocky; few weakly developed prismatic cracks. Very hard consistence. Common small roots. Abrupt wavy lower boundary.
25-85	Brown (10YR 5/3). Loamy sand with a thin layer of banded silt loam at 35 cm. Structureless. Loose consistence. Common small roots. Few pumice grains. Few clay skins along root channels in top 10 cm. Abrupt smooth lower boundary.
85-115	Brown (10YR 5/3), with dark brown and black organic stains between depositional layers. Common distinct strong brown and yellowish-red mottles. Silty clay loam with bands and lenses of silt loam. Banded structure (due to deposition of sand and silt, with well developed vertical cracks when dry. Slightly hard consistence. Common small roots. Abrupt smooth lower boundary.
115-140	Brown (7.5YR 4/2). Common prominent yellowish-red mottles along old root channels. Clay. Moderate coarse vertical cracks. Very hard consistence. Few small roots. Clear wavy lower boundary.
140-160	Dark brown (7.5YR 3/2), with common small brown patches. Clay with areas of silty clay. Weak medium to fine subangular blocky structure. Hard consistence. Few small fibrous roots. Few small soft manganese nodules. Abrupt irregular lower boundary.
160-200+	As 85-115.

Associated soils	Closely associated with clay soils on old levee material, especially north of the Meki River where many local variations occur.
Variations	The subsoil sand (or loamy sand) horizon may occur at depths between 20 and 75 cm and may vary in thickness from 15 to 60 cm. Thin silt loam layers, lenses and convolutions are commonly present within sand horizons. The dominant subsoil horizon is a mottled and banded deposit of silt loam or silty clay loam. Lensing and convoluting are common in this horizon and thin sand layers may also be present. Clay layers usually occur below 75 cm and attain thicknesses of up to 25 cm. An alkali phase below 50 cm has an ESP averaging 37.

Characteristic	Horizon (depth in cm)				
	0-12	12-25	25-85	85-115	115-140
Bulk density g/ml	0.92	0.90	1.23	0.82	0.90
Gravel % >2 mm	0	0	1.1	0.4	0
Sand % 2 mm – 0.05 mm	29	26	89	15	4
Silt % 0.05 mm – 0.002 mm	41	42	6	58	45
Clay % <0.002 mm	30	32	5	27	51
Organic matter %	3.9	2.5	0.3	1.0	1.4
Total N %	0.25	0.15	0.02	0.07	0.11
pH (1:5)	7.0	7.1	7.3	7.5	6.0
Conductivity (1:5 at 25^o) μmhos/cm	120.0	90.0	80.0	150.0	120.0
Carbonate %	0	0	0	0	0
Soluble sodium meq %	0	0	0	0	0
TEB meq %	32.8	31.8	14.6	31.9	34.1
CEC meq %	34.3	35.9	14.4	33.7	41.0
Base saturation	96	89	100	95	83
Exch. Na meq %	0.1	0.2	0.2	1.8	2.9
Exch. K meq %	3.3	2.5	0.9	0.7	1.0
Exch. Mg meq %	5.6	5.9	3.5	7.7	9.4
Exch. Ca meq %	23.8	23.2	10.0	21.7	20.8
Exch. Na % (ESP)	<1	<1	1	5	7
Available P (Olsen) ppm	12	4	3	6	25
Total P ppm	570	470	330	430	530
Total K ppm	7 500	6 950	2 600	5 450	6 850
Total Mg ppm	5 850	6 050	3 800	6 400	6 650
Copper ppm	30	30	20	30	40
Manganese ppm	1 570	1 630	1 290	2 220	1 130
Zinc ppm	150	150	90	160	180

C. CLAY SOILS ON OLD LEVEE MATERIAL

Distribution	Widespread in the central parts of the Meki Delta flanking old levee ridges and seasonally flooded clays
Location	3 km west of the mouth of the Meki River
Landform	Old levee, level
Land use	Previously under maize

Horizon (depth in cm)	Description
0-15	Brown (10YR 4/3). Silty clay loam. Cloddy very hard consistence. Common small roots. Clear wavy lower boundary.
15-40	Brown (10YR 5/3). Few small distinct strong brown mottles associated with lenses of coarse material. Silty clay. Moderate subangular blocky structure. Common small roots. Gradual smooth lower boundary.
40-75	Greyish-brown (10YR 5/2), with bands of brown (10YR 5/3). Common prominent yellowish-red mottles along cracks and on ped faces. Silty clay loam. Banded structure with well developed vertical cracks when dry. Very hard consistence. Common small roots. Abrupt irregular lower boundary.
75-153	Yellowish-brown (10YR 5/4), with streaks of brown (10YR 5/3). Common distinct yellowish-red mottles in heavier textured layers. Loamy sand with thin convoluted bands and lenses of silt loam and silty clay loam. Structureless sand; strongly developed vertical cracks in silty layers. Loose consistence. Common small roots. Abrupt irregular lower boundary.
153-240+	As 40-75 cm, becoming less banded with depth.

Associated soils	Closely associated with the sandy soils on old levee material, especially north of the Meki River where many local variations occur. Profiles become heavier textured towards seasonally flooded clays.
Variations	This soil is an integrade between soils B and F and considerable variations occur, depending on the location of the site with respect to areas of old levee or seasonally flooded clay. When this soil is near sandy soils on old levees, sand layers are usually present below 1 m, and not above 75 cm, (see type profile) and the topsoil comprises heavier textured horizons which are strongly mottled below the plough layer. The amount of sand within the profile decreases away from the sandy levees towards the seasonally flooded clays, where sandy layers may be absent from the profile. An alkaline phase has an ESP over 20 below about 50 cm.

Characteristic	Horizon (depth in cm)				
	0-15	15-40	40-75	75-153	153-240+
Bulk density g/ml	0.89	0.89	0.89	1.06	0.84
Gravel % >2 mm	0	0	0.7	0.4	6.5
Sand % 2 mm – 0.05 mm	6	2	3	66	29
Silt % 0.05 mm – 0.002 mm	64	46	60	20	34
Clay % <0.002 mm	30	52	37	14	37
Organic matter %	2.9	1.5	1.1	0.3	0.6
Total N %	0.21	0.11	0.08	0.03	0.04
pH (1:5)	6.7	6.8	7.1	7.4	7.2
Conductivity (1:5 at 25^{o}) μmhos/cm	100.0	80.0	90.0	80.0	210.0
Carbonate %	0	0	0	0	0
Soluble sodium meq %	0	0	0	0	0
TEB meq %	32.6	36.7	33.7	20.0	27.0
CEC meq %	35.7	41.8	37.1	19.7	28.1
Base saturation %	91	88	91	100	96
Exch. Na meq %	0.3	0.6	1.6	1.5	2.0
Exch. K meq %	4.0	1.5	0.9	0.7	2.1
Exch. Mg meq %	8.0	10.3	9.5	4.8	6.5
Exch. Ca meq %	20.3	24.3	21.7	13.0	16.4
Exch. Na % (ESP)	<1	1	4	7	7
Available P (Olsen) ppm	7	4	6	4	3
Total P ppm	420	320	340	360	300
Total K ppm	8 200	8 050	6 400	3 100	5 200
Total Mg ppm	6 550	7 400	6 800	4 800	5 450
Copper ppm	30	30	30	20	30
Manganese ppm	2 310	2 330	2 240	1 250	1 690
Zinc ppm	170	180	170	110	140

D. BASIN CLAYS

Distribution	Flanking the current levee of the Meki River
Location	Meki Delta, 3 km south of Meki Town
Landform	Level clay basins
Vegetation	Dense *Acacia/Croton* woodland with grass understorey
Horizon (depth in cm)	**Description**
0-10	Greyish-brown (10YR 4/2). Clay to silty clay. Strong coarse subangular blocky structure. Very hard consistence. Common small roots. Clear smooth lower boundary.
10-30	Greyish-brown (10YR 5/2). Few small faint brown patches. Clay with silty areas. Strong coarse subangular blocky structure. Very hard consistence. Common small, and few medium roots. Clear smooth lower boundary.
30-55	Dark greyish-brown (10YR 4/2). Few small faint brown patches. Clay with silty areas. Moderate subangular blocky structure. Very hard consistence. Common small, and few medium roots. Few dark specks of organic matter. Gradual smooth lower boundary.
55-200+	Dark greyish-brown (10YR 4/2). Few small faint brown patches. Clay with silty areas. Weak, becoming very weak below 85 cm, subangular blocky structure. Very hard consistence. Few small roots. Few dark specks of organic matter.
Associated soils	Towards the Meki River, these soils grade into coarser textured levee materials. Away from the river, towards the central part of the delta, they are associated with clays and sands on old levees. Near the edge of the delta, they grade into lacustrine clay loams.
Variations	This soil often exhibits dark buried topsoils below the surface. Subsoil horizons contain varying proportions of fine sand and silt in the form of small lenses. Towards the lacustrine terraces, subsoils become paler in colour, coarser textured and calcareous. The formation of surface cracks under natural vegetation gives rise to rapid rates of infiltration which decrease significantly after cultivation.

Characteristic	Horizon (depth in cm)				
	0-10	10-30	30-55	55-100	100-200+
Bulk density g/ml	0.85	0.90	0.94	0.87	0.91
Gravel % >2 mm	0	0	0	0	0
Sand % 2 mm – 0.05 mm	6	4	4	3	4
Silt % 0.05 mm – 0.002 mm	44	44	40	45	33
Clay % <0.002 mm	50	52	56	52	63
Organic matter %	6.1	2.2	1.8	1.6	2.0
Total N %	0.40	0.15	0.12	0.11	0.13
pH (1:5)	6.5	6.7	6.5	6.5	6.7
Conductivity (1:5 at 25°) μmhos/cm	130.0	170.0	70.0	70.0	70.0
Carbonate %	0	0	0	0	0
Soluble sodium meq %	0	0	0	0	0
TEB meq %	43.0	37.2	38.0	36.6	40.8
CEC meq %	45.5	40.6	42.0	39.7	42.2
Base saturation %	95	92	90	92	97
Exch. Na meq %	0.2	0.2	0.2	0.3	0.4
Exch. K meq %	2.7	2.2	1.7	1.3	1.7
Exch. Mg meq %	8.7	9.3	9.8	8.8	9.3
Exch. Ca meq %	31.4	25.5	26.3	26.2	29.4
Exch. Na % (ESP)	<1	<1	<1	<1	1
Available P (Olsen) ppm	11	3	0	1	3
Total P ppm	590	480	400	410	370
Total K ppm	8 100	7 800	7 750	7 000	8 200
Total Mg ppm	7 000	7 250	7 400	7 100	7 550
Copper ppm	30	40	40	40	40
Manganese ppm	1 850	1 830	1 870	1 870	1 750
Zinc ppm	180	180	180	170	180

F: SEASONALLY FLOODED CLAYS

Distribution	Widespread on the fringes of the Meki and Catar deltas
Location	2.5 km south west of the mouth of the Meki River
Landform	Seasonally flooded grassland; very gentle slope towards the lake
Vegetation	*Sporobolus* grassland used for seasonal grazing
Horizon (depth in cm)	**Description**
0-10	Greyish-brown (10YR 5/2). Common distinct mottles. Clay. Strong coarse subangular blocky structure. Extremely hard consistence. Many small roots. Few small pumice stones. Clear smooth lower boundary.
10-20	Dark grey (10YR 4/1). Few distinct yellowish-red mottles. Clay. Strong, very coarse subangular blocky structure with a few large vertical cracks. extremely hard consistence. Many small roots. Clear smooth lower boundary.
20-50	Brown (7.5YR 4/2). Few distinct prominent yellowish-red mottles. Clay. Strong coarse subangular blocky structure with a few large vertical cracks. Extremely hard consistence. Many small roots. Clear smooth lower boundary.
50-80	Very dark grey (10YR 3/1). Few distinct brown, and common prominent strong brown, mottles along old root channels. Clay. Moderate medium to coarse subangular blocky structure with a few weakly developed vertical cracks. Extremely hard consistence. Common small roots. Gradual smooth lower boundary.
80-155	Brown (10YR 4/2). Few faint dark brown and prominent yellowish-red mottles. Clay. Moderate coarse, breaking to fine angular blocky, structure with well developed pressure faces between structural units. Very hard consistence. Common small roots. Few small soft manganese nodules. Abrupt smooth lower boundary.
155-175	Dark grey (10YR 4/1). Clay. Moderate coarse, breaking to fine, angular blocky structure with well developed pressure faces between structural units. Very hard consistence. Common small roots. Few small hard carbonate concretions. Abrupt smooth lower boundary.
175-230+	Greyish-brown (2.5Y 6/2). Loamy coarse sand. Structureless. Loose consistence. Few small roots. Common pumice stones. Few small hard carbonate concretions. Positive reaction with HCl.
Associated soils	Grades into clay soils on old levees towards higher-lying areas of the delta and into silty swamp soils towards the lake. Associated with periodically flooded sandy soils near overflow channels of the Meki River and with saline/alkaline soils along the north-eastern lake shore.
Variations	Sand may be present at any depth below 150 cm. Along the north-eastern shoreline silt contents are higher than normal, and subsoils are locally alkaline adjacent to saline/alkaline silt bars. Where alkalinity is extensive alkaline phases have been mapped.

Characteristic	Horizon (depth in cm)					
	0-10	10-20	20-50	50-80	80-175	175-230+
Bulk density g/ml	0.81	0.88	0.97	0.89	0.95	1.10
Gravel % >2 mm	0	0	0	0	0	0.8
Sand % 2 mm – 0.05 mm	4	2	3	3	2	88
Silt % 0.05 mm – 0.002 mm	44	26	23	33	14	8
Clay % <0.002 mm	52	72	74	64	84	4
Organic matter %	3.8	2.0	1.6	1.3	1.2	0.2
Total N %	0.22	0.14	0.12	0.09	0.08	0.02
pH (1:5)	6.1	6.5	6.6	7.2	7.7	8.1
Conductivity (1:5 at 25^{o}) μmhos/cm	110.0	180.0	390.0	400.0	520.0	160.0
Carbonate %	0	0	0	0	0	0.5
Soluble sodium meq %	0.2	0.1	0.2	0.3	0.4	0.1
TEB meq %	32.4	38.3	38.9	38.3	52.5	20.5
CEC meq %	41.8	45.2	43.4	42.0	54.0	13.4
Base saturation %	78	85	90	91	97	100
Exch. Na meq %	1.4	2.3	3.2	4.5	6.5	1.0
Exch. K meq %	2.1	1.3	2.4	1.1	1.3	0.9
Exch. Mg meq %	9.3	10.7	10.3	9.7	12.7	3.7
Exch. Ca meq %	19.6	24.0	23.0	23.0	32.0	14.9
Exch. Na % (ESP)	3	5	7	10	12	7
Available P (Olsen) ppm	17	3	19	3	6	1
Total P ppm	570	290	380	350	260	180
Total K ppm	8 200	8 950	9 100	7 400	9 700	3 250
Total Mg ppm	7 200	8 000	8 000	7 200	9 150	2 950
Copper ppm	40	40	40	40	40	10
Manganese ppm	1 450	1 560	1 010	1 770	1 130	660
Zinc ppm	180	200	190	180	210	80

H. SANDY TERRACE SOILS OVERLYING COARSE PUMICE

Distribution	Widespread on the lower and upper terraces west and north east of Lake Zwai
Location	At 'Zwai Farm'
Landform	Lowest lacustrine terrace; level
Land use	Irrigated tomatoes
Horizon (depth in cm)	**Description**
0-20	Greyish-brown (10YR 5/2). Sandy loam. Weak subangular blocky structure. Slightly hard consistence. Common small roots. Clear wavy lower boundary.
20-60	Greyish-brown (10YR 5/2). Loamy sand. Very weak subangular blocky structure, somewhat compacted. Soft consistence. Few small roots and pumice stones. Diffuse smooth lower boundary.
60-110	Light grey (10YR 7/2). Loamy sand. Compact structure. Soft consistence. Few small roots and pumice stones. Clear wavy lower boundary.
110-200+	Light grey (10YR 7/2). Loam, with lenses of loamy sand. Weak, angular blocky structure. Slightly hard consistence. Few small roots and pumice stones.
Associated soils	Medium-textured soils occur in close association on all terraces. South of Meki, east of the Bulbula River and west of Zwai, Soil H flanks saline/alkaline land.
Variations	Topsoil textures vary from sandy loam to loam; subsurface textures from loamy coarse sand to sandy loam. Subsoils may be very coarse-textured to depth, or medium-textured layers may occur below 1 m. About 50% of the sites sampled had a subsoil ESP of over 20; depth to alkali varied from 60 to 100 cm. A small area with lava stones and boulders on the ground surface, to the east of the Bulbula River, has been mapped as a bouldery phase.

Characteristic	Horizon (depth in cm)			
	0-20	20-60	60-110	110-200+
Bulk density g/ml	1.09	1.10	1.07	0.93
Gravel % >2 mm	0.5	0.6	0.4	0.8
Sand % 2 mm – 0.05 mm	59	63	67	48
Silt % 0.05 mm – 0.002 mm	31	27	25	40
Clay % <0.002 mm	10	10	8	12
Organic matter %	1.1	0.5	0.1	0.1
Total N %	0.14	0.07	0.02	0.01
pH (1:5)	7.2	6.9	9.7	10.4
Conductivity (1:5 at 25^{o}) μmhos/cm	120.0	100.0	510.0	1 270.0
Carbonate %	0	0	4.5	5.0
Soluble sodium meq %	0.1	0.1	0.7	1.9
TEB meq %	18.0	16.4	52.9	64.4
CEC meq %	17.9	17.3	16.8	24.1
Base saturation %	100	95	100	100
Exch. Na meq %	0.6	0.4	8.4	22.8
Exch. K meq %	3.1	2.7	3.4	5.7
Exch. Mg meq %	2.8	2.6	2.3	1.6
Exch. Ca meq %	11.5	10.7	38.8	34.3
Exch. Na % (ESP)	3	2	50	95
Available P (Olsen) ppm	4	1	0	3
Total P ppm	200	180	180	200
Total K ppm	5 950	5 950	5 050	10 050
Total Mg ppm	4 200	4 500	5 200	9 450
Copper ppm	10	10	10	10
Manganese ppm	640	640	540	600
Zinc ppm	80	80	80	90

J. MEDIUM-TEXTURED TERRACE LOAMS OVERLYING ASH

Distribution	Extensive on the middle terraces west and north-east of Lake Zwai
Location	1 km west of Zwai Town
Landform	Second lacustrine terrace, level
Land use	Previously under tef
Horizon (depth in cm)	Description
0-35	Light brownish-grey (10YR 6/2). Loam. Weak to moderate sub-angular blocky structure. Slightly hard consistence. Common ash grains. Common small roots. Clear smooth lower boundary.
35-140+	Light grey (10YR 7/2), dry. Yellowish-brown (10YR 5/4), moist. Silt loam. Weak subangular blocky structure, indurated in the top 15 cm. Slightly hard consistence. Common ash grains. Few small roots. Calcareous.
Associated soils	Soil J occurs on all terraces in close association with sandy soils, but flanks clay loams south of Meki and both north and south of the Catar River. Small inclusions (unmapped) of clay loam occur within Soil J.
Variations	Textures vary from sandy loam to silt loam. Sandy loam subsoils are less compact than normal. About 75% of sites sampled had a subsoil ESP of over 20 and the depth to subsoil alkali varied from 35 to 75 cm. Silty areas around the Meki and Catar deltas have been mapped as a silty phase.

Characteristic	Horizon (depth in cm) 0-35	35-140+
Bulk density g/ml	0.94	0.96
Gravel % >2 mm	0	0
Sand % 2 mm – 0.05 mm	36	35
Silt % 0.05 mm – 0.002 mm	47	52
Clay % <0.002 mm	17	13
Organic matter %	2.5	0.3
Total N %	0.17	0.03
pH (1:5)	7.7	9.2
Conductivity (1:5 at 25^{o}) μmhos/cm	120.0	280.0
Carbonate %	0	15.5
Soluble sodium meq %	0	0
TEB meq %	36.9	>65.3
CEC meq %	32.2	26.4
Base saturation %	100	100
Exch. Na meq %	0.3	6.0
Exch. K meq %	3.0	5.1
Exch. Mg meq %	3.1	4.2
Exch. Ca meq %	30.5	>50
Exch. Na % (ESP)	<1	23
Available P (Olsen) ppm	0	0
Total P ppm	210	200
Total K ppm	9 600	7 850
Total Mg ppm	8 750	10 150
Copper ppm	10	10
Manganese ppm	1 020	830
Zinc ppm	110	80

M. CLAYS WITH COARSE SANDY SUBSOIL

Distribution	Widespread on western lake margins
Location	1 km north of Zwai Town
Landform	Level lake margin (seasonally flooded)
Vegetation	*Sporobolus* grassland used for seasonal grazing

Horizon (depth in cm)	**Description**
0-25	Dark grey (10YR 4/1). Very few faint yellowish-brown mottles. Clay. Strong coarse subangular blocky structure. Extremely hard consistence. Many small roots. Abrupt wavy lower boundary.
25-67	Light grey (10YR 7/1), with brown staining along roots. Loamy sand to sandy loam, with a 10 cm layer of gravel and coarse sand at base. Structureless and compact. Common small roots. Common pumice grains and few small pumice stones. Abrupt smooth lower boundary.
67-120	Light grey (5Y 7/2). Few prominent reddish-brown and dark red mottles increasing with depth. Loamy sand. Structureless. Loose consistence. Few small roots. Common pumice grains, and few small pumice stones in bottom 10 cm. Clear smooth lower boundary.
120-135	Light grey (2.5Y 5/0). Few prominent strong brown mottles. Gravelly loamy sand. Structureless. Loose consistence. Few small roots. Common pumice grains and small stones. Abrupt smooth lower boundary.
135-200+	Grey (5Y 5/1). Few to common prominent brownish-yellow mottles along root channels. Sandy clay loam with lenses of loamy sand. Common pumice grains and a few bands of small pumice stones.

Associated soils	Towards the permanently waterlogged areas near the lake, topsoils increase in organic matter and clay surface textures give way to sandy loam. Towards the terraces, saline/alkaline soils occur intermittently associated with ground water seepage at the terrace foot.
Variations	Along the western edge of the Meki Delta, there is a subsoil increase in clay. The clay topsoil varies in depth from 15 to 45 cm, depending on microtopography.

Characteristic	Horizon (depth in cm)			
	0-25	25-67	67-120	135-200+
Bulk density g/ml	0.81	0.82	0.80	0.65
Gravel % >2 mm	0	0	1.1	0.4
Sand % 2 mm – 0.05 mm	15	64	76	27
Silt % 0.05 mm – 0.002 mm	18	24	18	41
Clay % <0.002 mm	67	12	6	32
Organic matter %	4.5	0.3	0.2	0.1
Total N %	0.32	0.03	0.02	0.02
pH (1:5)	7.5	8.1	7.9	7.6
Conductivity (1:5 at 25^{o})μmhos/cm	150.0	70.0	70.0	80.0
Carbonate %	0	0	0	0
Soluble sodium meq %	0	0	0	0
TEB meq %	42.1	13.4	21.0	43.8
CEC meq %	45.5	12.9	22.3	45.5
Base saturation %	93	100	94	96
Exch. Na meq %	2.0	1.0	1.4	2.1
Exch. K meq %	2.3	1.1	1.6	2.1
Exch. Mg meq %	13.3	3.8	6.0	14.5
Exch. Ca meq %	24.5	7.5	12.0	25.1
Exch. Na % (ESP)	4	8	6	4
Available P (Olsen) ppm	1	0	0	0
Total P ppm	220	110	120	250
Total K ppm	7 150	3 100	6 150	10 850
Total Mg ppm	6 350	2 550	5 850	10 650
Copper ppm	20	10	10	10
Manganese ppm	280	160	300	740
Zinc ppm	70	60	90	190

MORE DETAILED ANALYSES

More detailed analyses were undertaken on selected soils affected by salt and/or alkali. These included electrical conductivity determinations on the saturated paste of soils having conductivities of 400-4 000 μmhos/cm in the 1:5 extract (Table 1).

TABLE 1 Distribution of soil salinity in the Zwai area

Degree of salinity	Soil type	Depths (cm)	Electrical conductivity at 25°C (μmhos/cm)		Ratio of 1:5 extract to saturated paste determinations
			1:5 extract	saturated paste	
Traces of salinity in the subsoil	F	50-100	400	1 920	1 : 4.8
		100-200	520	1 730	1 : 3.3
	Fa	40-80	580	1 700	1 : 2.9
		100+	950	3 200	1 : 3.4
	H	100+	660	2 100	1 : 3.2
		40-140	520	3 300	1 : 6.3
	J	55-80	510	1 630	1 : 3.2
		60+	610	1 650	1 : 2.7
		110-200	570	2 340	1 : 4.1
		30-60	890	2 400	1 : 2.7
		60+	560	2 850	1 : 4.9
Traces of salinity throughout the profile	N	0-30	740	2 420	1 : 3.3
		0-30	650	2 520	1 : 3.9
		100+	630	2 800	1 : 4.4
		0-30	960	3 200	1 : 3.3
Saline in the subsoil	Ba	80-130	1 280	8 000	1 : 6.3
	L	90-150+	1 000	6 725	1 : 6.7
Saline throughout the profile	N	15-30	1 180	5 580	1 : 4.7
		130+	1 095	6 500	1 : 5.9
		85-140	775	7 600	1 : 9.8
		0-45	1 600	8 800	1 : 5.5
		60-110	1 700	10 500	1 : 6.2
		0-30	3 700	19 000	1 : 5.1

Amongst other things, the data in Table 1 indicate that a fairly stable relationship exists between the conductivity determined from the 1:5 soil-water extract and that determined on the saturated paste. For the non-saline soils (i.e. those with a conductivity of less than 4 000 μmhos/cm in the saturated paste) the mean ratio of the determinations on the 1:5 extract to those on the paste is 1:3.8, whereas the ratio for the saline soils averages 1:6.3. Because of the relative stability in these relationships, the electrical conductivity of a 1:5 soil-water suspension can be reliably and simply evaluated in terms of the equivalent saturated conductivity.

A limited number of determinations were also carried out to assess the level of total boron in soils with contrasting concentrations of salt and alkali (Table 2).

TABLE 2 **Total boron**

Soil type	Depth (cm)	Total boron (ppm)	EC 1:5 extract at 25°C (μmhos/cm)	ESP
Ca	0-10	1.21	190	7
	30-50	0.94	900	46
	100+	0.59	290	55
G	0-40	0.70	80	1
	100-140	0.50	70	30
H	0-25	0.36	60	1
	150+	0.70	320	26
H	0-30	0.52	70	<1
	30-80	0.46	60	4
	100+	0.84	960	69
J	0-30	1.90	240	2
	55-80	2.74	510	30
	95-125	3.14	630	40
J	0-50	0.59	160	2
	50+	3.71	610	42
L	0-30	0.34	70	1
	65-90	1.84	1 170	82
	135-160	4.04	1 050	91
N	0-30	3.90	2 830	100
	50-100+	1.90	1 620	91

Boron toxicity may be present in saline soils; the levels at which excess boron affects plant growth have been defined by the USDA (1954). The highest concentrations of boron around Zwai occur in soils with a combination of high salinity and alkalinity whether at depth on the terraces, or in Soil N. It is not considered however that boron levels will be a limiting factor to plant growth in those areas proposed for irrigation.

METHODS OF SOIL ANALYSIS

Moisture and bulk density

10 ml of fine earth were placed in a preweighed container and reweighed. The sample was dried at 105°C for 4 hours, cooled and reweighed. The dried sample was finely ground (bulk to pass 50 mesh sieve), and kept for total element determinations including organic matter and trace elements.

Mechanical analysis

The fine earth, <2 mm in diameter, was pre-treated with hydrogen peroxide to remove organic matter and dispersed. Particles <50 μ were determined by settling; the clay and silt fractions (<2 μ and 50 μ-2 μ) were separated and measured. The sand fraction was determined by subtraction. The gravel fraction (>2 mm) was determined by sieving.

pH and conductivity

10 ml of fine earth were placed in a container and 50 ml of distilled water added. The suspension was shaken for 30 minutes and allowed to settle before measurements were taken. Conductivity measured at 25°C.

Exchangeable cations

A plug of washed and dried cotton wool was placed in the stem of a 7 cm polypropylene filter funnel and covered with about 8 g of acid-washed sand. 5 g of soil and sufficient acid-washed sand (5-10 g) to allow easy solution flow were mixed and placed in the funnel. A final layer of 8 g of acid-washed sand was added and the whole covered with a circle of filter paper to prevent mixing when the solutions were added. If the conductivity figure was greater than 500 μmhos/cm in a 1:5 soil to water suspension, pre-leaching was undertaken to remove soluble salts. The prepared samples were then leached with 10 x 20 ml aliquots of neutral normal ammonium acetate over a period of time greater than 2 hours and less than 24 hours. The leachate was made up to a volume of 250 ml and mixed well.

Exchangeable sodium and potassium were determined on a Technicon flame photometer using lithium as an internal standard. Exchangeable magnesium and calcium were determined on a Perkin Elmer 290 atomic absorption spectrophotometer, using 1 000 ppm strontium as the releasing agent.

The analytical method for determining exchangeable bases, using normal ammonium acetate leaching, brings non-exchangeable calcium into solution, so that the data presented under the heading 'exchangeable calcium' can be misleading. In the majority of subsoils, where sodium levels are high, the sum of exchangeable sodium, potassium and magnesium approximate to the cation exchange capacity. It is evident, therefore, that in these soils, though the amount of total calcium may be high, the level of exchangeable calcium is low.

Cation exchange capacity and soluble sodium

After completion of the leaching process described above, excess ammonium acetate was removed with 4 x 25 ml aliquots of 80% industrial methylated spirit. The exchanged ammonium salts were then replaced in the soil by leaching with 4 x 20 ml aliquots of normal potassium chloride at a pH of 2.5. The leachate was made up to a volume of 100 ml and the ammonia determined colorimetrically as indophenol blue on a Technicon AutoAnalyser at 625 m μ. Soluble sodium was determined by flame photometry after leaching as above.

Total nitrogen (kjeldahl method)

0.2 g of finely ground dried soil were placed in a 50 ml Kjeldahl flask graduated at 40 ml. 2 g of sodium sulphate containing 0.1 g of selenium and 4 ml of concentrated sulphuric acid were added and heated until all the carbon was destroyed, and for a further 15 minutes after clearing. The digested sample was cooled and a small amount of water added to prevent the digest solidifying. When cool the volume was made up to 40 ml. After complexing manganese and iron with citrate/tartrate, the nitrogen was determined colorimetrically as indo-phenol blue on a Technicon AutoAnalyser at 625 m μ.

Organic matter

Assuming an ultimate carbon: nitrogen ratio of 15, sufficient soil was weighed to contain about 10-15 mg of carbon. In low nitrogen soils, the minimum weight of soil taken was 2 g., The weighed sample was placed in a 250 ml conical flask and 10 ml of normal potassium dichromate were added, followed by 20 ml of concentrated sulphuric acid. The temperature of the reactants was raised to 130± 5°C by this addition and all organic matter was oxidised. After cooling for 30 minutes, 70 ml of distilled water were added and well mixed. Aliquots were centrifuged to remove clay particles and fine calcium sulphate crystals, before the green chromium sulphate was measured colorimetrically on a Technicon AutoAnalyser at 625 m μ. Calibration was by standard sucrose solution.

Total elemental analysis

0.2 g of finely ground soil were digested with 2 ml of perchloric acid at 200°C for 4½ hours, in a test tube graduated at 15 ml and contained in an aluminium heating block. The digest, after cooling, was made up to the 15 ml mark with distilled water and shaken well.

Phosphorus was determined colorimetrically on a Technicon AutoAnalyser at 625 m μ. Ascorbic acid was used as the reducing agent. Sodium and potassium were determined on a Technicon AutoAnalyser flame photometer with lithium as an internal standard. Magnesium and the trace elements, copper, manganese and zinc, were determined by atomic absorption spectroscopy. In the case of magnesium, 1 000 ppm strontium were used as a releasing agent.

Available phosphorus (Olsen's Method)

5 g of soil were shaken for 30 minutes with 100 ml of M/2 sodium bicarbonate and filtered. After acidifying to neutralise the bicarbonate,phosphorus was determined colorimetrically on an AutoAnalyser at 625 m μ, by the molybdate blue method using ascorbic acid as the reducing agent.

Carbonate determination

5 g of soil were shaken with 50% (by volume) hydrochloric acid in a closed conical flask. The gas evolved was measured by a calcimeter calibrated in % carbonate. If the volume of the calcimeter was exceeded, less soil was taken and the method repeated.

Boron

60 ml of water were added to 30 ml of soil, simmered for 10 minutes and then filtered. The colour developed in an aliquot of filtrate by a methylene blue/hydrogen perioxide reagent was extracted into dichloroethane and measured in a colorimeter at 660 m μ.

Appendix 7

Available soil moisture

Available water capacities and moisture characteristic curves are shown in Table 1 and Figure27, respectively, for the main irrigable soils. Field capacity moisture contents were determined on undisturbed soil cores taken in the field one day after wetting by hand, or one day after irrigation or heavy rainfall. Moisture contents at 2, 5, 10 and 15 bars (atmospheres) tension were determined on disturbed samples in the laboratory by means of pressure membrane apparatus. The difference in the volumetric moisture contents at field capacity and at 15 bars (permanent wilting point) was taken as the available water capacity of the soil.

The available water capacities of heavy-textured soils (clay to clay loam) were found to be lower than anticipated and generally less than 10%. This figure may vary, however, according to the previous wetting history of the soil, since the degree of clay swelling and the water content at field capacity are to an extent related. In practice, most samples were taken from soils which had previously been dry; the available water capacities may therefore be underestimated. The high figure for available water capacity (of 16.8%) in a loamy sand subsoil on the Meki Delta may be due to high moisture content at the time of measurement of the field capacity. Available water capacities of 10-19% and 10-13%, respectively, in medium and coarse-textured horizons of terrace soils, are generally consistent with the textures.

Figure 27 shows that, whereas the actual moisture contents at equivalent tensions are less in Soil H (coarse-textured) than in Soils B and J (medium-textured), the available water capacity of Soil H is greater. Moreover, most of the available water in the heavier-textured soils is held at tensions greater than 2 bars while the opposite applies to most of the coarser-textured soils. Consequently, plant growth is expected to decline more rapidly during irrigation intervals on the heavier soils, since only small water deficits would cause a major increase in water tension.The actual decrease in growth during dry periods will also be determined by the leaf and rooting characteristics of the crop and by the intensity of evaporation. As a generalisation it has been assumed that, on all soils with a complete crop canopy, the growth rates of most actively-growing crops would decline as irrigation intervals exceed five days, and that irrigation should be applied more frequently on those soils with low levels of water held between field capacity and 2 bars water tension.

TABLE 1 Summary of available soil moisture

Soil	Location	Depth (cm)	Field texture	True density (g/ml)	Apparent density (g/ml)	Porosity (%)	Moisture at field capacity (volume basis) (%) (i)*	(ii)*	Moisture at wilting point (volume basis) (%)	Available water (volume basis) (%)	Air-filled pore space at field capacity (volume basis) (%)	Mechanical analysis: Clay < 0.002 mm (%)	Silt 0.002 to 0.05 mm (%)	Sand 0.05 to 2 mm (%)
A Soils on the Meki River levee	Irrigated farm 3 km south east of Meki Town	0-45	clay loam to silty clay	2.519	1.058	58.0	31.3		21.4	9.9	26.7	40	41	19
	Irrigated farm 1.5 km south east of Meki Town	0-20	silty clay loam	2.431	1.022	58.0	40.5		27.8	12.7	17.5	21	57	22
B Sandy soils on old levee material	5 km south east of Meki Town	0-20	clay loam	2.536	1.106	56.4	31.1		23.3	7.8	25.3	31	41	28
		35-85	loamy sand	2.605	1.144	56.1	25.5		12.6	12.9	30.6	7	6	87
	9 km south east of Meki Town	0-20	silty clay loam	2.515	1.116	55.7	33.7		23.5	10.2	22.0	28	56	16
		35-120	loamy sand	2.643	1.318	50.3	25.3		9.5	16.8	25.0	5	5	90
C Clay soils on old levee material	3 km north west of the Meki River mouth	0-20	Clay	2.501	1.075	57.1	36.1		28.1	8.0	21.0	55	43	2
		20-40	silty clay loam	2.499	1.089	56.5	37.8		30.1	7.7	18.7	37	60	3
F Seasonally flooded clays	Grassland about 2.5 km west of the Meki River mouth	20-80	clay	2.543	1.176	53.8	44.2		37.2	7.0	9.6	71	23	6
H Sandy terrace soils overlying coarse pumice	Irrigated farm 2 km south of Abosa 'Zwai Farm'	0-30	sandy loam	2.465	1.010	58.0		23.0	11.1	11.9	35.0	17	25	58
		25-85	loamy sand	2.459	1.010	58.9		24.0	11.8	12.2	34.9	6	6	88
		0-30	sandy loam	2.533	1.140	56.2	27.6		9.8	17.8	28.6	10	31	59
	Adamitulu Ranch	20-60	loamy sand	2.508	1.192	47.5		21.9	11.4	10.5	25.6	7	26	67
	Southern boundary of Adamitulu Ranch	0-30	sandy loam	2.428	1.108	54.4	29.3	26.9	13.6	13.3	26.3	n.d.	n.d.	n.d.
		0-30	coarse sandy loam	2.420	1.063	56.1	30.5	27.5	11.9	15.6	27.1	n.d.	n.d.	n.d.
J Medium-textured terrace loams overlying ash	1 km west of Zwai Town	0-30	loam	2.462	1.079	56.2	33.6		22.9	10.5	22.6	17	47	36
		60-100	silt loam	2.537	1.116	56.1	34.6		20.4	14.2	21.5	13	52	35
	Adamitulu Ranch	0-45	loam	2.418	1.063	56.0	28.9	29.3	16.9	12.2	26.9	n.d.	n.d.	n.d.
		70-130	silt loam	2.484	0.962	61.3	33.9	31.9	16.0	16.9	28.4	n.d.	n.d.	n.d.
	Irrigated farm 2 km north of Bulbula rock sill	0-20	loam	2.427	0.936	61.4	31.5		13.2	18.3	29.9	11	41	48
	Irrigated farm 0.5 km north of Bulbula rock sill	0-20	silt loam	2.383	0.852	64.2	27.3		12.9	14.4	36.9	18	52	30

* Field capacity determinations (i) taken 1 day after irrigation or artificial saturation; (ii) taken 1 day after several days of continuous rainfall. n.d. = not determined.

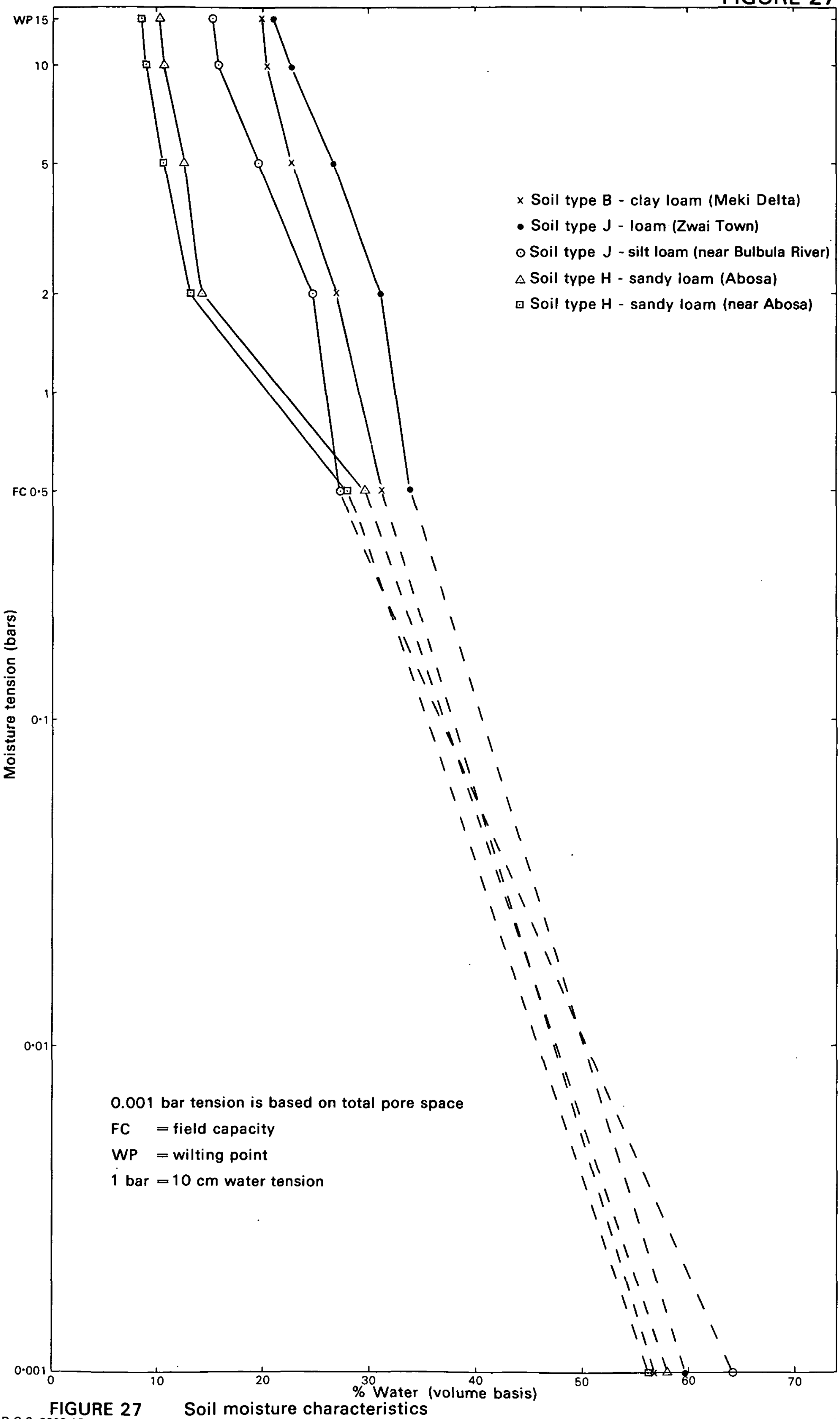

FIGURE 27 Soil moisture characteristics

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Appendix 8

Soil water intake

Water intake was measured at 20 sites using a double-ring infiltrometer, which consisted of inner and outer rings, of approximately 30 and 60 cm diameter respectively, fed by a storage tank of the same diameter as the inner ring. The rings were inserted about 10 cm into the ground and a head of 10 cm of water was maintained in the inner ring. Intake was recorded at regular intervals for 9 hours during the day: 12 times in the first hour, 4 times in the second, twice in the third and thereafter every hour. Overnight intake during a 15-hour period was used to calculate the average final rate of infiltration. The data in Table 1 are based on the average of three replicated measurements at each site, except where indicated.

Intake was found to be closely related to land use and soil texture but also reflected surface soil structure; indeed, the intake rate on clay soils was essentially a function of soil structure and ranged from 5 to 50 mm/hour, the faster rates being on uncultivated land with well developed surface cracks. Figure 28 shows that these soils demonstrated rapid water intake for the first 10 minutes, until the swelling of the structural units decreased the number of large pores, thereby slowing down intake. Sandy soils on old levees, with sandy layers near the ground surface exhibited fairly rapid intake rates (over 40 mm/hour). Intake on the heavier-textured levees was appreciably slower (only 4 mm/hour). Medium and coarse-textured terrace soils showed a slower intake than expected, probably due to poor structure caused, in part, by subsoil alkalinity. While intake on the terrace loams (Soil J) averaged only about 25 mm/hour, the coarse-textured soils (Soil H) under cultivation had an average intake of 44 mm/hour.

The significance of these intake rates should be assessed in conjunction with the crop water and leaching requirements (Appendix 2). The total water application proposed per irrigation is 50 mm. Figure 28 shows that even the soil with the lowest intake rate will accept this amount in about 5 hours, assuming the soil is unsaturated but already moist from previous irrigation. A soil with a final intake rate approaching 50 mm/hour (the highest encountered in the project area)would, if the soil were drier than the field capacity moisture content, accept over 50 mm of water in one hour. It is concluded that all soils in the project area have intake rates which can satisfy both crop water and leaching requirements (Appendix 2). Although drainage losses may initially be excessive on some soils, it is anticipated (in part due to the high silt contents) that intake rates should decrease as a result of intensive cultivation.

TABLE 1 Accumulated intakes and infiltration rates of soils in the Zwai area

Soil	Profile characteristics	Soil condition prior to test	Average accumulated intake after 9 hours (mm)	Average final rate of infiltration (mm/hour)
A Soils on the Meki River levee	Clay loam to clay, slightly mottled at depth	Cultivated, prepared for irrigation	402	25
B Sandy soils on old levee material	Clay loam over layered sand, silty clay loam and silty clay	Cultivated, cloddy surface	1 039	44
	Clay loam over layered loamy sand and silty clay loam	Cultivated, cloddy surface	633	45
	Silty clay loam over silt loam with layers of clay	Cultivated, cloddy surface	450	40
C Clay soils on old levee material	Clay loam to silty clay over mottled alkaline silty clay with sand layers	Cultivated, cloddy surface	291	4
D Basin clays	Clay to silty clay throughout, cracking strongly to 40 cm	Uncultivated, many surface cracks	856	48**
	Clay to silty clay over calcareous silt loam at 80 cm	Cultivated, cloddy surface	151	5
F Seasonally flooded clays	Mottled clay over calcareous loamy sand at 175 cm	Uncultivated, a few surface cracks	834	21*
H Sandy terrace soils overlying coarse pumice; often alkaline in the subsoil	Sandy loam over calcareous loamy sand	Cultivated	1 311	46
	Sandy loam over coarse loamy sand	Cultivated, prepared for irrigation	1 306	44
	Sandy loam over coarse sandy loam	Cultivated, prepared for irrigation	621	41*
	Sandy loam over compacted loamy sand	Uncultivated	319	34
	Sandy loam over compacted loamy sand	Uncultivated	138	16
	Sandy loam over gravelly sandy loam, slightly indurated	Uncultivated (heavily grazed)	488	26
	Coarse sandy loam over compacted loamy gravel	Uncultivated (heavily grazed)	371	23*
J Medium-textured terrace loams overlying ash; often alkaline in the subsoil	Loam over sandy loam, silt loam and loamy fine sand	Cultivated	378	32
	Loam over indurated silt loam	Uncultivated	79	17
M Clays with coarse sandy subsoil	Clay over pumiceous sand	Cultivated	607**	34
R Meki Valley soils	Well structured heavy clay	Cultivated	1 498	45
S Meki Valley soils	Silt loam ash overlying heavy clay with seasonally impeded drainage	Cultivated	305*	21

*Based on 1 cylinder. **Based on 2 cylinders.

FIGURE 28

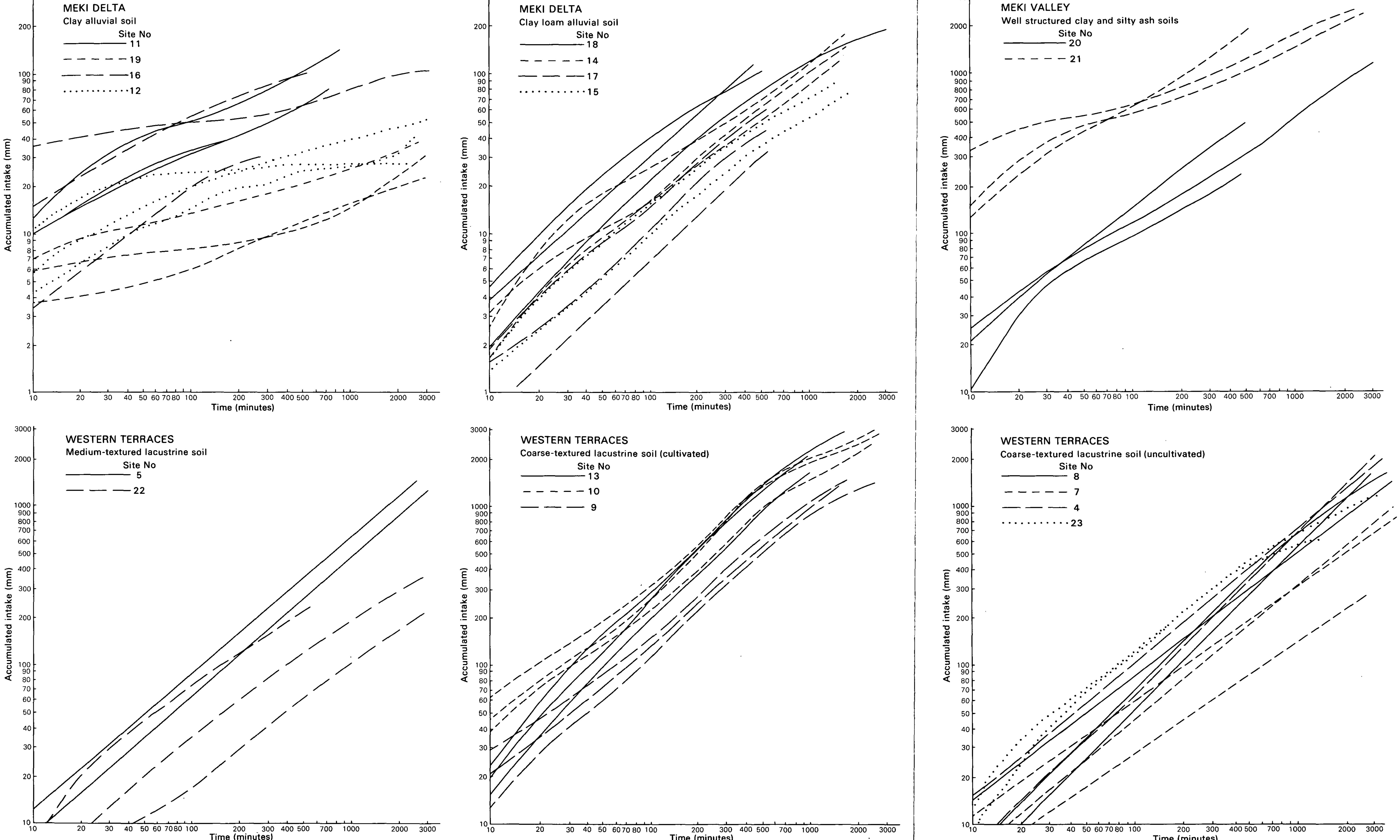

FIGURE 28 Infiltration rates of selected soils in the Zwai area

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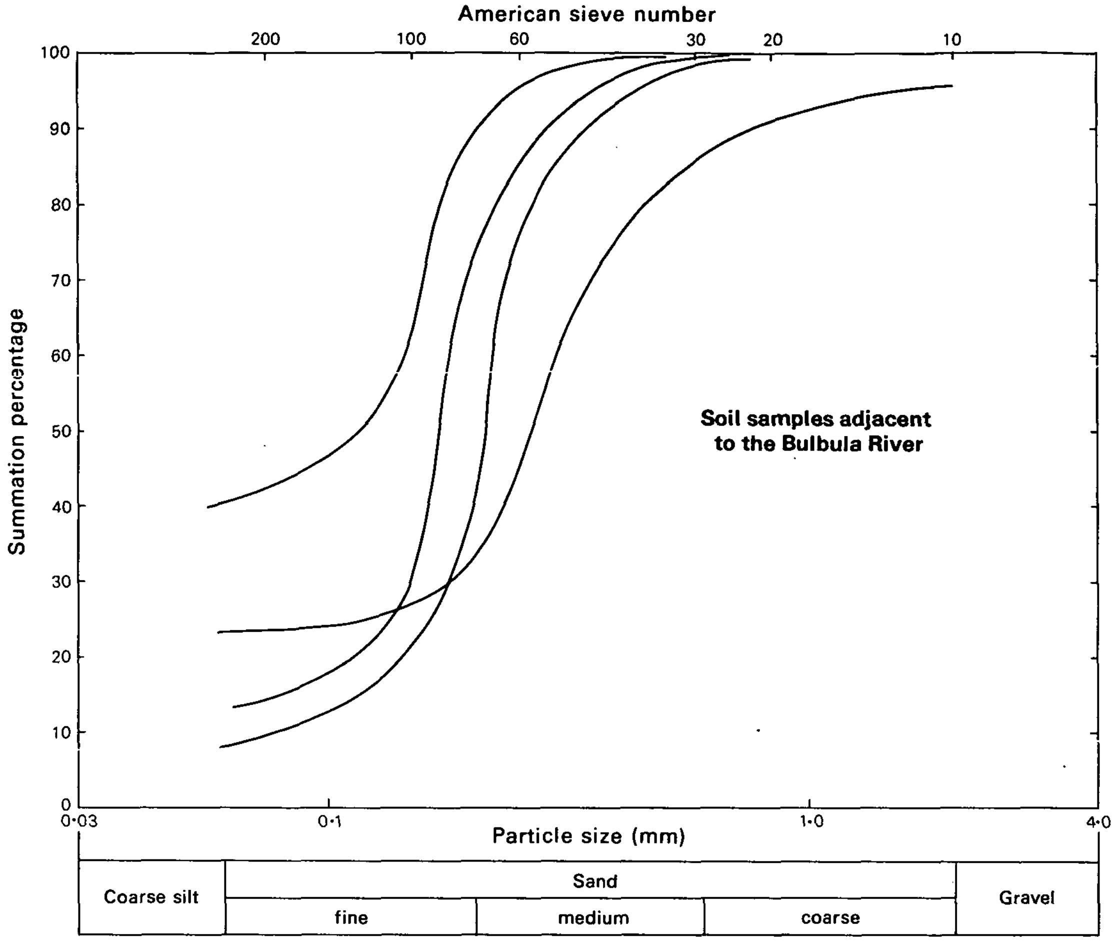
Appendix 9

Particle size analysis of soil samples

See Figure 29 on reverse



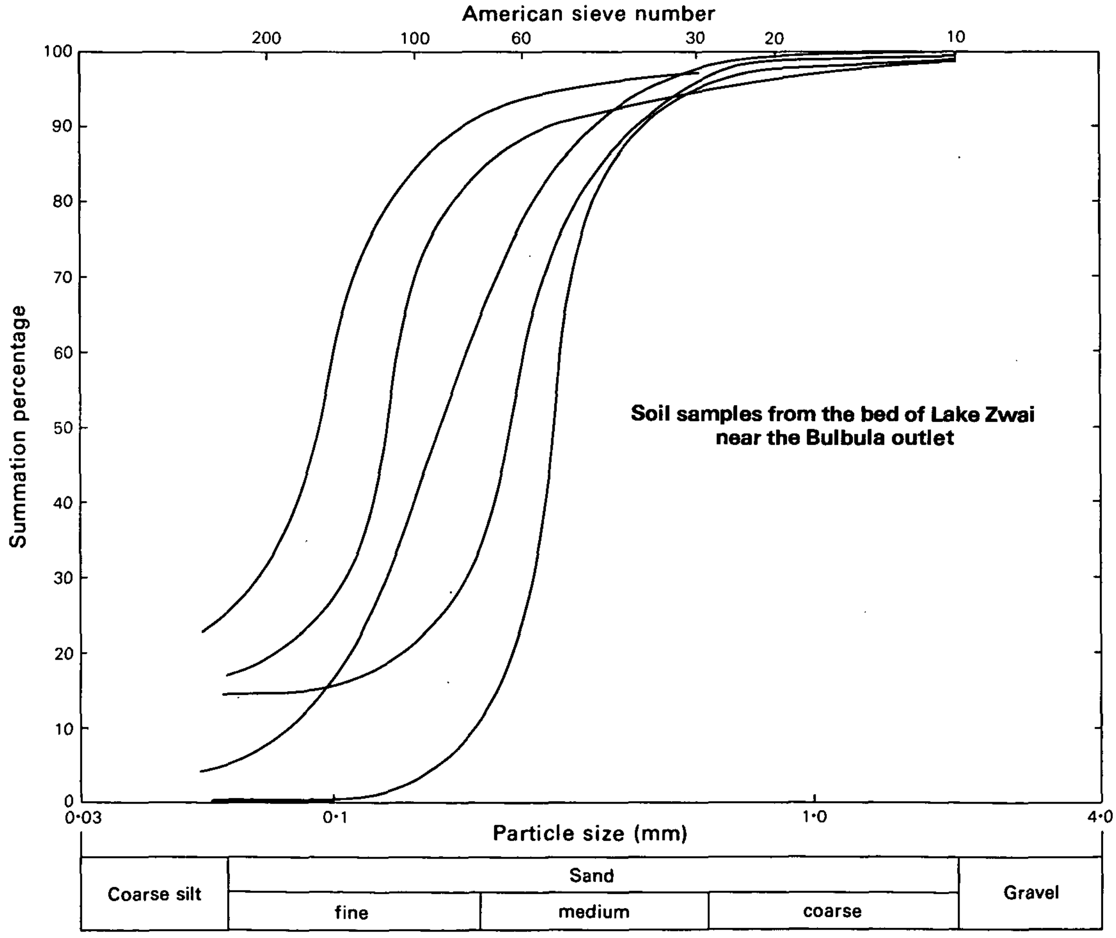


FIGURE 29 Particle size analysis of soils adjacent to the Bulbula River bed

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Appendix 10

Crop gross margin analysis

TABLE 1 **Gross margin schedules, Agricultural System 1, unimproved smallholdings; summary of direct costs, value of output and gross margins, ($/ha). (Yields in q/ha are shown in brackets for each crop)**

Item	Crop				
	Maize (11)	Tef (7)	Wheat (8)	Haricot beans (7.5)	Red peppers (10)
Value of output	165.0	210.0	200.0	375.0	750.0
Direct costs:					
Maintenance	4.0	4.0	4.0	4.0	4.0
Seed	15.0	17.5	30.0	50.0	15.0
Fertiliser	–	–	–	–	–
Pesticides	–	–	–	–	–
Bags	–	–	–	–	–
Fuel (electricity)	–	–	–	–	–
Hired labour	–	–	–	–	60.0
Total direct costs	19.0	21.5	34.0	54.0	79.0
Gross margin	146.0	188.5	166.0	321.0	671.0
Hired labour valued at $2/day					

TABLE 2 **Gross margin schedules, Agricultural System 2, improved rainfed smallholdings; summary of direct costs, value of output and gross margins ($/ha). (Yields in q/ha are shown in brackets for each crop)**

Item	Crop						
	Maize (25)	Tef (10)	Wheat (12)	Haricot beans (14)	Groundnuts (18)	Red peppers (16)	Sorghum (20)
Value of output	375.0	300.0	300.0	700.0	630.0	1200.0	300.0
Direct costs:							
Maintenance	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Seed	15.0	17.5	30.0	75.0	77.0	118.0	15.0
Fertiliser	54.0	54.0	54.0	54.0	54.0	54.0	54.0
Pesticides	5.6	–	–	21.0	20.5	75.6	–
Bags	25.0	10.0	12.0	14.0	18.0	16.0	20.0
Fuel (electricity)	–	–	–	–	–	–	–
Hired labour	–	–	–	–	60.0	100.0	–
Total direct costs	111.6	93.5	108.0	176.0	241.5	375.6	101.0
Gross margin	263.4	206.5	192.0	524.0	388.5	824.4	199.0
Hired labour valued at $2/day							

Table 3 Gross margin schedules, Agricultural System 3, improved irrigated smallholdings; summary of direct costs, value of output and gross margins ($/ha). (Yields in q/ha are shown in brackets for each crop)

Item	Long-cycle maize (60)	Tef (12)	Wheat (25)	Groundnuts (25)	Red peppers (30)	Haricot beans (Wet season) (22)	Haricot beans (Dry season) (22)	Maize-groundnuts (40/20)	Maize-red peppers (40/20)	Tomatoes (400)	Onions (Wet season) (300)	Onions (Dry season) (300)	Cabbages (350)	Carrots (150)
Value of output	900.0	360.0	625.0	875.0	2 250.0	1 100.0	1 100.0	1 300.0	2 100.0	2 400.0	1 800.0	1 800.0	2 100.0	1 800.0
Direct costs														
Maintenance	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Seed	15.0	17.5	30.0	77.0	118.0	75.0	75.0	85.0	132.9	140.0	85.0	85.0	125.0	66.0
Fertiliser	108.0	54.0	54.0	54.0	54.0	54.0	54.0	108.0	108.0	108.0	108.0	108.0	162.0	108.0
Pesticides	5.6	–	–	20.5	75.6	21.0	21.0	41.2	81.2	70.5	33.6	33.6	41.0	31.5
Bags	60.0	12.0	25.0	25.0	30.0	22.0	22.0	60.0	60.0	100.0	300.0	300.0	350.0	150.0
Stakes	–	–	–	–	–	–	–	–	–	120.0	–	–	–	–
Fuel (electricity)	4.8	4.8	4.8	4.8	22.8	4.2	10.6	4.8	22.8	40.3	19.1	21.2	19.1	19.1
Hired labour	–	–	8.0	–	40.0	12.0	16.0	26.0	16.0	104.0	166.0	182.0	186.0	150.0
Total direct costs	205.4	100.3	133.8	193.3	352.4	200.2	210.6	337.0	432.9	694.8	723.7	741.8	895.1	536.6
Gross margin	694.6	259.7	491.2	681.7	1 897.6	899.8	889.4	963.0	1 667.1	1 705.2	1 076.3	1 058.2	1 204.9	1 263.4

Fuel costs are taken as $1.27 per 1 000 m^3 water.
It is assumed that the costs of irrigation structures and their maintenance are an annual fixed cost to the farmer.
Gross margins for cabbages and carrots are tentative.
Hired labour is valued at $2/day.

TABLE 4 **Gross margin schedules, Agricultural System 4, large-scale mechanised rainfed farms; summary of direct costs, value of output and gross margins ($/ha). (Yields in q/ha are shown in brackets for each crop.**

Item	Crop					
	Maize (40)	Tef (12)	Wheat (18)	Haricot beans (18)	Groundnuts (20)	Red peppers (20)
Value of output	600.0	360.0	450.0	900.0	700.0	1 500.0
Direct costs:						
Seed	15.0	17.5	30.0	75.0	77.0	118.0
Fertiliser	81.0	54.0	54.0	54.0	54.0	108.0
Pesticides	5.6	–	–	21.0	20.5	75.6
Bags	40.0	12.0	18.0	18.0	20.0	20.0
Mechanised farm operations (fuel and maintenance)	72.8	54.6	73.8	66.3	93.7	73.5
Hired labour	84.0	92.0	58.0	106.0	134.0	166.0
Total direct costs	298.4	230.1	233.8	340.3	399.2	561.1
Gross margin	301.6	129.9	216.2	559.7	300.8	938.9

Hired labour valued at $2/day

Mechanised farm operation costs are aggregated and only apply to running costs and maintenance

TABLE 5 **Rates of application of seed, fertiliser, insecticides and fungicides on irrigated crops**

Crop	Seed (kg/ha)	Fertiliser (kg/ha)	Insecticide (litres/ha)	Fungicide (kg/ha)
Long-cycle maize	30	DAP 200	DDT 4	
Tef	50	DAP 100		
Wheat	100	DAP 100		
Groundnuts	110	TSP 100	Malathion 5.6	
Red peppers	4	DAP 100	DDT 4	Polyram 14
Haricot beans	50	TSP 100	Endosulfan 3	
Maize intercropped with groundnuts	50 100	) DAP 100) TSP 100	DDT 8	Polyram 6
Maize intercropped with red peppers	50 4	) DAP 200)	DDT 8	Polyram 14
Tomatoes	3	DAP 200	Malathion 5.6	Polyram 10
Onions	3	DAP 100) TSP 100)	DDT 24	
Cabbages	2	DAP 300	Malathion 11.2	
Carrots	6	DAP 100) TSP 100)		Carbaryl 4.5

DAP = Diammonium phosphate

TSP = Triple superphosphate

TABLE 6 Schedule of costs for fertilisers, seeds, seedlings and pesticides

Item	Unit	Cost ($)
Fertilisers:		
Diammonium sulphate	q	54
Triple superphosphate	q	54
Seeds:		
Maize	q	30
Tef	q	35
Wheat	q	30
Groundnuts	q	70
Red peppers	kg	20
Tomatoes	kg	20
Cabbages	kg	25
Onions	kg	12
Carrots	kg	11
Seedlings: *		
Red peppers	ha	118
Tomatoes	ha	140
Cabbages	ha	125
Onions	ha	85
Pesticides:		
DDT	litre	1.40
Malathion	litre	3.66
Endosulfan	litre	7.00
Polyram	kg	5.00
Carbaryl	kg	7.00

*Seedling costs include all nursery cultivation, chemicals, fertiliser and labour

TABLE 7 Estimated crop labour requirements (labour-days/ha) for each agricultural system

Crop	Agricultural system			
	1	2	3	4
Maize	78	76	103	42
Tef	90	93	138	92
Wheat	68	74	130	58
Groundnuts	*	115	126	67
Red peppers	187	202	242	83
Haricot beans (wet season)	75	86	112	53
Haricot beans (dry season)	*	*	136	*
Maize – groundnuts	*	*	184	*
Maize - red peppers	*	*	258	*
Tomatoes	*	*	315	*
Onions (wet season)	*	*	263	*
Onions (dry season)	*	*	271	*
Cabbages	*	*	243	*
Carrots	*	*	225	*

*Crops not recommended under rainfed conditions

Appendix 11

Derivation of fixed costs

For each of the four agricultural systems defined in Part 8, fixed costs vary; they are, however, constant for any particular system, regardless of the cropping pattern. Fixed costs are derived from farm capital investments, taking into account both interest and depreciation, and are calculated by applying appropriate capital recovery factors (CRF). The interest rate employed is 10% per annum.

System 1: unimproved rainfed smallholdings

Fixed costs are computed on the basis of 2 ha holdings and it is assumed that the farmer owns two oxen which he replaces every five years. Since the salvage value of an ox is $50 and the cost of a new ox is $100, the net capital outlay for replacing two work oxen is $100 every five years. The fixed costs are summarised in Table 1.

TABLE 1 **Fixed costs for Agricultural System 1, based on 2 ha farms**

Item	Capital cost ($)	Life (years)	CRF*	Annual capital charge	
				($)	($/ha)
2 work oxen	100	5	0.264	26.40	13.20
1 plough	20	3	0.402	8.04	4.02
Total annual fixed costs/ha					17.22

* Capital recovery factor

System 2: improved rainfed smallholdings

On these holdings there is investment in more expensive work oxen, improved ploughs and handsprayers. The replacement cost of a new ox is $125 and the salvage value $50. The fixed costs are summarised in Table 2.

TABLE 2 **Fixed costs for Agricultural System 2, based on 2 ha farms**

Item	Capital cost ($)	Life (years)	CRF	Annual capital charge	
				($)	($/ha)
2 work oxen	150	5	0.264	39.60	19.80
1 improved plough	80	5	0.264	21.20	10.60
1 handsprayer	120	10	0.163	19.60	9.80
Total annual fixed costs/ha					40.20

System 3: improved irrigated smallholdings

On these holdings fixed costs include all costs relating to the provision of irrigation water to the farm, with the exception of pumping costs. Annual irrigation fixed costs/ha have been estimated by summing the discounted (at 10%) capital, operating, and maintenance costs (unmodified by social coefficients) over the life of the project (20 years), so as to determine the present value of these costs (Tables 3 and 4). When this present value is multiplied by the 20-year capital recovery factor (at an interest rate of 10%, the CRF = 0.117) and then divided by the total area under irrigation the average annual irrigation fixed costs/ha are obtained.

TABLE 3 Fixed irrigation costs ($) — Phase 1

Charge	Actual cost	Discounted cost (present value)
Capital	4 712 100	3 484 000
Operational	4 684 300	1 939 600
Maintenance	3 632 300	1 325 700
Total cost	13 028 700	6 749 300
Average annual fixed costs = 6 749 300 x 0.117 ÷ 1 730 = 456.5 $/ha		

TABLE 4 Fixed irrigation costs ($) — Phase 2

Charge	Actual cost	Discounted cost (present value)
Capital	14 717 000	8 491 300
Operational	5 061 900	2 021 600
Maintenance	7 057 900	2 400 400
Total cost	26 836 800	12 913 300
Average annual fixed costs = 12 913 300 x 0.117 ÷ 3 770 = 400.7 $/ha		

The capital investment costs for oxen, improved ploughs and handsprayers are the same as for System 2, although the farm size (1.5 ha) is smaller; thus the annual fixed costs per hectare are higher. Costs for these items, together with the fixed costs for irrigation calculated in Tables 3 and 4, are presented in Table 5.

TABLE 5 Total annual fixed costs for Agricultural System 3, on 1.5 ha farms

Item	Annual fixed costs ($/ha)
Phase 1	
2 work oxen	26.4
Improved plough	14.1
Handsprayer	13.0
Irrigation costs	456.5
Total	510.0
Phase 2	
2 work oxen	26.4
Improved plough	14.1
Handsprayer	13.0
Irrigation costs	400.7
Total	454.2

System 4: improved rainfed large-scale (90 ha) farms

In this agricultural system the fixed costs are represented by investments in machinery (Table 6).

TABLE 6 Fixed costs for Agricultural System 4, on 90 ha farms

Item	Number	Capital cost ($)	Life (years)	Annual capital charge ($)
Tractors	2	39 525.50	5	10 426.20
Land leveller	1	12 650.00	6	2 918.10
Disc plough	1	2 909.50	6	668.10
Disc harrow	1	6 957.50	4	2 194.80
Planter/ridger	1	7 003.50	5	1 847.40
Trailer	1	4 048.00	8	758.80
Maize sheller	1	2 560.00	8	479.90
Groundnut lifter	1	5 376.50	5	1 418.20
Handsprayers	24	2 860.00	10	470.00
Total		83 890.50		21 181.50
Total annual fixed costs/ha = $235.3				

Appendix 12

Derivation of the net value of production foregone

The development of irrigation around Lake Zwai will, in effect, replace existing agriculture with a more intensive system. While irrigation will provide the means by which a new stream of benefits is created, the production of the previous system will be permanently lost. Thus the net value of production foregone by this substitution should appear as a cost attributable to the new developments.

It is assumed that the present rainfed cropping pattern consists of 80% maize, 10% tef and 10% haricot beans. From farm surveys and gross margin analysis, costs and value of production per hectare have been estimated (Table 1). The net value of production per hectare of $75.63 has been taken as the net value of production foregone for every hectare upon which irrigated agriculture is substituted for rainfed agriculture. Thus in Phase 1 the maximum value of production foregone will be $130 800, and in Phase 2 $285 000. These figures do not take into account possible improvements to existing agriculture. On the other hand, a significant proportion of the land proposed for irrigation is not at present cultivated and therefore contributes little to current production. Overall, it is probable that the estimates of production foregone are excessive.

TABLE 1 Average values of production and costs of existing unimproved rainfed agriculture ($/ha)

Item	Crop			Weighted average
	Maize	Tef	Haricot beans	
Value of production	165.00	210.00	375.00	190.50
Fixed costs	17.22	17.22	17.22	17.22
Seed	15.00	17.50	50.00	18.75
Labour	78.00	90.00	75.00	78.90
Total costs	110.22	124.72	142.22	114.87
Net value of production	54.78	85.28	232.78	75.63

Family labour valued at the shadow wage rate of $1/day

Appendix 13

Costs for materials and construction

Costs for engineering works are derived from the outline designs in Figures 18, 21 and 23, together with the unit costs presented in Table 1. The irrigation layout shown on Figure 23 has been assumed to be applicable to all irrigation areas, though the general application of the basin method of irrigation will actually depend on the results of topographic surveys and irrigation trials. Irrigation structures have been costed at approximately 1.5 times the cost of the canal system (this accords with general experience), though with minor variations from area to area depending on local factors of topography, distance and height from water source, etc. Irrigation pumps have been selected and costed for each area in accordance with the head and discharge required. The costings for canal linings in certain areas is tentative, however, pending further field study of infiltration losses. The costing for the flood control works on the Meki Delta is based on designs shown in Figure 18 and Text Map 7. The costing of the Bulbula control works is based on Figure 21 and Map 6.

TABLE 1 Unit costs

Item	Unit	Cost ($)
Bush clearance, land grading and improvement of existing cultivated land	ha	300
Grading of land on the Western lake margins	ha	100
Excavation for canals and drains	m^3	3
Excavation for structures	m^3	8
Excavation in rock	m^3	10
Underwater excavation (dredging) in soft material	m^3	7
Dredging in Lake Zwai	m^3	10
Construction of embankments and backfilling	m^3	6
Structural concrete, including shuttering and reinforcement	m^3	300
Mass concrete	m^3	130
Fabricated steelwork	kg	4
Asbestos-cement pipe including laying and jointing		
i. 200 mm diameter	m	15
ii. 400 mm diameter	m	60
iii. 600 mm diameter	m	110
Gabions	m^3	75
Power		
i. electricity	kWh	0.025
ii. diesel	hp. hour	0.189
Fuel		
i. petrol	litre	0.75
ii. diesel	litre	0.50
Low-cost housing	m^2	200

Irrigation development costs for Phases 1 and 2 are shown by area in Tables 2 and 3. The estimated life and the annual maintenance costs of the capital items (as a percentage of the capital cost) are given in Table 4. Table 5 lists the conversion factors used to modify the annual capital and operating costs in the social cost-benefit analysis.

TABLE 2 Irrigation development costs ($000's) – Phase 1

Location	Area on Text Map 8	Area (ha)	Clearing and levelling	Inlet canals	Field canals	Drainage canals	Pumps and pump housing	Pipe-lines	Irrigation canal structures	Concrete canal linings	Raised earth embank-ments	Total capital costs by locations
Meki Delta Riverside	A1	300	90.00	–	132.00	40.50	100.50	1.50	135.00	28.20	30.00	557.7
Bulbula East	A2	140	42.00	–	59.50	19.88	36.40	36.40	63.00	–	–	257.2
Western Terraces	A3	340	102.00	19.72	149.60	48.28	88.40	18.70	153.00	–	–	579.7
Bulbula West	A3	680	204.00	39.44	299.20	96.50	176.80	176.80	459.00	–	–	1 451.8
Catar Delta	A4	270	81.00	–	118.80	39.15	90.45	1.35	182.25	25.38	–	538.4

TABLE 3 Irrigation development costs ($000's) – Phase 2

Location	Area on Text Map 8	Area (ha)	Clearing and levelling	Inlet canals	Field canals	Drainage canals	Pumps and pump housing	Pipe-lines	Irrigation canal structures	Concrete canal linings	Raised earth embank-ments	Total capital costs by locations
Meki Delta	B1	2 160	648.00	125.28	1 036.80	695.52	712.80	280.80	2 905.20	203.04	1 080.00	7 687.4
Western Terraces	B2	480	144.00	27.84	216.00	72.00	451.20	399.84	645.60	45.12	–	2 001.6
Bulbula East (1)	B3	200	60.00	–	90.00	30.00	68.00	138.00	269.00	18.80	–	673.8
(2)	B3	100	30.00	–	45.00	15.00	34.00	78.00	134.50	9.40	–	345.9
Catar River South	B4	170	51.00	–	81.60	27.20	101.15	0.85	228.65	15.98	–	506.4
Western Lake Margins	B5	660	66.00	38.28	280.50	280.50	250.80	–	594.00	–	198.00	1 708.1

TABLE 4 Estimated life and annual maintenance costs for capital items

Item	Estimated life (years)	Annual maintenance charge (%)
Irrigation construction		
Canals and drains	30	2.5
Pumps and pump housing	20	10.0
Pipelines	30	1.0
Irrigation canal structures	30	2.0
Raised earth embankments	30	2.0
Staff housing, workshops, offices, stores	20	6.5
Office and workshop equipment	30	10.0
Electrical works	30	4.0
Roads	30	4.0
Transport vehicles, bicycles	5	10.0
Bulbula sluice and channel works	40	2.5
Flood protection works	40	2.0
Farm level capital costs		
Oxen	5	10.0
Improved ploughs	5	10.0
Handsprayers	10	10.0

TABLE 5 Derivation of conversion factors for costs, based on the manual labour cost component for each item and a shadow wage rate of $1.00/day

Item	Manual labour cost %	Conversion factor
Irrigation construction		
Clearing and levelling	85	0.58
Inlet canals	40	0.80
Field canals	100	0.50
Drainage canals	100	0.50
Pumps and pump housing	–	1.00
Pipelines	–	1.00
Irrigation canal structures	15	0.93
Concrete canal linings	20	0.90
Raised earth embankments	70	0.65
Average for all irrigation construction:		
Phase 1		0.76
Phase 2		0.79
Staff housing, workshops, offices and stores	20	0.90
Office equipment	–	1.00
Electrical works	–	1.00
Roads	50	0.75
Transport	–	1.00
Bulbula sluice	–	1.00
Bulbula channel works	30	0.85
Embankments, flood protection	60	0.70
Meki River dykes	40	0.80
Oxen	–	1.00
Improved ploughs	–	1.00
Handsprayers	–	1.00
Fuel: electricity, petrol, diesel	–	1.00
Seed, fertiliser, bags	–	1.00
Chemicals	–	1.00
Project staff	20	0.90
Family, hired labour on farm	100	0.50
All maintenance	40	0.80

Appendix 14

Estimates of machinery running costs on large-scale non-irrigated farms

Estimates are made in Tables 1-4 of running costs for farm machinery. Where appropriate, estimates for the running costs of specific farm operations are also made. Running costs include maintenance, fuel consumption, and wages. The results were used in estimates of gross margin costs for large-scale and rainfed mechanised farms. Table 1 provides basic data relating to machinery.

TABLE 1 Estimates of tractor and machinery prices (c.i.f. Addis Ababa, 1974), life and number of hours worked per year

Equipment	Estimated cost ($)	Estimated life (years)	Number of hours worked/year
Tractor, 70 hp	19 762.75	5	1 800
Land leveller	12 650.00	6	1 000
Disc plough	2 909.50	6	600
Disc harrow	6 957.50	4	800
Planter/ridger	7 003.50	5	500
Trailer	4 048.00	8	800
Maize sheller	2 560.00	8	500
Groundnut lifter	5 376.50	5	500
Prices collected from importers in Addis Ababa early in 1974, increased by 15% to arrive at the prices in the table. The maize sheller specified can shell 3.6 tons of maize/hour.			

It has been assumed that the average annual maintenance charge for each item of equipment is 15% of the initial cost per year. Hourly maintenance charges are presented in Table 2.

TABLE 2 Hourly maintenance charges for equipment and machinery

Equipment	Annual maintenance cost ($)	Number of hours worked/year	Hourly maintenance cost ($)
Tractor	2 964.40	1 800	1.65
Land leveller	1 897.50	1 000	1.90
Disc plough	436.40	600	0.73
Disc harrow	1 043.60	800	1.30
Planter/ridger	1 050.50	500	2.10
Trailer	607.20	800	0.76
Maize sheller	384.00	500	0.77
Groundnut lifter	806.50	500	1.61

Tractor running costs are computed as follows:

Hourly fuel consumption: 6 litres of diesel/hour at $0.50/l	= $3.00/hour
Driver's wages	= $0.60/hour
Maintenance (Table 2)	= $1.65/hour
Total running and maintenance costs	= $5.25/hour

Table 3 provides estimates of the running costs of operations performed by tractor.

TABLE 3 Annual tractor and implement running costs

Operation	Number of hours/ha	Hourly maintenance cost ($/ha)	Hourly tractor running costs ($/ha)	Total cost ($/ha)
Land levelling	1.0	1.90	5.25	7.15
Disc ploughing	3.0	0.73	5.25	17.94
Disc harrowing	1.5	1.31	5.25	9.84
Planting/ridging	1.5	2.10	5.25	11.02
Groundnut lifting	5.0	1.62	5.25	34.35

Table 4 gives estimates of the total hourly running costs for a tractor-operated maize sheller and trailer.

TABLE 4 Hourly costs for a trailer and a maize sheller operating with a tractor

Equipment	Hourly maintenance cost ($)	Hourly tractor running cost ($)	Total running cost ($/ha)
Maize sheller	0.77	5.25	6.02
Trailer	0.76	5.25	6.01

Appendix 15

Social cost-benefit analysis of the Lake Zwai irrigation development

TABLE 1 Schedule of costs (modified by social coefficients) for Phase 1, ($ 000s)

Item	Year																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project capital costs																				
Irrigation construction	445.4	445.4	445.4	445.4	786.1															
Staff housing	189.0																			
Workshops	18.0	18.0	18.0																	
Offices and stores	36.0	22.5																		
Bulbula works		0.9																		
Flood protection, Meki Delta		40.0																		
Transmission lines	10.0	10.0	10.0	20.0	10.0															
Roads	18.8	18.8																		
Transport (including bicycles)	10.0	20.0	60.0			20.0	20.0	60.0			20.0	20.0	60.0			20.0	20.0	60.0		
Office equipment, tools, etc.	25.0	25.0																		
Research substations	172.0	172.0																		
Farm-level capital costs																				
Oxen	30.0	30.0	30.0	30.0	53.0	30.0	30.0	30.0	30.0	53.0	30.0	30.0	30.0	30.0	53.0	30.0	30.0	30.0	30.0	53.0
Improved ploughs	16.0	16.0	16.0	16.0	28.2	16.0	16.0	16.0	16.0	28.2	16.0	16.0	16.0	16.0	28.2	16.0	16.0	16.0	16.0	28.2
Handsprayers	24.0	24.0	24.0	24.0	42.4						24.0	24.0	24.0	24.0	42.4					
Project operating costs																				
Project staff salaries	142.9	166.7	186.7	199.6	222.3	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1	206.1
Transport, fuel and lubricants	2.0	4.0	10.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Office supplies	1.0	1.0	1.0																	
Soil sample analysis	4.7	4.7	4.7	4.7	8.3															
Farm-level operating costs																				
Seed and nurseries		45.2	90.6	135.9	181.2	261.1														
Fertiliser		43.2	86.4	129.6	172.8	249.0														
Chemicals		20.6	41.1	61.7	82.2	118.5	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6	788.6
Bags		22.4	44.8	67.2	89.6	129.1														
Electricity for pumping		5.4	10.7	16.1	21.4	30.9														
Labour (family and hired)		89.8	179.6	269.4	359.2	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7	517.7
Maintenance																				
Irrigation works		13.8	27.7	41.5	55.4	79.8	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2	168.2
All other capital items		35.1	59.3	71.1	78.3	88.4														
Total costs	1 154.8	1 294.5	1 346.0	1 543.2	2 201.4	1 757.6	1 757.6	1 797.6	1 737.6	1 772.8	1 781.6	1 781.6	1 821.6	1 761.6	1 815.2	1 757.6	1 757.6	1 797.6	1737.6	1 772.8
+15% contingency	1 328.0	1 488.7	1 547.9	1 774.7	2 531.6	2 021.2	2 021.2	2 067.2	1 998.2	2 038.7	2 048.8	2 048.8	2 094.8	2 025.8	2 087.5	2 021.2	2 021.2	2 067.2	1998.2	2 038.7
Production foregone	22.7	45.4	68.1	90.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8	130.8
Grand total	1 350.7	1 534.1	1 616.0	1 865.5	2 662.4	2 152.0	2 152.0	2 198.0	2 129.0	2 169.5	2 179.6	2 179.6	2 225.6	2 156.6	2 218.3	2 152.0	2 152.0	2 198.0	2 129.0	2 169.5

TABLE 2 Schedule of costs (modified by social coefficients) for Phase 2 ($ 000s)

Item	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project capital costs																				
Irrigation structures	813.3	813.3	813.3	813.3	813.3	813.3	813.3	813.3	813.3	813.3	813.3	1 272.9								
Staff housing	63.0			9.0																
Workshops		45.0																		
Offices and stores		18.0																		
Bulbula sluice	75.0																			
Bulbula channel deepening				46.8	46.8	17.0														
Flood protection, Meki Delta	280.0	80.5	80.5																	
Transmission lines	10.0	10.0	10.0	10.0	10.0															
Roads	37.5	37.5	37.5	37.5	37.5															
Transport (including bicycles)	30.0	60.0	30.0			30.0	60.0	30.0			30.0	60.0	30.0			30.0	60.0	30.0		
Office equipment, tools etc.	10.0	10.0	10.0																	
Farm-level capital costs																				
Oxen	30.0	30.0	30.0	30.0	30.0	60.0	60.0	60.0	60.0	60.0	90.0	106.9	60.0	60.0	60.0	90.0	106.9	60.0	60.0	60.0
Improved ploughs	16.0	16.0	16.0	16.0	16.0	32.0	32.0	32.0	32.0	32.0	48.0	57.0	32.0	32.0	32.0	48.0	57.0	32.0	32.0	32.0
Handsprayers	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	48.0	61.6	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Project operating costs																				
Project staff salaries	82.1	98.8	127.4	149.6	182.5	199.2	221.4	232.9	249.8	249.8	253.3	253.3	237.1							
Transport, fuel and lubricants	4.5	11.5	16.0											254.1	254.1	254.1	254.1	254.1	254.1	254.1
Office supplies	1.0	1.0	1.0	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	24.3	17.0							
Soil sample analysis	4.7	4.7	4.7																	
Design costs (consultancy)	20.0																			
Farm-level operating costs																				
Seed and nurseries		45.2	90.6	135.9	181.2	226.5	271.7	317.0	362.3	407.6	452.9	498.2	569.1							
Fertiliser		43.2	86.4	129.6	172.8	216.0	259.2	302.4	345.6	388.8	432.0	475.2	542.8							
Chemicals		20.6	41.1	61.7	82.2	102.8	123.3	143.9	164.5	185.0	205.6	226.2	258.3	2 847.4	2 847.4	2 847.4	2 847.4	2 847.4	2 847.4	2 847.4
Bags		22.4	44.8	67.2	89.6	112.0	134.4	156.8	179.2	201.6	224.0	246.4	281.5							
Electricity for pumping		5.4	10.7	16.1	21.4	26.8	32.2	37.5	42.9	48.2	53.6	59.0	67.3							
Labour (family and hired)		89.8	179.6	269.4	359.2	449.0	538.9	628.6	718.4	808.2	898.0	987.8	1 128.4							
Maintenance																				
Irrigation works		23.8	47.6	71.4	95.2	119.0	142.9	166.6	190.5	214.2	238.1	261.9	299.1	411.5	411.5	411.5	411.5	411.5	411.5	411.5
All other capital works		22.3	39.4	52.0	61.1	69.7	75.7	81.3	86.9	92.5	98.1	103.7	112.4							
Total costs	1 501.1	1 533.0	1 740.6	1 961.2	2 244.5	2 519.0	2 810.7	3 048.0	3 291.1	3 546.9	3 906.6	4 694.4	3 659.0	3 629.0	3 629.0	3 705.0	3 760.9	3 659.0	3 629.0	3 629.0
+15% contingency	1 726.3	1 763.0	2 001.7	2 255.4	2 581.2	2 896.9	3 232.3	3 505.2	3 784.8	4 078.9	4 492.6	5 398.6	4 207.9	4 173.4	4 173.4	4 260.8	4 325.0	4 207.9	4 173.4	4 173.4
Production foregone	22.7	45.4	68.1	90.8	113.4	136.1	158.8	181.5	204.2	226.9	249.6	285.1	285.1	285.1	285.1	285.1	285.1	285.1	285.1	285.1
Grand total	1 749.0	1 808.4	2 069.8	2 346.2	2 694.6	3 033.0	3 391.1	3 686.7	3 989.0	4 305.8	4 742.2	5 683.7	4 493.0	4 458.5	4 458.5	4 545.9	4 610.1	4 493.0	4 458.5	4 458.5

TABLE 3 **Projections of irrigated areas (ha) during the development of Phase 1, assuming the use of Rotation 2**

Areas	Year								
	1	2	3	4	5	6	7	8	9	20
Area developed	0	300	600	900	1 200	1 729.5	1 729.5	1 729.5	1 729.5	1 729.5
Area cropped*										
Maize-red peppers (intercropped)	0	100	200	300	400	576.5	576.5	576.5	576.5	576.5
Maize-groundnuts (intercropped)	0	200	400	600	800	1 153	1 153	1 153	1 153	1 153
Haricot beans	0	200	400	600	800	1 153	1 153	1 153	1 153	1 153

*Double-cropping throughout

TABLE 4 **Projections of crop production (q) during the development of Phase 1, assuming the use of Rotation 2**

Crop	Year										
	1	2	3	4	5	6	7	8	9	10	20
Maize	0	7 200	15 600	25 200	36 000	53 508	59 226	63 744	67 062	69 180	69 180
Red peppers	0	1 200	2 600	4 200	6 000	8 918	9 871	10 624	11 177	11 530	11 530
Groundnuts	0	2 400	5 200	8 400	12 000	17 836	19 742	21 248	22 354	23 060	23 060
Haricot beans	0	2 640	5 720	9 240	13 200	19 620	21 716	23 373	24 589	25 366	25 366

TABLE 5 **Projections of value of crop production ($ 000s) during the development of Phase 1, assuming the use of Rotation 2**

Crop	Year										
	1	2	3	4	5	6	7	8	9	10	20
Maize	0	108.0	234.0	378.0	540.0	802.6	888.4	956.2	1 005.9	1 037.7	1 037.7
Red peppers	0	90.0	195.0	315.0	450.0	668.9	740.3	796.8	838.3	864.8	864.8
Groundnuts	0	84.0	182.0	294.0	420.0	624.3	691.0	743.7	782.4	807.1	807.1
Haricot beans	0	132.0	286.0	462.0	660.0	981.0	1 085.8	1 168.6	1 229.5	1 268.3	1 268.3
Total value	0	414.0	897.0	1 449.0	2 070.0	3 076.8	3 405.5	3 665.3	3 856.1	3 977.9	3 977.9

TABLE 6 ***Projections of irrigated areas (ha) during the development of Phase 2, assuming the use of Rotation 2***

Areas	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	20
Area developed	0	300	600	900	1 200	1 500	1 800	2 100	2 400	2 700	3 000	3 300	3 769.5	3 769.5	3 769.5	3 769.5
Area cropped*																
Maize-red peppers (intercropped)	0	100	200	300	400	500	600	700	800	900	1 000	1 100	1 256.5	1 256.5	1 256.5	1 256.5
Maize-groundnuts (intercropped)	0	200	400	600	800	1 000	1 200	1 400	1 600	1 800	2 000	2 200	2 513	2 513	2 513	2 513
Haricot beans	0	200	400	600	800	1 000	1 200	1 400	1 600	1 800	2 000	2 200	2 513	2 513	2 513	2 513

*Double-cropping throughout

TABLE 7 Projections of crop production (q) during the development of Phase 2, assuming the use of Rotation 2

Crop	Year															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	20
Maize	0	8 400	18 000	28 800	40 800	52 800	64 800	76 800	88 800	100 800	112 800	124 800	141 546	145 824	148 902	150 780	150 780
Red peppers	0	1 400	3 000	4 800	6 800	8 800	10 800	12 800	14 800	16 800	18 800	20 800	23 591	24 304	24 817	25 130	25 130
Groundnuts	0	2 800	6 000	9 600	13 600	17 600	21 600	25 600	29 600	33 600	37 600	41 600	47 182	48 608	49 634	50 260	50 260
Haricot beans	0	3 080	6 600	10 560	14 960	19 360	23 760	28 160	32 560	36 960	41 360	45 760	51 900	53 469	54 597	55 286	55 286

TABLE 8 Projections of value of crop production ($ 000s) during the development of Phase 2 assuming the use of Rotation 2

Crop	Year															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	20
Maize	0	126.0	270.0	432.0	612.0	792.0	972.0	1 152.0	1 332.0	1 512.0	1 692.0	1 872.0	2 123.2	2 187.4	2 233.5	2 261.7	2 261.7
Red peppers	0	105.0	225.0	360.0	510.0	660.0	810.0	960.0	1 110.0	1 260.0	1 410.0	1 560.0	1 769.3	1 822.8	1 861.3	1 884.8	1 884.8
Groundnuts	0	98.0	210.0	336.0	476.0	616.0	756.0	896.0	1 036.0	1 176.0	1 316.0	1 456.0	1 651.4	1 701.3	1 737.2	1 759.1	1 759.1
Haricot beans	0	154.0	330.0	528.0	748.0	968.0	1 188.0	1 408.0	1 628.0	1 848.0	2 068.0	2 288.0	2 595.0	2 673.5	2 729.9	2 764.3	2 764.3
Total value	0	483.0	1 035.0	1 656.0	2 346.0	3 036.0	3 726.0	4 416.0	5 106.0	5 796.0	6 486.0	7 176.0	8 138.9	8 385.0	8 561.9	8.669.9	8 669.9

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These publications have a restricted distribution and are not available to booksellers. The Division makes a report on each completed project. The report is published as a *Land Resource Study* or *Technical Bulletin* only with the consent of the government concerned.

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