WATER MANAGEMENT STUDY AT KAUDULLA IRRIGATION SCHEME, SRI LANKA

I – Interim report on Yala season 1978 and Maha season 1978/79

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ABSTRACT

The irrigation schemes of the Dry Zone in Sri Lanka have traditionally supported two paddy crops; one grown in the Maha season with irrigation water supplementing high rainfall, the other in the Yala season with a limited water supply from local tanks (reservoirs). Water use in these schemes is reportedly inefficient. Diversion of water under the Mahaweli Development Scheme is making it possible to settle and farm new areas in the Dry Zone and it is important that all irrigation water should be used efficiently.

An irrigation water management study has been set up at Kaudulla, near Polonnaruwa in the North Central Province, to investigate the efficiency of a typical scheme under normal operating conditions. Since April 1978 a network of instruments has been operating to monitor rainfall tank water levels, irrigation and drainage channel flows, groundwater levels and evaporation over the area of the Kaudulla scheme. Initial results are presented for the first two cropping seasons of the study.

Preliminary conclusions indicate that irrigation water management is comparatively efficient during the Yala, but that rainfall over the cropped area could be used more effectively as a substitute for irrigation water during the Maha.

A list of titles of other reports in the OD series is given at the end of this report.

CONTENTS Page

TABLES

FIGURES

PLATES

CONTENTS (Continued)

PLATES (Continued)

1.1 Agricultural development in Sri Lanka is strongly influenced by rainfall, which is in turn influenced by the two monsoons which dominate weather patterns in the Bay of Bengal and the Indian Ocean. The south-west monsoon affects the island most strongly from May to September and the north-east monsoon from December to February. The south-west of Sri Lanka and most of the central hill mass, which receive considerable amounts of rainfall during both monsoons, are said to comprise the "Wet Zone" of the island. The flatter lands in the north and east, where rainfall is concentrated in the north-east monsoon, comprise the "Dry Zone". The terms "Wet" and "Dry Zone", together with their division by the 75 inch annual rainfall isohyet, are somewhat arbitrary, but they provide a useful basis for a general consideration of the effect of rainfall on the agriculture of Sri Lanka.

1.2 Coconuts, rubber, tea and rain-fed rice form the main crops of the Wet Zone. In the Dry Zone irrigated paddy rice predominates, using water stored in ancient tanks (reservoirs) which were built between the 3rd and 12th centuries AD. In subsequent centuries most of these tanks fell into disrepair but many have recently been rehabilitated and returned to active use by the Sri Lanka Irrigation Department (ID). The tanks comprise earthern bunds ponding streamflow, sometimes supplemented by water diverted through canals from nearby catchments.

1.3 In the northern Dry Zone most of the annual rainfall occurs during the North-East monsoon. Tank storage is used to supplement this rainfall and the Maha paddy crop is grown between October and March. Depletion of the tanks usually precludes irrigation of a full Yala paddy crop during April to September, which is the dry season in this part of Sri Lanka.

1.4 To augment dry season tank storage the Mahaweli Development Project was initiated during the 1960s and is now planned for completion during the early 1980s. The project is an extensive scheme for the interbasin transfer of water from the Mahaweli Ganga, Sri Lanka's major river, into the catchment areas of several of the largest tanks in the North-Central Dry Zone of the country. Diverted water will be used for both power generation and irrigation. About 650 000 acres of new paddy lands and 250 000 acres of existing paddy are planned to benefit from the additional irrigation water which is expected to be available.

1.5 To obtain full benefit from water diverted under the Mahaweli scheme, and from existing sources, it is essential that all irrigation water should be used as efficiently as possible. The ID are aware of the need for efficient irrigation practices and in 1974 they established a Water Management Division in order to investigate all aspects of water use on selected schemes.

1.6 The topic of water management on irrigation schemes, of particular relevance to the ID, was one of the potential areas of research identified by Mr C L Abernethy, Head of the Overseas Development Unit (ODU) of the Hydraulics Research Station (HRS), during a visit to Sri Lanka in 1975. The present study developed from a suggestion in Mr Abernethy's report on his visit that the ODU might usefully collaborate with the Sri Lanka Irrigation Department on water management research.

1.7 Having considered studies then taking place in Sri Lanka, and others proposed, the report concluded that there remained a need for a detailed examination of the water budget of a typical scheme under normal operating conditions. The ID were asked to specify an irrigation scheme of between 1000 and 10 000 acres for study and they chose the Kaudulla scheme, situated near Polonnaruwa in the North-Central Dry Zone of Sri Lanka.

1.8 Kaudulla tank was impounded during the 3rd century and repaired during the 11th and 12th centuries. Restoration was begun by the ID in 1958 and the tank now has a storage capacity of 104 000 acre-feet at full supply level. At present it provides water for the irrigation of 10 500 acres of paddy rice.

A further 31 000 acres are scheduled for development in the near future as part of the Mahaweli Development Project. The tank received its first water diverted from the Mahaweli Ganga during December 1976.

1.9 The proposals for the Kaudulla water management study are that it should monitor the water budget of the whole irrigation scheme, including the tank and its catchment area, under normal operating conditions over two complete Maha and Yala seasons. Analysis of the benefits of applying different water management practices will be done by desk studies, including a mathematical model of the scheme, using data obtained from the field measurements. The study is being undertaken by three organisations in collaboration:

i) the Overseas Development Unit (ODU) of the Hydraulics Research Station (HRS), UK;

ii) the Institute of Hydrology (IH), UK;

iii) the Irrigation Department (ID), Sri Lanka.

Funding of the UK input is provided by the Overseas Development Administration (ODA).

1.10 At present field data are available for the 1978 Yala season and the 1978/79 Maha season. These observations are derived from the data collection network (Fig 1) planned jointly by ODU, IH and ID personnel during site visits. Measuring equipment was installed by ID staff who maintain a program of regular observations.

1.11 When planning the study a basic philosophy of using simple measurement techniques was adopted and this is being adhered to. Wherever possible techniques already familiar to the ID are employed. The aim of this approach is to achieve results to an appropriate degree of accuracy as cheaply as possible using limited manpower. If this approach is successful it has the merit that it can be applied elsewhere in Sri Lanka by the ID themselves and in other countries by the ODU.

1.12 This report summarises the findings from a preliminary study of the first full year of data. It describes some of the problems encountered and considers what further work should be done. The conclusions reached in this report must be considered as preliminary assessments only, whose main value will be as a basis for discussion.

2 DESCRIPTION OF THE SCHEME

2.1 Scheme Area and Study Area

2.1.1 The Kaudulla Scheme at present comprises some 10 500 acres of irrigable paddy land, together with associated land for housing, rain-fed "highland" cropping plots and market centres. The Scheme is divided into two Stages (Fig 1) each receiving water from separate main channels leading from sluices in the bund of Kaudulla Tank. In addition, parts of Stage II receive water from Ambagaswewa, a restored village tank in the north-east of the Scheme. The land which lies within the ID administrative boundaries of Stages I and II has been termed the "Scheme Area".

2.1.2 For the purposes of the Water Management Study, the boundary has been extended to include the catchment area of Kaudulla Tank, and the Scheme Area and Tank catchment, taken together, comprise the "Study Area".

Kaudulla Tank catchment and supply of Mahaweli water 2.2

2.2.1 The "natural" catchment of Kaudulla Tank, as defined by the watersheds of the subcatchments of the streams which feed it, has been extensively modified by irrigation works. During the 6th Century AD, a diversion channel was built to the west of Kaudulla so that water could be sent from Minneriya Tank, to the south, towards Kantalai Tank, to the north. This channel, the Minneriya-Kantalai Yoda Ela (MKYE), has subsequently been restored and enlarged, and it now commences at a radial gate spill in the bund of Minneriya Tank. At junctions with the two major streams which are intersected by the Yoda Ela, Gal Oya and Alut Oya, radial gate spills have been constructed (Plates 1 and 2). Under normal circumstances run-off from the upper catchments of these two streams is diverted via the MKYE to Kantalai, and water tends only to be released from the spills to Kaudulla Tank during the north-east monsoon when there is a danger of flooding land close to the Yoda Ela. A number of causeway spills have been constructed in the right bank of the MKYE to cope with excess flood flows, and at two places the Yoda Ela channel expands to form village tanks, Rota Wewa and Matale Wewa.

2.2.2 The southern limit of the Kaudulla Tank catchment is defined by Minneriya Tank bund, and to the east of the MKYE spill there is a second radial gate spill from which water can be issued directly to Kaudulla Tank via the channel of the Aggalawan Oya. Since the construction of the Polgolla Barrage, near Kandy, and of associated works which together comprise the earlier stages of Phase I of the Mahaweli Development, it has been possible to send Mahaweli water to Kaudulla via Minneriya. The following route is used:

i) From the Mahaweli Ganga at Polgolla Barrage by tunnel to Ukuwela Power Station on the Sudu Ganga (5 miles).

ii) Via the Sudu Ganga and Amban Ganga to the diversion dam at Bowatenna (18 miles).

iii) Via the Amban Ganga, continuing below Bowatenna to the anicut (diversion weir) at Elahera (9 miles).

iv) Via the Elahera-Minneriya Yoda Ela (supply channel) to Minneriya Tank (20 miles).

v) Via the Aggalawan Oya to Kaudulla Tank (4 miles).

2.2.3 Within the Kaudulla Tank catchment a small amount of paddy is grown, mainly fed from the village tanks of Ratmale Wewa and Rota Wewa. The remainder of the catchment is largely covered by scrub forest, or by land which is reverting to scrub after shifting cultivation, known as chena in the Dry Zone (Plates 34 and 35).

Kaudulla Tank – bund, spill and sluices 2.3

2.3.1 At full supply level Kaudulla Tank has a capacity of 104 000 acre-feet, and a surface area of 6100 acres. The sill of the lower of the two sluices is 30 ft below full supply level so that the tank is comparatively shallow. The bund is over 5½ miles long and has been formed by using fairly short embankment sections to link together a range of low hills which runs north and south between the tank and the irrigated Scheme Area. The tank spill, sited near the northern end of the bund, consists of 12 radial gates, each 20 ft wide, and the spill channel is a natural drainage channel (possibly the original course of the Alut Oya?) which joins the Kaudulla Oya about a mile east of the Low Level Sluice.

2.3.2 Irrigation water is issued via two sluices. The Low Level Sluice (Plates 5 and 6), towards the south of the bund, supplies Stage I of the Scheme by releasing water initially into the channel of the Kaudulla Oya, the main drainage stream which runs along the southern edge of the Scheme. Some 2½ miles downstream, after picking up any flow from the Tank Spill channel, the Kaudulla Oya reaches an anicut, or diversion weir, at which flow is normally diverted into the Stage I Main Channel. Radial gates in the anicut structure allow the release of floodwater to drainage along the Kaudulla Oya itself. Stage II of the Scheme is fed by the High Level Sluice (Plates 3 and 4), whose sill, at 25 ft below full supply level, is 5 ft higher than that of the Low Level Sluice. Flow enters directly into the Stage II Main Channel.

Scheme layout – channels and paddy tracts 2.4

2.4.1 As the operation of the system of irrigation supply channels will be considered in detail later in the Report, it will only be covered in outline here. From each of the main channels of Stages I and II a network of branch, distributary and field channels (in decreasing size order) supplies water to the paddy fields.

2.4.2 The paddy fields are laid out within tracts of land which vary in size between 200 and 1500 acres, each tract being fed by its own network of distributary and field channels. There are 9 tracts within Stage I and 12 in Stage II with respective acreages (calculated at the Scheme design stage) of 4752 and 5935 respectively. The design area of paddy land within the existing Kaudulla Scheme is therefore 10 687 acres.

Topography and soils 2.5

2.5.1 The topography of the Scheme Area is gently undulating, with slopes between irrigation channels and drainage streams seldom exceeding 3%. Stage I, which drains south-eastwards into the Kaudulla Oya/Kahambiliya Oya system, is generally flat, with large areas over which slopes within paddy tracts do not exceed 1%. Stage II drains north-eastwards, via Ambagaswewa and via the stream which runs to the east of paddy tracts 9 to 12, and has slightly more undulating topography than Stage I, with slopes ranging up to 3%.

2.5.2 On the gently undulating land of Stage II, a typical soil sequence comprises well drained Red Brown Earth soils on the ridge, imperfectly drained Red Brown Earths on slopes where paddy cultivation is well established, and poorly drained Low Humic Gley soils in the valley bottoms (Plate 30). The characteristics of these soils are fully described by Panabokke[17]. Although classified as "well drained", the Red Brown Earth (RBE) soils on the ridges are used for paddy cultivations in areas where they lie in the command of irrigation channels. Field permeabilities of different soil types will be compared later in the report (Chapter 6), but it is interesting that farmers and soil surveyors feel strongly that the permeabilities of paddy fields laid out in well drained soils decrease significantly after fields have been cultivated for a number of years. This may be due to a combination of (a) reduced flow through the field beds following the development of mudded soil layers which are less permeable than the original soil, and (b) progressive compaction of field bunds which would reduce seepage from field to field. A reconnaissance soil survey prepared for the Study by the ID Land Use Division indicates that some 10% of the irrigated Scheme Area is laid out on well drained RBE soils, the remaining 90% being on the more poorly drained soils.

Farm holdings 2.6

2.6.1 Farmers on the Kaudulla Scheme have holdings partly of paddy land, and partly of "highland" which lies above the command of the irrigation channels. On Stage I the farms comprise 3 acres of paddy land and 2 acres of highland, and on Stage II they comprise 2 acres of paddy and 1 acre of highland.

The highland plot provides a site for the farmer's house, and also for the cultivation of vegetables and tree crops, including banana, betel, chillies, coconuts, cow peas, jak fruit, mango, manioc and papaw. On the irrigated land the farmers now grow two paddy crops each year as access to Mahaweli water has reduced the risk of water shortage in the Yala season.

Cultivation of paddy rice 2.7

2.7.1 The first stage of land preparation for paddy, after irrigation water has become available, is to flood each field (liyadde) and then to plough (Plate 28), burying most of the stubble and weeds. After a period of one to two weeks, to allow some breakdown of the organic matter, fields are levelled and field bunds (liyadde bunds) repaired where necessary. Although the use of tractors is increasing, most of the paddy land at Kaudulla is still prepared using buffalo. The following figures, from the Agricultural Extension Office at Medirigiriya, relate to land preparation on Stage II for the 1978 Yala:

3602 acres by buffalo
1054 acres by four wheeled tractor
875 acres by single axle tractor

Most farmers, without co-operation or external financial assistance lack the capital to purchase or even hire tractors. It costs around 400 Rs (£13)/acre to hire a tractor and driver, and hire of buffaloes costs 60 Rs (£2)/day.

2.7.2 In many paddy tracts the fields are small and irregularly shaped (Plates 32 and 33), making them unsuitable for mechanised cultivation. Traditional methods of cultivation using buffalo are labour intensive, but as the farmer and his family do most of the work the outlay of capital is small, especially as a reasonable proportion of farmers own buffalo themselves. With the increasing price of fuel, and in the absence of a labour shortage at Kaudulla, the use of buffalo is likely to continue to be the most economic method of land preparation. Overall shortages of power, either animal or mechanical, do occur at peak periods of land preparation. These shortages result in considerable staggering of planting dates, so that more irrigation water has to be used later in the cropping season than would be the case if all planting took place within a period of, say, three weeks. Under existing conditions it seems unlikely that staggering of planting dates will be reduced. Farmers or contractors seem to have neither the incentive (nor possibly the capital) to increase the numbers of buffaloes and tractors available for effective use over only two very short periods of the year.

2.7.3 Varieties of paddy seed used in Kaudulla are divided into two groups according to the approximate lengths of growing seasons. In the Maha, when rainfall is plentiful, longer season varieties are used, and BG 11–11, a 4–4½ month variety is the most popular on the Scheme. As the Yala crop relies heavily on irrigation, shorter season varieties are used, the most popular being BG 34–8, a 3 month variety. Actual cropping periods do not precisely follow the times specified for each variety, and for the water balance modelling work cropping periods of 135 days for Maha and 105 days for Yala have been selected as typical of the Scheme. A more precise picture of actual dates of land preparation, sowing, transplanting and harvesting achieved by farmers at Kaudulla is likely to emerge from work carried out by Tinsley and Seneviratne from the Maha Illuppallama Research Station. During Yala 1978 and Maha 1978/79 they interviewed a number of farmers in Tracts 2 and 6 of Stage II of Kaudulla and their results, when published, should provide interesting information on actual timing of cultivation activities on parts of the Scheme.

2.7.4 Paddy may be broadcast, or cultivated in nurseries and subsequently transplanted (Plate 29). Seed is usually pregerminated, as sprouted seed grows more quickly and is less susceptible to damage from birds and insects. Transplanted paddy does not necessarily outyield broadcast paddy, but transplanting into fields which are already flooded suppresses weed growth and offsets the effects of poor seed quality and indifferent water management which can reduce yield from broadcast paddy. Although continuous flooding of the fields is effective in suppressing many weeds, further weed control by the application of herbicides or hand weeding is often practised. Herbicides are most effective when the weeds are small, before they have had a chance to crowd the crop, and they are marketed as sprays, emulsifiable concentrations or granules which can be added to standing water.

2.7.5 Farmers are recommended to apply a basal fertiliser at the time of the second ploughing prior to sowing or transplanting, and two or three top dressings at later stages of growth of the crop. The basal fertiliser mainly contributes phosphorous and potassium together with a small amount of nitrogen. At Kaudulla, urea in granular form is used as a nitrogen top dressing.

2.7.6 The most serious insect pests in Sri Lanka are leafrollers, brown hoppers, stem borers, gall midges, thrips and paddy bugs. Insecticides are available for treatment and knapsack sprayers are used quite widely on the Scheme. Rats can be a nuisance, but they are fairly easily controlled by poison baiting. Crabs, which burrow into liyadde bunds, can reduce crop yields by nibbling the bases of plants before the tillering stage. They also burrow right through liyadde bunds and cause leakage of water ponded in fields. They can be controlled by squirting insecticide solution into their burrows.

2.7.7 Paddy is generally harvested by hand using sickles. At harvest the moisture contents of grain and straw are about 18% and 50% respectively and the crop is dried in the sun to reduce moisture prior to stacking. Threshing usually takes place on a threshing floor consisting of a circular patch of well cleaned earth situated on higher ground to raise it above the general level of the paddy fields. Threshing is carried out by bullocks or tractors continuously working round and round over the sheaves on the threshing floor. Winnowing usually takes place by tossing the threshed paddy into the air so that straw and chaff are blown away from the grain by the wind (Plate 31). The grain is then dried in the sun and bagged for storage at a moisture content of 12–13%.

2.7.8 Although the paddy varieties commonly grown at Kaudulla have potential yields of 140 bushels/acre, actual yields achieved by farmers on the Scheme are around 70–80 bushels/acre. There are several possible reasons for these low yields:

i) Poor quality seed. Although the genetic viability of high-yielding varieties lasts only a few seasons, some farmers do not renew their seed every 2–3 years from certified sources.

ii) Inadequate use of fertilizers. Due to financial constraints fertilizers are not always applied in the amounts recommended. Some farmers neglect to apply the basal mixtures and use only the top dressings as these show immediate and visible results.

iii) Poor weed control. New varieties tend to be short and erect, weeds are not shaded out to the extent they are by the taller traditional types. Chemical methods of weed control are not popular as herbicides are expensive.

iv) Ineffective plant protection. It is important to use the appropriate chemicals at the appropriate time but unfortunately most farmers, due to the costs, only act when their crops are seriously threatened. To be effective it is also important for adjacent farmers to synchronise their spraying and dusting operations.

v) Poor water management. Shortages of water can seriously affect the yield. Paddy can develop two different types of roots, swamp roots which function in waterlogged anaerobic conditions and 'dry foot' roots which need aeration. The swamp root is confined almost totally to the top 100 mm of soil, the plant is therefore vulnerable to moisture stress soon after a field dries out. Paddy is able to change from one root system to the other but only at the expense of yield. Subjecting the paddy to alternate periods of inundation and aeration is likely to stimulate new roots, again lowering the yield.

2.7.9 The majority of the information in this section on paddy cultivation has been obtained from discussions with agricultural extension officers, engineers, farmers and soil surveyors on site at Kaudulla. Additional background material has been derived from other sources (see Refs 1, 9, 13, 19).

MEASUREMENTS 3

Study proposals 3.1 Following a site visit by D W Holmes (DWH) and H Gunston (HG) during February and March 1977 detailed proposals were made for Phase 1 of the study, the installation of measuring devices in the field. Much of the work was completed during 1977 and a second site visit was made by DWH and HG during February and March 1978 to discuss progress. An amended version of the proposals[11] was prepared following this visit. The proposals summarised the planned measurements under a number of sub-headings and the same format is used in the following description of the current data collection network.

Inputs to the Study Area 3.2

3.2.1 *Issues to the Minneriya–Kantalai Yoda Ela (MKYE) from Minneriya Tank.* A gauge post was installed near the railway bridge and current meter rating of the section was carried out to establish the stage-discharge curve. Daily records have been supplied by ID from April 1978. This is not a direct input to the Project Area but it can be the source of flows to Kaudulla Tank via Gal Oya or Alut Oya radial gates.

3.2.2 *Issues to Aggalawan Oya from Minneriya Tank.* A gauge post was installed and the section was rated. Daily records have been supplied from April 1978. Prior to rating of the cross-section issues were calculated from records of the radial gate openings and Minneriya Tank levels.

3.2.3 *Issues from Rotawewa, Matale Wewa and Ratmale Wewa.* Due to an administrative reorganisation these village tanks came under ID control on 1 March 1978. Daily records of sluice openings and tank levels have been supplied from the start of the 1978 Yala season.

3.2.4 *Issues from Gal Oya and Alut Oya radial gates in rainy periods.* ID standing orders require observers at such time for flood prevention measures. Records of discharges in rainy periods, with information on their variation with time, have been supplied, calculated from gate openings and MKYE water levels.

3.2.5 *Spill from 10 trapezoidal relief channels in MKYE in rainy periods.* The spill sections have been surveyed and data on their cross-sections have been supplied. From April 1978 to the present (July 1979) no spill has been recorded.

3.2.6 *Seepage losses from the MKYE.* This is probably a minor input and has not been measured directly. Further studies of conveyance losses in the irrigation channels of the scheme, including ponding tests, should give an indication of the likely magnitude of seepage losses from the MKYE.

3.2.7 *Rainfall.*

i) Daily rainfall measurements are made at six sites over the Study Area, as shown in Fig 1. At two sites, Gal Oya Spill and Kaudulla Tank Low Level Sluice, raingauges were already installed before work on the Study commenced (Plates 20 and 21). At the remaining four sites, Ambagaswewa, Diyasenapura, Fourth Mile Camp (Stage II) and Kaudulla Tank High Level Sluice (Headworks), gauges were installed during the 1977/78 Maha season (Plates 22 to 25).

ii) Recording raingauges were installed early in 1978 at Diyasenapura, Fourth Mile Camp and Kaudulla Tank High Level Sluice.

Rainfall data are discussed in Chapter 5.

3.2.8 *Surface and sub-surface drainage into the Study Area.* See para 3.5.

Outputs from the Study Area 3.3

3.3.1 *Surface and sub-surface drainage from the Study Area.* See para 3.5.

3.3.2 *Issues to Migollewa from Tract 9 of Stage II.* This small tank receives rainfall runoff and can be fed by a field channel from Tract 9. No area-capacity curve exists and only 22 acres of paddy are served by Migollewa. No measurements are therefore being made on this tank.

3.3.3 *Evaporation losses from water surfaces and vegetation.* Meteorological stations have been established at Diyasenapura and Kaudulla Tank High Level Sluice (Headworks) to provide climatic data from which evaporation can be estimated (Plates 24 and 25). Sites are shown in Fig 1. Observations are made daily at these stations as follows:

i) Maximum and minimum air temperatures (Screen).

ii) Wet and dry bulb air temperatures (Screen).

iii) Wind run (Cup counter anemometer).

iv) Hours of bright sunshine (Campbell Stokes recorder).

v) Pan evaporation (Class A pan, unscreened).

vi) Daily rainfall.

vii) Continuous rainfall record (Dines recording raingauge).

viii) Wind direction.

Evaporation estimates prepared from these observations are discussed in Chapter 5.

Measurements within the Study Area 3.4

3.4.1 *Kaudulla Tank level.* Daily records have been supplied since April 1978.

3.4.2 *Issues from Kaudulla High Level and Low Level Sluices and spill when available.* The Low Level Sluice issues are calculated from the opening and Kaudulla Tank levels and have been supplied since April 1978. The first gauge post (KWH(b) in Fig 5) in the Stage II main channel is situated several hundred feet downstream from the sluice. It has been used since April 1978 to calculate issues but it is intended to supplement this measurement with observations of water levels at the sluice outlet. High Level Sluice issues will then be determined from sluice openings and recorded heads across the sluice. Records of spill have been provided, calculated from the radial gate openings and Kaudulla Tank levels.

3.4.3 *Ambagaswewa level.* Daily records have been supplied since April 1978. The area-capacity curve for the tank was supplied during a site visit in February 1978.

3.4.4 *Issues from Ambagaswewa sluices and spill when applicable.* Daily records have been supplied since April 1978, based on stage-discharge curves at gauge posts A(l) and A(m) (Fig 5). When data are available on the datum levels of these gauge posts issues will be calculated from the known sluice openings, tank levels and downstream water levels.

3.4.5 *Issues to 9 paddy tracts of Stage I and 12 tracts of Stage II.* Daily records of water levels at 15 gauge posts in Stage I channels and 37 gauge posts in Stage II channels, at positions shown in Figs 2 and 4, have been supplied since April 1978. These levels have been used to establish discharges through rating curves obtained by current metering. Loss of gauge posts through their use for tethering water buffaloes has frequently occurred. Each gauge post has its marking related to a nearby bench mark situated in a safe place and of permanent construction. When a post is lost a replacement is levelled in so that its markings bear the same relationship to the bench mark as did those of the missing post. This avoids the need for re-rating sections and has helped to reduce gaps in the records. Some of the stage-discharge curves show a need for further points to be obtained and it is hoped that the standardised current metering techniques suggested[12] for all irrigation and drainage channels will improve the definition of surface flows within the scheme. For the duration of the study it will be necessary to treat the current meter rating of channels as a continuous exercise.

3.4.6 *Channel conveyance losses.* To measure conveyance losses in a typical irrigation channel ID staff carried out a ponding test between the two drop structures at 2m 27ch and 3m 0ch on Stage II, Branch Channel 1 (Fig 4). See para 6.6 for details.

3.4.7 *Surface drainage from paddy tracts.* From the Blocking Out Plans (BOP) of the scheme a number of points were identified for possible measurement of surface drainage. After field inspection of these sites 10 were accepted in Stage I and 5 in Stage II (Figs 3 and 5). Eight of the sites are stream cross-sections, four are at culverts and three at bridges. Gauge posts have been installed at these sites within straight reaches of the natural channels, upstream of the culverts and on the upstream faces of the bridges. Current metering has been carried out to obtain ratings. Records have been supplied from April 1978 although gaps due to losses of gauge posts have been more extensive than in irrigation channels. The BOP and four chain engineering survey sheets have been used to determine what areas of the scheme contribute surface flow to each drainage measurement site.

3.4.8 *Sub-surface drainage from tracts.* Weekly observation of water surface levels in twenty existing wells, at locations shown in Figs 3 and 5, have been supplied from February 1978. The levels are referred to a common datum of Mean Sea Level (MSL).

3.4.9 *Seepage from Kaudulla Tank through the bed.* A preliminary estimate of the seepage through the bed of Kaudulla Tank has been made from measurements of evaporation, tank sluice issues and tank levels for periods of no rainfall.

3.4.10 *Seepage from Kaudulla Tank through the bund.* Observations have been made at sites where there is measurable seepage, using small portable Parshall flumes available in the ID. No flows of greater than 0.5 cusec were measured, and generally discharges were smaller than this figure, which is negligible in terms of the scheme water budget.

3.4.11 *Areas of paddy cultivation.*

i) The local Agricultural Extension office at Medirigiriya has provided estimates of the total acreages of paddy land within the Scheme Area which were irrigated from Kaudulla and Ambagaswewa Tanks during Yala 1978 and Maha 1978/79. These figures have initially been provided as separate totals for Stages I and II of Kaudulla, but data are also available for the individual paddy tracts within the overall Scheme Area.

ii) A set of air photographs of much of the Mahaweli Development area was taken in February 1979. It is understood that the existing Kaudulla Scheme lies within the area covered by these photographs, and it is hoped to use copies of prints of Kaudulla to indicate how the existing boundaries of irrigated paddy land differ from those originally specified in the Kaudulla Scheme BOP.

3.4.12 *Paddy field (liyadde) ponding tests.* A number of field ponding tests have been carried out to study the variation of percolation rates within paddy fields over the different soil types within the Scheme Area (Plates 26 and 27). Individual fields (liyadde) were ponded up, and rates of fall of water levels monitored at intervals over 24 hour periods. The results of these ponding tests are discussed in Chapter 6. A reconnaissance soil map of the Kaudulla Scheme area, prepared by the Land Use Division of ID, has greatly assisted in planning the ponding test programme.

Surface and sub-surface drainage 3.5

3.5.1 In paragraphs 3.2 and 3.3.1 the topics of surface and sub-surface drainage into and out of the Study Area were referred to this section. Figs 3 and 5 show the 15 sites specified for surface drainage measurements, some on the boundaries of the Study Area and some within it, plus 20 well level observation points to assist estimation of sub-surface drainage.

3.5.2 The weekly observations of groundwater levels in the 20 wells have been used to plot water table contours over the scheme at the start of the 1978 Yala season, during close down before the 1978/79 Maha season and at the end of that season. Contours and spot heights from the 4 chains to 1 inch and 2 miles to 1 inch maps of the area have been combined to produce ground level contours over the scheme (Fig 6).

3.5.3 Observations of surface drainage flows, based on the stage-discharge curves of the 15 sites shown in Figs 3 and 5 have not been very successful. There have been problems in obtaining adequate numbers of points on the curves, with gauge post losses and with temporary dams, in the vicinity of some posts, built to re-use drainage water for irrigation. It is hoped that the standardised current metering techniques suggested[12] for all irrigation and drainage channels, together with detailed cross-section surveys at all drainage measurement sites, will improve the future data.

IRRIGATION AND DRAINAGE CHANNEL FLOWS 4

4.1 The general layout of the tank, main irrigation channels and paddy tracts is shown by Fig 1 and has been referred to in Section 2.4.

4.2 Across the scheme, from the tank to the downstream ends of Stages I and II, the land is gently sloping, falling about 150 ft in level. The irrigation channel gradients are small, with design values of 0.0003 for main and branch canals and 0.0004 for distributary and field channels. Typical bed widths are 10 to 20 ft in main and branch canals, 3 to 6 ft for distributary channels and 1 to 2 ft for most field channels. Design side slopes are usually 1 on 1. Branch Channel 1A of Stage II is concrete lined, some 2½ miles in length and with bed widths of 2.5 to 4 ft. All the channels in Tract 11 of Stage II, taking off from Branch Channel 1A, are also concrete lined. All other channels in the Kaudulla scheme are unlined.

4.3 The main and branch canals lie along natural ridges in the topography as do the distributary and field channels in most tracts. Since the terrain is almost flat these ridges are not usually apparent at ground level. From the paddy fields any surplus water drains away to the tract boundaries, which are formed by existing streams, accounting for the irregular shapes of the tracts in Fig 1.

4.4 A limited degree of control of the irrigation channel flows is provided by wooden gates at offtakes from the main and branch canals (Plate 9). These gates have a number of discrete settings from open to closed, achieved by padlocking their vertical stems through one of a series of holes. Unofficial flow control activities are practised by some cultivators as shown by Plates 15 and 18.

4.5 Kaudulla scheme is subject to a rotational issue regime of 3 days with water and 4 days without, for each part of the scheme. Table 15 shows the times at which various tracts should receive water but, in practice, this is not adhered to very strictly.

4.6 When planning the network of irrigation and drainage flow measurement sites an attempt was made to work on a tract by tract basis for the former and to locate satisfactory sites for the latter. No flow measurement structures exist on the scheme and a number of drop structures on Stage II have their crest heights varied by stopboards during normal operations which renders them difficult to incorporate into a measurement network.

4.7 Because of the size of the scheme and the need to keep manpower requirements and costs to a reasonable level it was decided that all surface flow measurements should be carried out by establishing stage-discharge curves for channel cross-sections. Daily observations of water levels on gauge posts at all measurement sites would then convert directly to discharges.

4.8 The advantages of this approach are that it uses techniques familiar to the ID, is much cheaper than building large numbers of expensive flumes, it does not introduce head losses and it can be utilised at other irrigation schemes in Sri Lanka by the ID if effective at Kaudulla. The disadvantages of the approach are that it is susceptible to gauge post losses, measurement accuracy is lower than would be the case with flumes and the stage-discharge curve needs to be frequently checked by current metering in order to take account of channel cross-section changes and growth of vegetation.

4.9 Fig 1 shows the 52 irrigation channel gauge posts and 15 drainage channel posts currently in use. Data are available from these posts, with some gaps, from April 1978 on a daily basis. Analysis of these data has shown that the irrigation channel stage-discharge curves are better than those for drainage streams but that most of the sites would benefit from further field work. A standardised current metering technique has been suggested(12) and channel cross-section surveys have been requested at all sites. With reliable cross-section data it should prove possible to extrapolate and interpolate stage-discharge curves which have relatively few observations.

4.10 At present the difficulties experienced with the drainage stream observations have been by-passed to some extent by the use of the Ambagaswewa sub-system of the Kaudulla scheme. Ambagaswewa (Fig 1) is a tank within the Kaudulla scheme which receives drainage water from paddy tracts 4, 5, 6, 7 and 8 of Stage II. From a water balance study of Ambagaswewa typical drainage figures have been derived for general application over the scheme.

4.11 It was hoped that it would prove possible to derive information on channel conveyance losses from successive gauge post observations in reaches where offtakes were closed. At present this is not possible and it is planned to carry out a number of channel ponding tests at selected locations in order to determine typical channel bed seepage rates for the soils on the scheme. To date, one such test has been carried out during the close down period following the 1978 Yala season. See para 6.6 for details.

RAINFALL AND EVAPORATION 5

Rainfall data, 1978/79, and spatial variability of rainfall 5.1

5.1.1 As mentioned in the 'Measurements' section of the report, rainfall has been measured daily at the six sites over the Study Area which are shown in Fig 1. Daily rainfall totals for all gauges for the period April 1978 to March 1979 are listed in Tables 1 to 12 together with daily areal rainfall means for the Kaudulla Tank catchment and for the Scheme Area, derived using Thiessen polygons.

5.1.2 The full set of daily rainfall values has been listed in order to show the considerable variation which occurs in raingauge catch over quite small distances. The extreme distance between two raingauges within the Study Area (Gal Oya Spill to Ambagaswewa) is less than 12 miles, and the five gauges excluding Gal Oya Spill lie roughly within a rectangle whose longer side is less than 7 miles. A number of anomalies are apparent in the listed rainfall data, eg no rainfall was recorded for Diyasenapura on the day of the cyclone, 23 November 1978, and there is a persistent, if irregular, indication that rainfall from Ambagaswewa tends to be entered on the wrong day. These few anomalies do not, however, account for the more general variation of daily catches between gauges which must largely be due to the localised nature of convective rainstorms.

5.1.3 Following the practice of the Hydrology Division of ID, all raingauges within the Study Area have been mounted on concrete plinths with rims four feet above ground level. Although there is evidence from work carried out by IH in Kenya(6) that the catch of a raingauge under tropical conditions may be reduced by 2–3% by raising the raingauge rim four feet above the ground, for the practical purposes of the Study it was important to maintain uniformity of height between the new gauges installed and those which already existed in the Study Area at Gal Oya Spill and Kaudulla Tank Low Level Sluice. In addition, raingauges mounted at four feet are less likely to produce erratic readings due to interference or damage by stray animals.

Seasonal and monthly variation of rainfall 5.2

5.2.1 As has been mentioned in the Introduction, the climatic year in Sri Lanka is often divided into two six-monthly seasons:

i) The Yala, from April to September, the season of the south-west monsoon.

ii) The Maha, from October to March, the season of the north-east monsoon.

Provided that it is accepted that the dates defining these six-monthly seasons are arbitrary, with no precise climatic or agricultural significance, it is useful to discuss the variation of rainfall in terms of the Yala and Maha seasons as well as the variation from month to month.

5.2.2 The rainfall over the Tank catchment area from April 1978 to March 1979 is compared in the accompanying table with long-term (30 year) mean monthly rainfall totals for Minneriya[5], a station sited some two miles to the south of the Tank catchment. Considering first the typical pattern of variation of monthly rainfall totals through the year, as represented by the Minneriya data, the Maha season is clearly the wetter half of the year. The north-east monsoon is generally regarded as starting in late November or December[2,3,7] but the preceding "inter-monsoon" period during October and November is also typically wet at Minneriya. Following the peak of the rains in December, the monthly totals fall until March, following which there is a lesser peak in April. The Yala season becomes progressively drier with June – normally the first calendar month of the south-west monsoon – being the driest month of the year. In 1978 at Kaudulla no rain was recorded in June.

COMPARISON OF MONTHLY RAINFALL DATA
(Values in millimetres)

SEASON	YALA						MAHA						TOTAL
MONTH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	
Kaudulla Tank catchment (1978/79)	59	43	0	75	0	23	493	464	432	45	124	57	1815
Minneriya 30 year means (1931–60)	144	85	4	36	57	68	185	271	335	227	104	82	1598
Gal Oya Junction a) 13 year means (10/41 – 9/54)	135	91	4	32	55	66	218	271	313	208	83	99	1575
b) Standard deviations (mm)	54	86	9	38	43	67	107	121	166	132	107	68	–

5.2.3 The long-term data from Minneriya indicate the typical variation of monthly rainfall through the year, but it is also important to consider variation between years. Apart from the differences which appear in the table between the Minneriya values and those over the Tank catchment from April 1978 to March 1979, a second set of rainfall data is presented. This covers 13 years of rainfall record from October 1941 to September 1954, from a former raingauge site at Gal Oya Junction railway station, very close to the present gauge site at Gal Oya Spill. In addition to 13 year monthly mean values, which correspond closely to the 30 year means at Minneriya, the standard deviations of monthly totals from Gal Oya have been calculated to give some indication of variability between years.

Evaporation 5.3

5.3.1 Values for open water evaporation, E_o, and potential transpiration, E_t, have been calculated, using Penman equations, from data collected at the meteorological stations installed for the Study at Kaudulla Tank High Level Sluice and at Diyasenapura. Mean monthly values for E_o from High Level Sluice are shown in Table 13, and for E_t from Diyasenapura in Table 14. In order to present data as a calendar year starting in January, the 1979 January to March values have been placed *before* the 1978 April to December values in the tables.

5.3.2 For modelling purposes the E_o data from High Level Sluice have been used to estimate tank evaporation from Kaudulla and Ambagaswewa. The E_t data from Diyasenapura have been used as a basis for calculating crop water use, crop factors proposed by Dr Joshua[14] having been used to estimate evaporation from the paddy crop over the Maha and Yala seasons. Monthly totals of E_o (High Level Sluice) and E_t (Diyasenapura) are presented in the table on this page, together with Dr Joshua's values for "reference crop evapotranspiration", E_{to}, calculated using long-term climatic means from Maha Illuppallama, a station some 35 miles west of Kaudulla.

COMPARISON OF MONTHLY EVAPORATION DATA
(Values in millimetres)

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
E_t, Diyasenapura	127	126	155	162	189	198	198	205	201	161	126	109	1957
E_{to}, Maha Illuppallama	119	127	157	150	163	175	190	193	190	157	109	114	1844
E_o, High Level Sluice	174	171	220	216	239	255	263	273	267	205	153	143	2579
E_{pan}, High Level Sluice	132	135	202	192	226	273	275	307	282	164	106	110	2404
E_o/E_{pan}, High Level Sluice	1.32	1.27	1.09	1.13	1.06	0.93	0.96	0.89	0.95	1.25	1.44	1.30	–

Notes: a) All data from Diyasenapura and High Level Sluice are presented with 1979 values from January to March, and 1978 values from April to December.

b) Maha Illuppallama data are derived from long-term climatic means, see Joshua[14].

5.3.3 Reference crop evapotranspiration is a concept presented in the FAO Irrigation and Drainage Paper 24, "Crop Water Requirements"[4], and the values used by Dr Joshua[14] have been calculated using the "Modified Penman" equation presented in the FAO Paper. Although the widespread use of the FAO Paper has resulted in the increasing acceptance of the "Modified Penman" equation, there is as yet no general agreement amongst evaporation physicists that the "modified" equation gives better estimates of potential transpiration under tropical conditions than more orthodox Penman-type equations which have been used in the past. For the present report the Penman E_o and E_t equations used are those accepted within IH for overseas work[16,18], the principal modification being the use of the latitude-related Angstrom equation suggested by Glover and McCulloch[8] in the incoming radiation term. (*Note:* A Kipp electrically recording solarimeter has recently been installed at High Level Sluice, from which it is planned to obtain radiation data which can be used to prepare a local Angstrom equation appropriate to Kaudulla and the North-Central Dry Zone.)

5.3.4 As there have been no meteorological stations in the past in the close vicinity of Kaudulla, it is not possible to compare the 1978/79 data and evaporation estimates from the Study Area with long-term mean values calculated from climatic data collected locally. Work is at present in progress, however, on comparing 1978/79 data from a number of evaporation stations in the North-Central Dry zone for which Penman values can be calculated, including Maha Illuppallama. These comparisons, together with results of calculating what might be called "orthodox" and "modified" Penman potential transpiration estimates from identical input data, will be presented in a separate report on evaporation estimation in the North-Central Dry Zone which is now being prepared.

5.3.5 Class A evaporation pan data have also been collected from unscreened pans at High Level Sluice and Diyasenapura, but the values have not been used for the modelling work. The monthly pan evaporation totals for High Level Sluice are shown in the table on page 14, together with the Penman E_o totals, and the E_o/E_{pan} ratios. It is proposed to include discussion of pan evaporation data in the separate report on evaporation in the North-Central Dry Zone, but it is of interest to compare the E_o/E_{pan} values shown with those in Table IV(e) of WMO Technical Note 126, "Comparison between Pan and Lake Evaporation"(10).

GROUNDWATER 6

6.1 This chapter relates to groundwater and the components of its flow quantified within this study. Groundwater changes have been monitored by observation wells (para 6.2), a channel ponding test has been carried out (para 6.6) and paddy ponding tests have been run (para 6.11).

6.2 There are twenty groundwater observation wells within the scheme area. These are shown in Fig 1 and a typical well is shown in Plate 19. They are generally within villages which tend to be on higher land than the lowland paddy. For this reason the position of the watertable relative to the paddy is a little uncertain. The possibilities of placing some wells in the lowlands are to be explored.

6.3 Records from these wells are available since February 1978. During this period the peak ground water levels occurred in December 1978, and it seems reasonable to assume that the peak will occur at this time every year because of the high rainfalls in October, November and December. The lowest groundwater levels occurred at the beginning of October – before the start of the monsoon.

6.4 The range from trough to peak varies from 4 ft to 21 ft with an average of about 10 ft. It is thought that the maximum groundwater level may be near the surface, but that for most of the year the groundwater will be too low for capillary action.

6.5 Groundwater contours have been plotted using the Calcomp General Purpose Contouring Program (GPCP) on the Station's ICL 1904S digital computer. Data consist of the twenty groundwater readings plus two synthetic readings which help produce more realistic contouring. Two plots are shown in Figs 7 and 8. The GPCP also produces volumes above a fixed datum, so groundwater volume changes are easily computed if a storage coefficient is known. Using a coefficient of 10% the groundwater volume change within the scheme area downstream of Kaudulla Tank bund (28 000 acres) was 17 930 ac ft during the Yala season 1978 (April 2 – September 30) and 12 580 ac ft during the Maha season 1978/79 (Oct 1 – March 31).

6.6 A channel ponding test was run in October 1978 to determine the seepage to the groundwater table. Thirteen sections were surveyed on Branch Channel No 1 of Stage II between 2m 27ch and 3m 0ch. The drop structures at either end were boarded up and three-hourly readings of three gauge posts in the reach were taken for a period of 48 hours.

6.7 A simple analysis was carried out to evaluate the conveyance loss per unit wet area of channel bed. (This preliminary analysis did not differentiate between seepage and evaporation because the prototype of the Theoretical Demand Model described in Chapter 10 requires one figure for total conveyance loss.) The analysis showed that the rate of 'seepage' fell from 204 mm/day in the first 12 hour period to 71 mm/day in the fourth 12 hour period.

6.8 The reduction in seepage rate was attributed to the falling head and increased permeability towards the top of the channel banks. An average rate of 125 mm/day was taken as a best figure.

6.9 It was attempted to run another ponding test in April 1979, but although cross-sections had been surveyed and gauge posts set up, a last minute lack of transport prevented the exercise.

6.10 It is hoped to run another ponding test in October 1979 when either Mr Holmes or Mr Dawson will be present. The possibilities of taking groundwater observations during the test from an existing nearby well or a specially bored well will be explored. This would enable a full seepage analysis to be carried out.

6.11 To estimate percolation losses from paddy fields within the Scheme, ponding tests were carried out in a number of individual fields (liyadde). An initial trial programme took place in July 1978, and a more extensive series of tests was carried out in June 1979. Sites were chosen to represent different combinations of soil types and slopes, and at each site three or four fields were chosen for ponding, these being approximately evenly spaced along a line downslope from a field channel to a drainage stream.

6.12 Fields were chosen for ponding where the crop had only recently been planted, and those with bunds which showed signs of active crab burrowing were avoided. By selecting fields in advance of the test day it was possible for them to be filled with 100–150 mm of water by the morning on which ponding was to start. After a final check of bunds for signs of visible seepage, four wooden rulers were stuck vertically and firmly in the soil of each field near the corners. An evaporation pan hook gauge was also used (Plates 26 and 27), the stilling well being firmly pressed into the soil of the field prior to levelling with a spirit level. Water levels were read hourly through the day until 5 or 6 pm, and rulers were left in position overnight so that a final set of readings could be taken the next morning. While tests were in progress, soil surveyors of the ID Land Use Division were classifying the soils of fields adjoining those which had been ponded.

6.13 A full analysis of results from the ponding tests in June 1979 has not yet been completed, but indications are that the rates of fall of water in ponded fields, *after making an allowance for evaporation,* vary between 10mm per day on Low Humic Gley soils and 50 mm per day on well drained Red Brown Earth soils. The term "field percolation rate", in the sense of a vertical percolation flow to a deep water table, has deliberately not been used for these figures. The paths of water movement beneath paddy fields, particularly beneath fields on well drained soils upslope, are complicated. A proportion of flow is downslope – either through the bases of the field bunds or beneath them. This results in the recharge of fields downslope and eventual subsurface flow into drainage streams.

6.14 The values of rate of fall of field water levels indicated by the ponding tests considerably exceed the rates of "percolation loss" predicted in the overall Scheme water budget (see Chapter 9). They also exceed the percolation loss values of 3 mm per day on LHG soils and 10 mm per day on well drained RBE soils assumed on page N25 of the Hunting Technical Services Report on the Victoria Scheme[13], although the source of these assumed values is not given.

6.15 At the present stage of the Study percolation losses over the paddy area have not been accurately quantified, although indications of a range of values have been given by the field ponding tests and the overall Scheme water budget. Future work will be carried out to attempt to define percolation losses more precisely.

IRRIGATION DUTIES – APPROACH 7

7.1 The results given in the following chapters are based on one year's data and hence should be treated with some reserve. An entirely new pattern may emerge from the next year's data. The results must also be qualified because

a) reliable stage-discharge relationships have not been established for many gauging stations;

b) only simple analysis has been carried out on some components of the water cycle;

c) some data are still not available.

Therefore it should be appreciated that results are based on partly synthetic data and some simplistic assumptions.

7.2 Three approaches have been adopted to estimate the irrigation duties. These are by:

a) Tract Issues.

b) Water Budget.

c) Theoretical Demand Model.

The approaches are described in detail in Chapters 8, 9 and 10 respectively, but a brief outline is also given in the following paragraphs.

7.3 Tract Issues are calculated by consideration of the flows at the rated stations. These stations are sited either on offtakes, when the issue down that offtake may be computed directly, or both upstream and downstream of an offtake so that the issue is the difference between the two. On the whole this method is not producing consistent results – many readings seem too high. This is thought to be because of the poor stage-discharge curves. It may also be because of the entry of considerable unmeasured volumes of drainage water and run-off into the channel system.

7.4 A Water Budget has been drawn up for the area downstream of Kaudulla Tank bund. Inputs to the area (rainfall and tank issues) have been compared with outputs (evaporation, percolation, drainage) and storage changes. This has produced the most reliable results.

7.5 A basic Theoretical Demand Model has been written. This calculates paddy irrigation requirements and hence requirements for each field channel. Then working up the system and adding in conveyance losses, distributary channel requirements, main channel requirements and finally tank issue requirements are calculated. At the moment simple assumptions have been made to compute crop usage, effective rainfall and channel losses; but these will be improved by more realistic routines. The basic modelling of the network of paddy lots and channels has been successfully completed and may now be used as a foundation for a more complex model. As yet only preliminary runs have been made to give simple minimum demand figures, but it is hoped that eventually the model will become a powerful tool in the prediction of the effects of different water management practices.

TRACT ISSUES 8

8.1 Some fifty gauge posts have been placed in irrigation channels over the Scheme area. It was hoped to monitor flows, cheaply and simply, within an accuracy of about ten per cent. Although it seems that this figure has not been attained, the data are still of value and will be of more value when stage-discharge relationships have been improved.

8.2 Difficulties in analysis have been encountered because of

a) poor stage-discharge relationships;

b) missing gauge posts;

c) uncertainty as to volume of drainage water and highland run-off entering the distribution system.

8.3 Results obtained are as follows:–

YALA 1978

Stage I	4 566 acres	Av. Tract Issue = 7.9 ft
Stage II	5 562 acres	Av. Tract Issue = 7.3 ft
Whole Scheme	10 128 acres	Av. Tract Issue = 7.6 ft

MAHA 1978/79

Stage I	5 212 acres	Av. Tract Issue = 6.5 ft
Stage II	5 791 acres	Av. Tract Issue = 6.0 ft
Whole Scheme	11 003 acres	Av. Tract Issue = 6.2 ft

Acreages are as given by Agricultural Extension Services at Medirigiriya.

8.4 It should be noted that much of the water issued to the high tracts is re-issued to lower tracts. The amount of drainage re-use is not known as yet, but drainage from 9 out of 21 tracts is re-used.

8.5 Generally, the upstream tracts receive larger water issues than downstream tracts; but no areas are known to be short of water.

8.6 The average tract issues given above are not consistent with the Water Budget described in Chapter 9. More confidence is placed in the Water Budget approach as the Tract Issues method has shortcomings described in para 8.2. It is hoped to improve the stage-discharge relationships when information on cross-sectional areas has been received.

WATER BUDGET 9

9.1 Water Budgets have been computed for the seasons Yala 1978 and Maha 1978/79 on the Scheme area downstream of Kaudulla Tank bund. The season dates used were:

Yala 1978	2 April – 30 September	(182 days)
Maha 1978/79	1 October – 31 March	(182 days)

9.2 Because of the relative confidence felt in the key parameters in the Water Budget equation, this method is considered to produce more reliable results than the Tract Issues approach described in Chapter 8.
In the Yala Water Budget the groundwater has not been considered as part of the system – hence deep percolation to the watertable is an output.
In the Maha Water Budget the groundwater is considered as part of the Scheme. This is because peak groundwater levels occurring in the Maha may be at or near the surface and hence the groundwater table may not be distinguishable from standing water in the paddy.

9.3 *YALA WATER BUDGET 2 April 1978 – 30 September 1978 (182 days)*
(All figures in acre-feet)

INPUT:	Kaudulla Tank Issues	43 800
	Rainfall	13 350
		57 150
OUTPUT:	Evaporation from Ambagaswewa	1 520
	Paddy Evapotranspiration	32 170
	Uncropped Evapotranspiration	8 520
	Conveyance Losses	3 500
	Paddy Drainage	6 970
	Paddy Percolation	5 450
		58 130
VOLUME CHANGE:	Ambagaswewa	– 980

Water Budget Equation: INPUT – OUTPUT = VOLUME CHANGE.

9.4 Derivations of the above figures are as follows:–

a) Kaudulla Tank Issues – the sum of Low Level (18 330) and High Level (25 470) Sluice Issues. The figures tie in with a water budget carried out on Kaudulla Tank and its catchment.

b) Average rainfall for the scheme was calculated using Thiessen polygons. There was 5.72 in (145.3 mm) on the 28 000 acres in the water budget area.

c) Ambagaswewa evaporation is the product of water surface area and Penman open-water evaporation from Diyasenapura Meteorological site. (See Fig 1 for its position relative to Ambagaswewa.)

d) Paddy Evapotranspiration calculated as follows:–

45 days – rainfall only evaporated from unprepared land	91 mm
15 days – open water evaporation during land preparation	117 mm
20 days – Crop Factor 1.00 x Penman E_t	132 mm
30 days – Crop Factor 1.15 x Penman E_t	223 mm
30 days – Crop Factor 1.20 x Penman E_t	238 mm
25 days – Crop Factor 0.90 x Penman E_t	159 mm
17 days – rainfall only evaporated from harvested land	8 mm
TOTAL	968 mm

968 mm (3.18 ft) on 10 128 acres of cropped paddy gives a total of 32 170 ac ft evapotranspirated. Crop Factors are taken from Reference 14.

e) The evapotranspiration from the uncropped area (ie everywhere except paddy) is taken as being exactly the rainfall. So, all rainfall is evapotranspirated, none runs off or percolates. The rainfall in the season is less than six inches and so the ground would be dry. It is expected that run-off and percolation would be small.

f) Conveyance losses are taken as 125 mm/day on the wet channel bed area. (See para 6.7 for justification of this figure.) A preliminary run of the Theoretical Demand Model using 125 mm/day gave a conveyance loss for the season of 3500 ac ft (although this figure has now been superseded).

g) Paddy drainage is derived from the figure reached in Chapter 11 of 1.1 ac ft drainage per acre. Of the 10 128 acres cultivated, the drainage from 3812 acres was re-used and hence was not lost to the system. Therefore paddy drainage lost to the system is 1.1 ft (approximately) from 6316 acres.

h) The paddy percolation is the unknown in the Water Budget and is calculated to balance the equation.

i) The volume stored at Ambagaswewa dropped by 980 ac ft according to the stage-capacity curves.

9.5 The Yala water use may be summarised as follows:

(A)	Evapotranspiration	3.2 ft
(B)	Percolation	0.5 ft
(C)	Drainage	1.1 ft
		4.8 ft

where (A) is explained in para 9.4 d)
(B) is 5450 ac ft on 10 128 acres (see Water Budget)
(C) is taken from Chapter 11.

Note that percolation is considered to be percolation to the watertable, and that lateral drainage through the subsoil is considered as drainage.

The figure of 4.8 ft duty on the paddy is lower than the figure of 7.6 ft derived in Chapter 8, but will be more realistic.

9.6 *MAHA WATER BUDGET 1 October 1978 – 31 March 1979 (182 days)*
(All figures are in acre-feet)

INPUT:	Kaudulla Tank Issues	42 720
	Rainfall	121 470
		164 190
OUTPUT:	Evaporation from Ambagaswewa	1 380
	Channel Evaporation	350
	Paddy Evapotranspiration	30 190
	Uncropped Evapotranspiration	34 280
	Drainage/Runoff	57 810
	Groundwater Flow Out	26 530
		150 540
VOLUME CHANGE:	Ambagaswewa	+ 1 070
	Groundwater	+12 580
		+13 650

Water Budget Equation: INPUT – OUTPUT = VOLUME CHANGE.

9.7 Derivations of the above figures are as follows:–

a) Kaudulla Tank Issues – the sum of Low Level (17 610) and High Level (25 110) Sluice Issues. Spill (78 000) is not included as it goes straight through the system.

b) Average rainfall for the scheme was calculated using Thiessen polygons. There was 4.34 ft (1322.3 mm) on 28 000 acres in the Water Budget area.

c) Ambagaswewa evaporation is the product of water surface area and Penman open water evaporation from Diyasenapura Meteorological site.

d) Channel evaporation is calculated on average evaporation on 225 miles of channel.

e) Paddy Evapotranspiration calculated as follows:–

16 days – weed growth, Crop Factor 1.0 x E_t	98 mm
15 days – open-water evaporation during land preparation	85 mm
30 days – Crop Factor 1.00 x Penman E_t	126 mm
40 days – Crop Factor 1.15 x Penman E_t	167 mm
45 days – Crop Factor 1.20 x Penman E_t	232 mm
20 days – Crop Factor 0.90 x Penman E_t	88 mm
16 days – available moisture evaporated	40 mm
TOTAL	836 mm

836 mm (2.74 ft) on 11 003 acres of cropped paddy gives a total of 30 190 ac ft evaporated. Crop Factors are taken from Reference 14.

f) The evapotranspiration from the uncropped area (ie everywhere except paddy) is estimated by multiplying the season's evapotranspiration (819.6 mm = 2.69 ft) by a crop factor of 1.0, by 0.75 to take into account areas with no vegetation, and by the uncropped area 16 997 acres.

g) Drainage/Runoff is the unknown in the Water Budget and is calculated to balance the equation.

h) During the Yala, when because of the lack of rain we know more about the Water Budget, it is possible to calculate what leaves the groundwater from within the scheme area. This is:

Groundwater Volume Change + Paddy Percolation + Channel Seepage.

Groundwater volume change (see para 6.5) in the Yala is 17 930 ac ft, paddy percolation is 5450 ac ft, channel seepage is 3150 ac ft.

Hence groundwater flow out = 26 530 ac ft.

Inspection of the groundwater contour gradients (see Figs 7 and 8 for two examples) during the Yala and Maha suggests that groundwater flow out will be similar in both seasons. Therefore it is postulated that groundwater flow out in the Maha is also 26 530 ac ft.

i) The volume stored at Ambagaswewa increased by 1070 ac ft according to the stage-capacity curves.

j) Groundwater volume, using a storage coefficient of 10%, increased by 12 580 ac ft (see para 6.5).

9.8 Considering the cropped area alone:—

INPUT = Kaudulla Tank Issues – Conveyance Losses + Rainfall – Ambagaswewa Storage Increase and Evaporation
= 42 720 – 3500 + 47 730 – 2450 = 84 500.

OUTPUT = Evapotranspiration + Paddy Percolation + Paddy Drainage/Runoff
= 30 190 + 7400 + Paddy Drainage/Runoff.

(where paddy percolation is assumed to be at the same daily rate calculated in the Yala)

INPUT = OUTPUT, hence Paddy Drainage/Runoff = 46 910 ac ft.

9.9 Considering the uncropped area alone (ie all but paddy).

From the Water Budget Total Drainage/Runoff = 57 810

From para 9.8 Paddy Drainage/Runoff = 46 910

Therefore Drainage/Runoff from uncropped areas = 10 900 ac ft.

Of the 73 740 ac ft rainfall on uncropped areas:

10 900 ac ft (15%) runs off

34 280 ac ft (46%) evapotranspirates

28 560 ac ft (39%) percolates.

9.10 These Maha results are based on many assumptions and are less reliable than the Yala results. However, the trend of excessive Drainage/Runoff is clearly shown. Results for both seasons are discussed in Chapter 12.

MATHEMATICAL MODEL FOR IRRIGATION DEMAND 10

10.1 As explained in paragraph 1.9 it is intended to develop a mathematical model of the Kaudulla irrigation scheme to assist with the analysis of the effects of different water management practices. To examine some of the requirements for modelling the scheme a computer program has been developed to calculate demand for water from the tank over a season.

10.2 The program is based on the procedures in a paper(14) by Dr W D Joshua of the Land Use Division of the ID. The paper determines field irrigation requirements for paddy lots from effective rainfall, crop water use, and field losses and it assumes an allowance for channel conveyance losses. The method uses monthly averages of the various parameters and assumes planting of the rice crop in three stages, each covering one third of the scheme area.

10.3 The computer program adopts a similar approach but it operates on daily data, assumes a random crop distribution over the scheme, allows more stages of crop planting and bases channel conveyance losses on seepage rates through calculated wetted perimeters of the irrigation channels. To permit future modifications to be made easily the program has been written with separate subroutines dealing with different aspects of the calculations. In the following paragraphs the program is described briefly, whilst in Appendix 1 it is discussed in more detail and with reference to its structure by subroutines.

10.4 For each individual paddy lot the program determines the field irrigation requirements, on a daily basis, at all stages of the crop growth. The equations used for this purpose are given in paragraph A.6.1 of Appendix A. Evapotranspiration and rainfall data for the runs described later comprised the daily values recorded on the Kaudulla scheme over the period 1 April 1978 to 31 March 1979. Evapotranspiration figures were from Diyasenapura meteorological site and rainfall figures were derived by applying the Thiessen polygon approach to the six stations in the scheme network.

10.5 The program converts the field irrigation requirements to channel discharges over an appropriate rotational issue period. At Kaudulla the arrangements are that about half the tracts receive water for three days and then no issues for four days, whilst the remaining tracts follow the same regime over the alternate period. In theory the main sluices are thus closed for one day each week.

10.6 From calculated discharges at all field channel offtakes the program proceeds from the most downstream paddy lot under each main channel offtake, adding in the relevant flows until a total value is determined for the main channel offtake. In order to retain a reasonably simple section of computer code which can deal with the various channel layouts found in an irrigation system the scheme is broken up into a large number of separate blocks of paddy lots. At Kaudulla Stage I was divided into 247 blocks and Stage II into 396 blocks.

10.7 From known channel dimensions and assumed roughness coefficients the program converts all discharges into equivalent depths of flow using the Manning equation and determines corresponding wetted perimeters. Channel conveyance losses are then added into the flows calculated from field irrigation requirements by assuming rates of seepage through the wetted area of the channel bed.

10.8 When the required flows have been determined under all offtakes from the main and branch channels the program once more works upstream, along these channels, adding in flows and corresponding conveyance losses, until the issue from the tank is obtained, for the particular time step and rotational issue period being considered. The whole process is repeated over the number of time steps appropriate for the season, rice variety and assumed planting distribution.

10.9 The final output from the program gives the total volume of water required at the tank sluice, together with the volume of conveyance losses in the main and branch channels and also the losses in the distributary and field channels. At each weekly time step and rotational issue period the program gives corresponding values for that period, together with more detailed tables which summarise conditions at all offtakes.

Water demand model runs for the Kaudulla Scheme 10.10

10.10.1 At present (July 1979) only four runs have been carried out for the Kaudulla Scheme with the version of the computer program described in paragraphs 10.1 to 10.9, as its development was proceeding right up to the time of production of this report. It is anticipated that further tests will be made, incorporating various values of the Kaudulla Scheme parameters in the model, in order to test the sensitivity of the results to different assumptions.

10.10.2 The four computer runs referred to relate to the 1978 Yala and 1978/79 Maha seasons and to Stages I and II separately for these seasons. The most basic assumption in all the runs is that the field losses are only to deep percolation and that there is no other drainage from paddy lots. This implies that exactly the right amount of water is being supplied to every paddy lot, with no wastage, so that the tank issues calculated by these runs are theoretical minimum figures for the particular set of conditions assumed. Varying these other conditions would give different estimates of tank issues and the assumptions presently made are detailed in Table 15 and discussed briefly in the following paragraphs. In general the assumptions have been based wherever possible on data collected for the two seasons.

10.10.3 In Table 15 the total cropping percentages are based on data received by one of the authors (HG) during his visit to Sri Lanka in 1979. The planting distribution is assumed to be linear over 6 weeks in every case at the intermediate percentage areas shown. The model used 4610 acres and 5867 acres of blocked out paddy lots in Stages I and II respectively and omitted all school and private lots.

10.10.4 The rotational issue periods are set as shown by Table 15. This is achieved in the model by data read in as 0 to indicate a closed offtake and 1 to show an open offtake.

10.10.5 Channel roughness coefficients, bed slopes and side slopes are based on ID design figures given in one of their publications(15).

10.10.6 Seepage losses for unlined channels are based on the results of the ponding test on Branch Channel 1 of Stage II (Chapter 6). The lined channels of Stage II, Branch Channel 1A and channels in Tract 11, are assumed to have 10 per cent of the seepage rate adopted for unlined channels. No separate allowance was made for evaporation losses when analysing the ponding test results so the ‘seepage’ rates quoted include evaporation.

10.10.7 Field preparation requirements are taken as 0.5 in/day, equivalent to 7 inches over a two week preparation period, as suggested elsewhere(14). The allowance for field losses to deep percolation is set at 0.06 in/day, a figure derived from the water budget calculations for the Yala season.

10.10.8 Crop water requirements are calculated from the daily evapotranspiration data from Diyasenapura, multiplied by the crop factor appropriate to the stage of growth (Fig 11). Effective rainfall on any day is assumed to be equal to the actual rainfall if less than or equal to 50 mm. Above 50 mm rainfall the effective figure is taken to be 50 mm. This approach considers that the bunds around liyadde act as efficient barriers, storing water from rainfall to a depth of 50 mm above their existing ponded level. Above this daily rainfall spill over the liyadde bunds is assumed.

10.10.9 Channel dimensions are taken from a list compiled earlier by the ID at the request of one of the authors (DWH). The list does not cover all channels in the scheme and a generalised curve of bed width v acreage commanded was produced from the available data and used to fill in gaps. Channel chainages required by the program do not follow the ID convention for Blocking Out Plans and they were obtained by measurement from the BOP mosaic of the scheme.

10.10.10 It is apparent from the preceding paragraphs that the data used by the program could be improved and this remains a future aim. However the preliminary figures quoted for theoretical minimum tank issues and corresponding channel losses in Table 16 are of interest for comparison with the equivalent values measured for the two seasons (Chapter 9). Figures 9 and 10 show recorded tank issues and theoretical tank issues plotted against rainfall. The actual tank issues in the Yala (Fig 9) are spread out much more than the theoretical issues. This implies that the crop planting dates are staggered over a longer period than the 6 weeks assumed for the model. In the Maha this is not the case (Fig 10), implying that crop planting is confined to a shorter period. Fig 10 also shows a similarity in shape between the recorded issues and theoretical issues curves. This is discussed in Chapter 12.

DRAINAGE 11

11.1 Fifteen gauge posts have been sited in drains and streams in order to evaluate the volumes of drainage and runoff. This method, as was feared, has produced no results. This is because

a) stream gauging is usually carried out during low flows and extrapolation of results for high flows, especially in a non-uniform channel, is not possible with any confidence;

b) gauge posts are sometimes washed away during high flows;

c) watercourses are often ill-defined or interlinked. In some cases flow may go both ways. This makes stage-discharge calibration difficult.

d) the effects of groundwater flow and highland runoff into the watercourses are not known. They could be estimated but the effort may not be justifiable given the difficulties listed above.

e) drains and streams are sometimes dammed to divert water (see Plate 18) and while this efficient water use is admirable, it does alter the stage-discharge relationship.

11.2 Ambagaswewa, to the North-East of the scheme (as shown in Fig 1) picks up drainage from Tracts 4, 5, 6, 7 and 8 of Stage II. It issues to Tracts 9 and 10 of Stage II. These issues, then, are supplied largely by drainage – although they can be supplemented by the Ambagaswewa Feeder Channel (A(b) on Fig 4) if there is insufficient water in the tank. For the Yala season 1978 a water budget has been carried out on the tank to determine the drainage input.

Water Budget INPUT – OUTPUT = VOLUME CHANGE

OUTPUT:	Evaporation	1524
	Issues to Tracts 9 and 10	5812
		7336
INPUT:	From Ambagaswewa Feeder Channel	3451
	Direct Rainfall	166
	Drainage from Tracts 4–8	2739
		6356
VOLUME CHANGE:		–980

All figures in acre-feet.
Drainage from Tracts 4–8 calculated to balance the water budget equation.

Assumptions:
1. No catchment runoff in the Yala.
2. No seepage from Ambagaswewa tank.

11.3 The estimated acreage of Tracts 4, 5, 6, 7 and 8 in Yala 1978 was 2482 acres – therefore average drainage is 1.1 ft. This figure has been adopted as the average tract drainage for the scheme in the Yala season 1978.

11.4 It should also be noted that:

a) the drainage figure calculated is a tract drainage figure – not a field drainage figure. Some drainage is re-used within each tract.

b) upstream tracts will tend to drain more than downstream tracts because they receive larger issues.

11.5 A similar study has not yet been possible for the Maha. This is because the assumption of no catchment runoff will be entirely invalid.

11.6 It is hoped to estimate catchment runoff now that the contour and spot level plan (Fig 6) has been prepared. If this is achieved then a drainage figure for the Maha can be computed by this method.

DISCUSSION 12

General 12.1

12.1.1 The two seasons, Yala and Maha, pose different problems and so are discussed separately in paras 12.2 and 12.3 respectively. One point common to both seasons is that rotational issues are not strictly observed and are sometimes ignored. If water is available continuously, it will be used and over-used continuously. The water savings afforded by rotational issues have not yet been evaluated, but it is hoped to analyse the effect of different rotations using an updated version of the Theoretical Demand Model. (Preliminary runs of this model, with minimum irrigation requirements as data, have been made and are described in Chapter 10. The results are shown in Table 16 and Figs 9 and 10.)

12.1.2 It should be stressed that knowledge of all parameters in the Water Budget is not complete; some simple assumptions have been made to achieve results which give an initial indication only of the relative importance of the parameters.

Yala Season 12.2

12.2.1 From the Yala water budget it may be seen that out of a total output of 58 130 ac ft, the seepage losses (3150), paddy drainage (6970) and paddy percolation (5450) are the parameters which may benefit from improved water management techniques.

12.2.2 Channel lining would not seem economic; lining the whole system would save a maximum of about 3150 ac ft and of course considerable seepage loss does still occur from even a lined channel. A more detailed analysis may show some highly permeable channel sections which would particularly benefit from lining.

12.2.3 Percolation (5450 ac ft) is smaller than was first expected. On the cropped area of 10 128 acres the season's percolation averages at about six inches, although of course there will be higher percolation from the well drained soils (10–15 percent of the area) than from the imperfectly drained soils and low humic gleys. Assuming the land to be inundated for 120 days (15 days for land preparation plus 105 days for crop growth) the average daily percolation rate is 1.37 mm/day. Possibly there is higher percolation during land preparation with a decreased permeability during crop growth. Certainly the low figure for percolation lends credence to the view that the puddling land preparation method used creates a relatively impermeable layer, especially after a few years of cultivation. The percolation values estimated from the water budget are considerably lower than values measured in the paddy ponding tests (although these figures include unknown quantities of sub-surface drainage moving laterally to surface drains as discussed in para 6.13). Percolation is unavoidable if the rice crop is to be kept inundated, and inundation gives high yields for minimum labour and effort. Only on well drained soils could "dry foot" rice cropping be sensibly advocated.

12.2.4 Drainage (6970 ac ft) could, and ideally should, be reduced; but as so much drainage is re-used the wastefulness is not critical. Obviously the way to cut back on drainage is to improve on-farm watering.

12.2.5 A climate for on-farm water economy could be created by

a) charging for water;
b) rationing water;
c) restricting channel flows by improved regulation;
d) convincing farmers of the need for careful water use.

12.2.6 Charging for water is at the moment impractical. No facilities exist for measuring the volume of water delivered to each farm (and although charges could be made on an area basis this is not relevant to water economy). Group chargings are also a possibility, although many problems are foreseen, and water measurement is still required, albeit less than for individual farms.

12.2.7 Water rationing is not possible for the same reasons; additionally such a strategy would require careful studies into water requirements for different soils and slopes so that each farm would receive an equitable ration.

12.2.8 Improved channel regulation by means of new structures would be costly and would have no guarantee of success. Farmer interference with structures is not considered antisocial behaviour and is to be expected. In an improved climate of opinion drop structures or gates would provide regulation and ease of flow measurement, but at the moment their value would be limited.

12.2.9 Farmer education is a complex subject and it is not proposed to offer any comment as yet, but the possibility of alerting the farmer to the need for water conservation, by increased farmer participation in water distribution, will be investigated.

12.2.10 It is apparent that there is no simple answer to the over-use of water. The obvious answer, charging for water, will require large expenditure on capital works and the setting up of an administration to collect the rates. Because there is so much drainage water re-used, paddy drainage is not excessively wasteful. Even the most efficient water use will still result in some drainage. Therefore, apart from investigation into farmer co-operation, on the basis of this one season's data, no recommendations are made for water economies in the Yala.

Maha Season 12.3

12.3.1 A different story emerges in the Maha season 1978/79. The drainage/runoff from paddy areas amounts to 46 910 ac ft (see para 9.8) from a cropped area of 11 003 acres. This is large compared with the water inputs – tank issues were 42 720 ac ft and rainfall on the cropped area was 47 730 ac ft. It is apparent that the rainfall is not being used effectively and that tank issues could be reduced. Fig 10 shows the recorded tank issues and the computed theoretical minimum demand plotted against rainfall. The theoretical demand model (described in Chapter 10) assumes that the first 50 mm of rainfall daily is effective and that all other rain runs off. In physical terms the model assumes that there is 50 mm of freeboard from the standing water level in the paddy field to the top of the liyadde bunds and that this space can impound rainwater. Because of the similarity in the shapes of the theoretical demand and actual tank issue curves it is thought that the assumption is along the right lines, but that the freeboard should be reduced to model the actual on-farm conditions. In fact although there is ample freeboard, cuts are made in the liyadde bunds to allow water movement from field to field. These cuts are often not filled to the full height of the bund, as they could be when there is rain.

12.3.2 As discussed in the previous paragraph, a climate for water economy is required. In the Maha season, this might be encouraged by a stricter policy towards closing the tank sluices; but as rainfall distribution can be variable over the scheme (see para 5.1.2), it is important to maintain a supply of water to areas unaffected by rain.

12.3.3 There is little point in applying any water saving measures if the water saved cannot be stored. In both 1977/78 and 1978/79 there was spill from the tank – 4700 ac ft and 78 000 ac ft respectively. (In 1978/79 there was a cyclone so this year is not typical.) Under these conditions it may prove difficult to persuade the farmer of the need for water conservation. To minimise spill, it might be advisable to introduce a modified tank operation procedure. Such a procedure should formalise

a) requesting water from upstream sources – in particular inflow from Minneriya in the Yala must be minimised to allow maximum tank drawdown in preparation for maximum impounding of the monsoon rains;

b) issuing according to field demands;

c) flood routing.

12.3.4 The modification of a tank operation procedure will be investigated in the near future. This and the more effective utilisation of rainfall on the paddy are seen as main areas for improvement in the Maha.

CONCLUSIONS 13

13.1 This interim report has been prepared to:

a) present the first findings of the Water Management Study after preliminary analysis of data for the Yala season 1978 and Maha season 1978/79;

b) indicate the areas in which future activities are warranted.

Data collection is continuing and further analyses, together with re-analysis of this first year's data (using improved techniques), will be the subject of a future report.

13.2 Generally, it is thought that water use in the Yala season 1978 was relatively efficient. Improvement could be achieved by better on-farm management, but no simple solution presents itself. The possibility of alerting the farmer to the need for water conservation, by increased farmer participation in water distribution, will be investigated (see para 12.2).

13.3 Water management in the Maha season would be improved by

a) more effective utilisation of rain falling directly on the paddy, and hence reduction of tank issues;

b) following a tank operation procedure to optimise the use of storage capacity by minimising spill.

These two factors will require further study (see para 12.3).

13.4 Although tracts should receive water on a rotational basis it seems as if this is not always the case. Continuous water supply leads to continuous water over-use and therefore a stricter adherence to the rota is recommended (see para 12.1).

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APPENDIX

APPENDIX A DETAILS OF THE COMPUTER PROGRAM FOR CALCULATION OF IRRIGATION DEMAND AT THE TANK

Master segment DEMAND A.1

A.1.1 The master segment of the program controls the calculation sequence by calling the various subroutines into operation as appropriate. It organises the reading of data and the printing of results and controls the cropping pattern over the scheme. The storage capacity of the program arrays was set to be adequate for Stage II of the Kaudulla scheme and Stage I and Stage II were treated separately throughout.

Subroutine SETUP A.2

A.2.1 This routine reads data, on input channel 1, relating to the main and branch channels of the scheme.

A.2.2 Offtakes are numbered sequentially, starting from the tank, along the main channel and then along any branches. At each offtake the channel bed width, side slope, bed slope, Manning roughness coefficient and seepage rate are read for the section of channel upstream of the offtake.

A.2.3 Chainages from the tank to each offtake, individual paddy lot areas (assumed constant under any offtake) and the lowest and highest paddy lot numbers under every offtake are also read by this subroutine. The paddy lot numbers are converted to sequential numbering over the scheme in the order of the offtakes.

Subroutine SETDF A.3

A.3.1 This routine reads data, on input channel 4, relating to the distributary and field channels of the scheme (D and F channels).

A.3.2 Under each offtake from the main and branch channels the channel side slope, bed slope, Manning roughness coefficient and seepage rates are assumed to be constant for D and F channels and are read in.

A.3.3 For analysis of channel conveyance losses the scheme is divided into blocks of paddy lots, numbered sequentially over the scheme in the order of the offtakes. The blocks are chosen so that successive groups of them can be combined in sequence under any offtake when computing channel losses. From the most downstream paddy lot under any offtake the program works through successive blocks of paddy lots and groups of blocks, continually adding in channel flows, calculated from the field irrigation requirements for individual lots, and corresponding conveyance losses. The sequence of addition of the groups is controlled by other variables, read in by the routine, in order that a few typical arrangements of irrigation channels can be made to cover the variations in layout across the scheme.

A.3.4 For each block of paddy lots the routine also reads six variables. These are the length of channel with field outlets, the length of channel upstream of this with no field outlets, bed widths of both of these channel reaches, the number of paddy lots in the block and a variable which is set to 0 if the discharge at the downstream end of the block is zero and to 1 otherwise.

Subroutine RUNDAT A.4

A.4.1 This routine reads data, on input channel 3, which control individual program runs.

A.4.2 Daily values of evapotranspiration and rainfall are read, for periods up to one year. Rainfall is converted to effective rainfall on the basis of an assumed relationship which could be modified easily in future if desired. Daily requirements for land preparation and field losses are read in as constant values.

A.4.3 Crop details read by this routine include the starting date of land preparation, the crop duration in days from the end of land preparation to the beginning of harvest, and daily crop factors to compute water requirements from evapotranspiration.

A.4.4 Each time step in the program is taken as one week and up to four rotational issue periods can be specified within each time step. The routine reads information on these periods and the offtakes can be set open or closed, as required, by a variable which is read as 1 or 0 respectively.

A.4.5 The crop planting distribution is read by the routine as the percentages of the scheme area brought under land preparation at successive time steps of one week, up to a maximum of 10 weeks. Once any paddy lot has been started it proceeds week by week through successive stages to harvest.

Subroutine RANDOM A.5

A.5.1 During preparation of the paddy lots this routine determines what additional percentage of the scheme area should be brought in at successive weekly time steps. It employs a random number generating routine to identify paddy lot numbers throughout the scheme. When this routine has started any paddy lot, master segment DEMAND updates the index number of the crop stage of the lot by one each time step. At harvest the crop index is set to 99.

Subroutine DUTIES A.6

A.6.1 At each time step this routine calculates the field irrigation requirement of each crop stage. If land preparation is not completed it uses the equation;

FIR = PL + FL – ER

where
FIR = field irrigation requirement
PL = land preparation requirement
FL = field losses
ER = effective rainfall.

After completion of land preparation the routine uses the relationship;

FIR = ETC + FL – ER

where
ETC = evapotranspiration of the crop.

Evapotranspiration of the crop is based on a daily crop factor, which varies with the stage of growth, multiplied by the potential evapotranspiration. Field irrigation requirements can be printed out if required by setting switch IFIRSW to 1.

A.6.2 For every paddy lot, at each time step, the routine converts the field irrigation requirement for the lot into a discharge, assuming supply to take place over the whole of the relevant rotational issue period. The routine then calls subroutine DANDFQ in order to sum the individual paddy lot discharges, with allowance for D and F channel conveyance losses, and a value of discharge required at each offtake from the main and branch channels is returned to routine DUTIES.

Subroutine DANDFQ A.7

A.7.1 Under each offtake from the main and branch channels the program data define the layout of distributary and field channels (subroutine SETDF). This routine sums successive paddy lot discharges, calculated in routine DUTIES, according to the sequence defined by the data. Field offtakes to paddy lots are assumed to be equally spaced over the length of channel having such offtakes.

A.7.2 Between field offtakes, and in lengths of channel with no such offtakes, conveyance losses are added to the flows determined from field irrigation requirements. This is done by calculating the additional flow needed to allow for seepage losses through the wetted perimeters of the channels. The routine calls subroutine WPERIM for this purpose.

A.7.3 A running total of conveyance losses in D and F channels, in volume terms, is maintained by the routine.

Subroutine WPERIM A.8

A.8.1 For an irrigation channel of known bed width, bed slope, side slope and Manning's roughness coefficient, carrying a known discharge, this routine calculates the depth of flow and the wetted perimeter of the cross-section.

A.8.2 The routine assumes that the hydraulic gradient, water surface slope and channel bed slope are the same. It calculates an initial depth of flow based on the channel cross-section, slope, discharge and an assumed typical average flow velocity for the scheme.

A.8.3 From this initial assumption the routine uses the Manning equation and the Newton–Raphson iterative approach to successively improve the initial estimate of flow depth to a tolerance of less than 0.001 of the bed width. At this point the routine calculates the wetted perimeter and returns its value, together with flow depth, to routine DANDFQ.

Subroutine CONVEY A.9

A.9.1 When all the required discharges have been calculated for main and branch channel offtakes, this routine works upstream, summing the values. It deals first with branch channels and finally with the main channel. Between offtakes appropriate allowances are made for conveyance losses, in the same manner as for D and F channels, by calling routine WPERIM. At the upstream end of the main channel the tank discharge for the particular time step and rotational issue period is obtained.

A.9.2 A running total of conveyance losses in the main and branch channels is maintained by the routine.

Subroutine OUTPUT A.10

A.10.1 This routine controls the main output from the program.

A.10.2 If full details of the random cropping pattern are required at every time step switch ICSW should be set to 1.

A.10.3 The standard output is given for each time step and each rotational issue period and comprises tables listing the following values for each offtake: tract served, offtake open or closed, chainage from tank, cropped area under offtake, upstream discharge, downstream discharge, offtake discharge, conveyance loss in channel upstream of offtake, depth of flow and conveyance losses in channels under offtake.

A.10.4 Beneath each table summaries are given of: tank discharge, tank issue volume, conveyance losses in main and branch channels and conveyance losses in D and F channels. The latter two items are expressed both in volume terms and as percentages of the tank issue volume.

A.10.5 At the end of the season the program summarises the water demand by printing out the total issue volume at the tank sluice, the conveyance losses in main and branch channels and the conveyance losses in D and F channels. As before the losses are given both in volume terms and as percentages of the tank issues.

TABLES

TABLE 1 DAILY RAINFALL (mm) APRIL 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	10.2	–	3.0	–	–	–	–	3.2
5	25.7	0.2	17.0	4.1	2.5	3.6	3.5	10.6
6	–	10.5	1.0	30.2	24.0	13.2	22.5	6.1
7	–	1.0	3.0	–	2.5	–	0.7	1.3
8	–	–	–	–	4.2	–	1.1	0.1
9	–	5.0	–	5.1	1.6	–	2.4	2.3
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–		–	–	–	–	–	–
13	–		–	–	–	–	–	–
14	–		–	–	–	–	–	–
15	–	Data	–	–	–	–	–	–
16	–	missing	–	–	–	–	–	–
17	–		–	–	–	–	–	–
18	–		–	–	–	–	–	–
19	7.9		–	–	–	–	–	1.9
20	–	–	–	4.3	–	–	1.6	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	0.8	2.0	17.0	–	1.5	20.3	7.6	6.3
24	–	1.5	–	–	–	–	–	0.7
25	–	1.0	2.2	–	1.5	5.6	2.4	1.3
26	4.6	–	–	–	–	5.1	1.8	1.3
27	–	9.7	0.5	22.1	2.0	5.6	10.8	4.7
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	0.2	10.7	0.7	2.5	5.1	0.2
TOTAL	49.2	–	43.9	65.8	40.5	55.9	59.5	40.0

TABLE 2 DAILY RAINFALL (mm) MAY 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	5.5	–	1.5	0.1
2	–	5.0	1.0	18.8	11.7	4.1	11.7	3.0
3	–	–	–	–	–	5.1	1.8	0.2
4	21.1	5.7	1.3	3.8	1.3	–	1.7	7.9
5	–	0.5	2.6	–	4.5	–	1.2	0.9
6	–	–	–	–	–	–	–	–
7	–	3.6	–	–	–	–	–	1.6
8	–	35.4	–	14.0	–	–	5.3	15.7
9	14.2	1.2	–	–	–	15.2	5.4	4.6
10	18.5	2.5	9.5	4.1	4.0	10.2	6.2	8.4
11	–	9.0	8.4	–	8.0	6.9	4.6	6.6
12	3.0	–	–	8.4	–	–	3.2	0.7
13	–	0.7	0.1	–	0.6	–	0.2	0.4
14	–	0.4	–	–	1.0	–	0.3	0.6
15	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	56.8	64.0	22.9	49.1	36.6	41.5	43.1	50.7

TABLE 3 DAILY RAINFALL (mm) JUNE 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15				NO RAINFALL RECORDED				
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
TOTAL								

TABLE 4 DAILY RAINFALL (mm) JULY 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	8.1	30.0	7.0	–	8.5	2.5	3.2	17.3
14	3.3	45.5	14.0	71.1	40.0	61.0	59.1	28.4
15	–	–	0.2	20.3	3.9	11.4	12.7	0.7
16	–	–	–	–	0.3	–	0.1	–
17	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	11.4	75.5	21.2	91.4	52.7	74.9	75.1	46.4

TABLE 5 DAILY RAINFALL (mm) AUGUST 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–
10	–	1.0	–	–	–	–	–	0.4
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	–	1.0	–	–	–	–	–	0.4

TABLE 6 DAILY RAINFALL (mm) SEPTEMBER 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	7.0	10.5	13.5	33.2	18.0	20.4	7.4
5	–	–	–	–	–	–	–	–
6	–	1.0	–	–	–	–	–	0.4
7	–	–	–	–	–	–	–	–
8	–	–	–	6.0	–	–	2.3	–
9	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
TOTAL	–	8.0	10.5	19.5	33.2	18.0	22.7	7.8

TABLE 7 DAILY RAINFALL (mm) OCTOBER 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	0.7	–	0.2	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	1.0	–	–	–	–	–	–	0.2
6	–	7.1	6.5	78.0	14.0	21.5	40.8	6.1
7	–	–	26.5	34.5	9.5	14.5	20.7	7.5
8	4.0	11.5	22.0	28.0	0.9	–	10.7	11.5
9	1.0	–	31.0	27.0	15.4	18.0	20.7	9.2
10	–	8.0	23.5	–	53.7	16.3	20.2	11.5
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–
14	–	–	–	–	2.0	–	0.5	0.1
15	54.5	–	–	13.0	–	–	4.9	12.9
16	63.5	34.0	62.0	53.0	70.0	31.3	49.8	48.7
17	1.5	49.2	108.0	19.0	122.0	145.0	91.4	59.0
18	41.5	9.3	5.0	–	13.0	18.5	10.1	16.4
19	40.0	27.6	23.5	75.5	29.4	46.0	52.7	30.5
20	7.0	16.5	22.0	45.0	22.0	9.0	26.0	15.4
21	–	14.5	6.0	23.0	18.0	32.8	25.1	10.0
22	11.0	9.3	15.5	24.0	22.5	24.0	23.5	12.3
23	–	9.0	0.5	5.0	7.3	14.0	8.9	4.9
24	–	–	–	–	–	–	–	–
25	26.0	1.3	–	5.0	–	–	1.9	6.7
26	59.0	14.0	9.0	10.0	9.0	5.0	8.0	22.8
27	6.5	3.0	18.5	5.0	4.6	27.0	12.7	8.9
28	–	–	16.0	–	11.0	12.0	7.2	4.8
29	30.0	0.3	–	–	–	1.0	0.4	7.2
30	–	2.5	24.5	30.0	9.0	11.0	24.8	7.9
31	53.0	16.3	2.0	33.0	3.2	51.5	31.6	22.8
TOTAL	399.5	233.4	422.0	508.0	437.2	498.4	492.8	337.3

TABLE 8 DAILY RAINFALL (mm) NOVEMBER 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	130.5	65.3	46.0	38.0	41.0	46.5	41.9	74.4
2	4.5	109.3	138.0	125.0	140.0	125.0	129.0	93.3
3	6.0	1.8	3.0	10.0	2.0	5.0	6.1	3.2
4	–	6.3	10.0	11.5	8.0	6.0	8.5	5.7
5	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–
8	8.0	–	–	–	–	–	–	1.9
9	12.5	1.3	0.1	–	4.5	8.0	4.0	4.0
10	55.0	16.5	16.5	50.0	9.5	36.5	34.3	26.4
11	–	7.0	20.5	–	15.0	27.5	13.8	9.9
12	–	–	–	–	–	–	–	–
13	3.5	–	–	–	–	–	–	0.8
14	–	2.8	4.5	8.5	13.0	4.5	8.3	2.9
15	–	–	5.5	–	14.0	–	3.8	3.4
16	–	–	–	–	–	–	–	–
17	–	–	0.5	–	3.0	–	0.8	0.2
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	7.5	3.3	–	0.5	–	–	0.2	3.2
21	18.0	3.3	4.0	–	3.0	2.0	1.5	6.9
22	164.0	10.3	18.0	25.5	18.2	8.5	17.5	48.6
23	16.5	–	175.0	175.0	191.0	175.0	179.3	60.5
24	–	–	–	–	9.5	17.5	8.7	1.1
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	6.0	–	–	–	–	–	2.7
29	–	1.0	–	–	0.5	–	0.1	0.5
30	–	16.8	7.0	5.0	7.2	7.5	6.5	9.5
TOTAL	426.0	251.0	448.6	449.0	479.4	469.5	464.3	359.1

TABLE 9 DAILY RAINFALL (mm) DECEMBER 1978

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	3.5	17.0	10.0	11.5	4.5	13.5	10.3	11.6
4	13.0	10.5	4.0	10.0	5.4	3.0	6.3	9.0
5	1.0	26.0	10.0	8.0	10.0	13.0	10.3	15.1
6	15.0	0.5	2.0	–	1.0	3.0	1.4	4.4
7	22.0	23.8	16.0	13.5	21.5	16.5	16.8	21.0
8	2.5	21.8	10.0	15.0	20.5	9.5	14.5	13.7
9	–	4.5	10.0	19.3	7.5	17.5	15.5	5.5
10	42.0	23.0	30.0	37.0	43.0	33.0	37.1	35.8
11	22.0	68.5	44.0	75.0	50.0	63.0	64.0	86.6
12	16.5	56.0	34.0	73.0	–	45.0	43.4	39.4
13	1.0	14.0	22.0	17.6	8.0	15.5	14.2	12.9
14	–	–	1.1	–	1.0	–	0.3	0.3
15	2.0	–	–	5.0	1.0	1.0	2.6	0.5
16	–	3.9	1.0	–	0.2	3.0	1.2	2.1
17	–	–	–	–	–	–	–	–
18	–	–	–	–	1.0	1.5	0.8	0.1
19	–	8.0	–	–	3.0	–	0.8	3.6
20	–	–	–	–	–	–	–	–
21	10.0	–	–	–	–	–	–	2.4
22	106.0	13.3	11.0	15.0	16.7	9.5	13.5	34.5
23	–	135.0	102.0	130.0	129.0	108.0	121.9	93.6
24	0.5	13.3	14.0	10.0	15.6	16.5	13.9	10.7
25	–	2.0	1.1	5.0	2.8	4.5	4.3	1.4
26	3.5	–	–	–	–	–	–	0.8
27	4.5	9.3	15.0	48.0	42.0	28.0	39.3	11.3
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	265.0	450.4	337.2	492.9	383.7	404.5	432.4	416.3

TABLE 10 DAILY RAINFALL (mm) JANUARY 1979

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	11.5	–	–	4.3	–
4	–	–	–	–	–	–	–	–
5	–	–	–	19.0	–	–	7.1	–
6	–	–	–	–	–	–	–	–
7	–	0.5	–	–	–	–	–	0.2
8	–	–	–	–	–	–	–	–
9	–	–	–	–	0.8	–	0.2	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	13.0	–	–	4.9	–
13	–	–	–	–	–	–	–	–
14	–	3.8	–	–	5.0	2.5	2.2	1.9
15	–	–	1.1	7.5	1.0	–	3.1	0.3
16	–	2.0	–	–	–	1.0	0.4	0.9
17	3.5	5.0	1.0	–	0.6	–	0.2	3.3
18	–	2.3	1.0	–	3.5	3.0	1.4	1.5
19	–	–	–	–	–	–	–	–
20	1.0	–	–	–	–	–	–	0.2
21	2.5	0.7	–	6.0	0.2	2.0	3.0	1.0
22	28.0	–	–	–	3.0	–	0.8	6.7
23	12.5	22.0	23.0	–	24.0	20.0	13.6	20.0
24	1.0	8.5	3.1	–	6.0	6.5	3.9	5.2
25	–	–	–	–	1.5	–	0.4	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	48.5	44.8	29.2	57.0	45.6	35.0	45.5	41.2

TABLE 11 DAILY RAINFALL (mm) FEBRUARY 1979

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	–	2.0	–	–	–	–	–	0.9
6	2.0	–	3.0	–	0.2	1.0	0.5	1.3
7	–	–	–	–	0.8	–	0.2	–
8	4.0	–	–	7.5	–	–	2.8	0.9
9	2.0	17.5	16.0	–	3.5	20.5	8.2	13.3
10	11.5	31.8	11.0	3.0	1.7	13.5	6.4	20.2
11	–	–	14.5	–	8.5	1.8	2.9	3.9
12	–	–	0.5	–	–	–	–	0.1
13	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–
15	–	–	–	12.5	–	–	4.7	–
16	1.0	–	–	–	–	–	–	0.2
17	–	4.5	–	–	0.5	–	0.1	2.0
18	60.5	–	–	–	–	–	–	14.3
19	29.0	61.8	21.5	–	10.0	3.5	3.9	40.0
20	–	17.5	68.0	91.7	98.0	85.0	91.1	31.2
21	–	2.5	1.0	4.3	–	–	1.6	1.4
22	–	–	–	5.0	–	–	1.9	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
TOTAL	110.0	137.6	135.5	124.0	123.2	125.3	124.3	129.7

TABLE 12 DAILY RAINFALL (mm) MARCH 1979

Date	Ambagaswewa	Diyasenapura	Fourth Mile Camp	Gal Oya Spill	High Level Sluice	Low Level Sluice	Tank Catchment	Scheme Area
1	10.0	–	–	–	–	–	–	2.4
2	3.5	12.3	1.0	37.5	14.0	–	17.9	6.9
3	7.5	10.0	21.0	19.0	7.0	12.0	13.3	12.2
4	1.5	26.0	12.0	–	11.0	35.0	15.4	16.8
5	–	–	0.5	–	0.5	5.0	1.9	0.4
6	–	–	–	11.7	–	–	4.4	–
7	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–
9	–	–	–	9.6	–	–	3.6	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–
TOTAL	22.5	48.3	34.5	77.8	32.5	52.0	56.5	38.7

TABLE 13 POTENTIAL TRANSPIRATION (E_t) BY PENMAN'S METHOD, DIYASENAPURA

Monthly mean values	Jan 79	Feb 79	Mar 79	Apr 78	May 78	Jun 78	July 78	Aug 78	Sep 78	Oct 78	Nov 78	Dec 78
T_{MAX} °C	29.9	31.2	32.5	35.0	33.8	33.8	32.7	32.5	34.1	33.3	30.1	29.6
T_{MIN} °C	22.3	22.4	22.4	24.0	25.2	25.8	24.8	24.1	25.1	23.9	22.9	22.8
T_{MEAN} °C	26.1	26.8	27.5	29.5	29.5	29.8	28.8	28.3	29.6	28.6	26.5	26.2
$T_{DEW\ POINT}$ °C	23.0	23.1	23.4	25.0	23.5	22.4	22.0	21.8	21.3	22.6	22.5	23.3
Sunshine h/day	8.0	8.3	9.1	7.9	8.1	7.4	7.5	7.4	7.8	7.2	7.1	5.7
Wind run km/day at 2 m	72	51	55	78	248	362	345	396	310	141	101	72
Incoming radiation term mm/day	4.69	5.13	5.55	5.51	5.46	5.13	5.18	5.19	5.39	4.99	4.52	3.80
Back radiation term mm/day	1.17	1.20	1.25	0.98	1.15	1.19	1.23	1.21	1.40	1.17	1.12	0.86
Net radiation term mm/day	3.52	3.93	4.30	4.53	4.31	3.94	3.95	3.98	3.99	3.82	3.40	2.94
Aerodynamic term mm/day	0.55	0.61	0.72	0.84	1.81	2.67	2.46	2.61	2.73	1.33	0.80	0.53
Potential transpiration (E_t) mm/day	4.1	4.5	5.0	5.4	6.1	6.6	6.4	6.6	6.7	5.2	4.2	3.5

TABLE 14 OPEN-WATER EVAPORATION (E_o) BY PENMAN'S METHOD, KAUDULLA TANK HIGH LEVEL SLUICE

Monthly mean values	Jan 79	Feb 79	Mar 79	Apr 78	May 78	Jun 78	Jul 78	Aug 78	Sep 78	Oct 78	Nov 78	Dec 78
T_{MAX} °C	29.8	31.4	33.1	34.2	33.0	33.0	32.3	32.7	34.3	32.8	29.5	29.1
T_{MIN} °C	21.1	21.1	21.6	24.0	25.3	25.9	24.9	24.8	24.6	23.4	21.9	21.9
T_{MEAN} °C	25.5	26.3	27.4	29.1	29.2	29.5	28.6	28.8	29.5	28.1	25.7	25.5
$T_{DEW\ POINT}$ °C	22.8	23.0	22.9	24.6	23.8	21.6	21.3	21.2	20.7	22.8	22.7	23.1
Sunshine h/day	9.0	8.8	9.9	8.6	7.9	7.9	8.1	8.3	8.9	7.9	7.0	6.4
Wind run km/day at 2 m	76	69	71	103	282	381	419	492	378	152	103	52
Incoming radiation term mm/day	6.34	6.75	7.61	7.40	7.11	6.71	6.76	6.94	7.37	6.50	5.57	5.12
Back radiation term mm/day	1.31	1.28	1.42	1.13	1.16	1.34	1.36	1.40	1.64	1.21	1.06	0.95
Net radiation term mm/day	5.03	5.47	6.19	6.27	5.95	5.37	5.40	5.54	5.73	5.29	4.51	4.17
Aerodynamic term mm/day	0.57	0.58	0.93	0.95	1.77	3.08	3.14	3.28	3.20	1.23	0.60	0.40
Open-water evaporation mm/day	5.6	6.1	7.1	7.2	7.7	8.5	8.5	8.8	8.9	6.6	5.1	4.6

TABLE 15 SUMMARY OF VALUES USED IN COMPUTER MODEL RUNS

Yala Crop	**Stage I**	**Stage II**
Land preparation starting date	26 April 1978	26 April 1978
Crop pattern	As Fig 11	As Fig 11
Planting distribution percentages	16.5(16.5)99.0	15.8(15.8)94.8

Maha crop	**Stage I**	**Stage II**
Land preparation starting date	15 October 1978	15 October 1978
Crop pattern	As Fig 11	As Fig 11
Planting distribution percentages	16.7(16.7)100.0	16.5(16.5)99.0

Rotational issue periods	**Stage I**	**Stage II**
Mon–Thu 8 am – 8 am 72 hours	Tracts 1–5	Tracts 1–6
Fri–Mon 8 am – 8 am 72 hours	Tracts 1B, 6–8	Tracts 7–12

Channel details	**Unlined**	**Lined**
Manning roughness coefficient	0.025	0.017
Bed slope, main and branch channels	0.0003	0.0003
Bed slope, distributary and field channels	0.0004	0.0004
Side slopes	1 on 1	1 on 1
Seepage losses (ft/day)	0.4	0.04

Note: 16.5(16.5)99.0 above ≡ 16.5, 33.0, 49.5, 66.0, 82.5, 99.0.

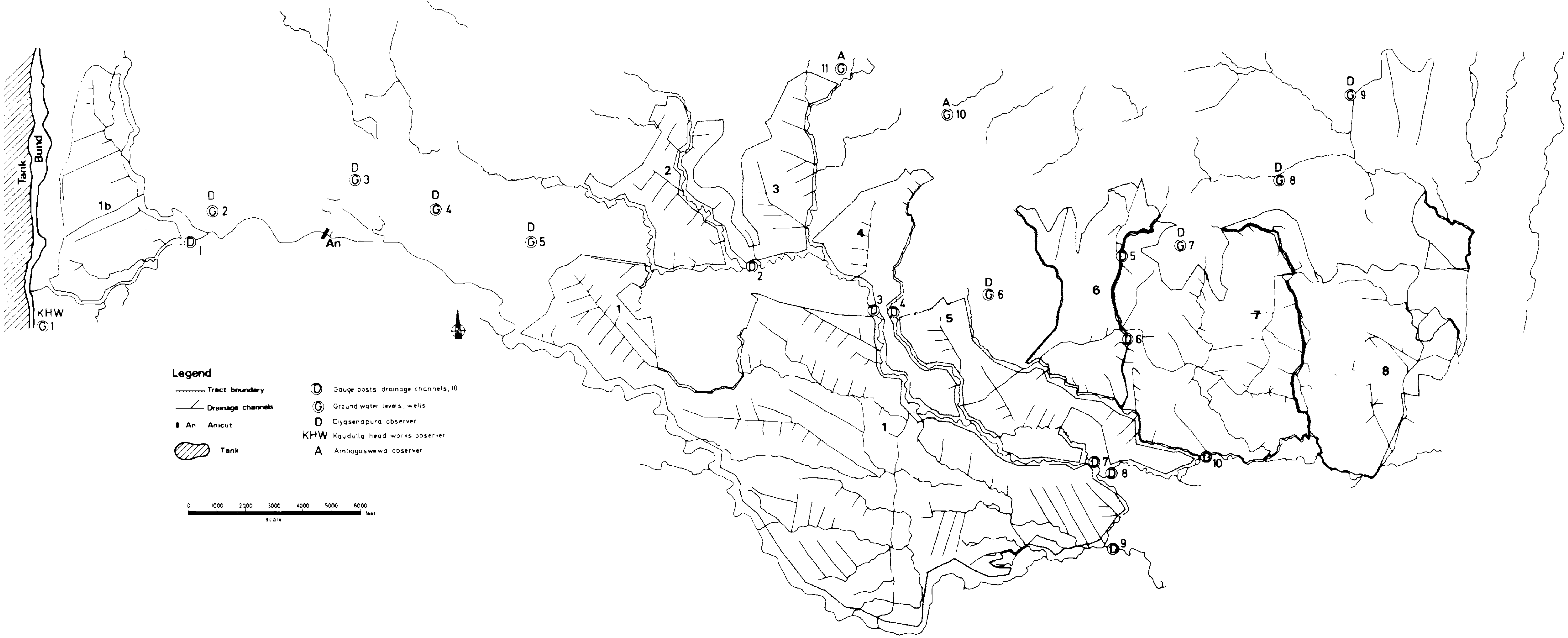
TABLE 16 THEORETICAL MINIMUM WATER DEMAND FROM COMPUTER MODEL RUNS

Season	Portion of Kaudulla Scheme	Cropped area (acres)	Theoretical minimum demand at the tank (acre-feet)	Water duty at the tank (feet)	Main and branch channel losses (per cent of tank issues)	Distributary and field channel losses (per cent of tank issues)
Yala 1978	Stage I	4 564	16 169	3.5	4.4	6.1
	Stage II	5 562	19 260	3.5	5.6	6.4
	All	10 126	35 429	3.5	–	–
Maha 1978/79	Stage I	4 610	12 312	2.7	6.4	8.5
	Stage II	5 808	15 235	2.6	7.9	8.7
	All	10 418	27 547	2.6	–	–
Yala + Maha 1978/79	All	10 272	62 976	6.1	–	–

Note: Approximate total lengths of channels in the Kaudulla Scheme are, in miles;

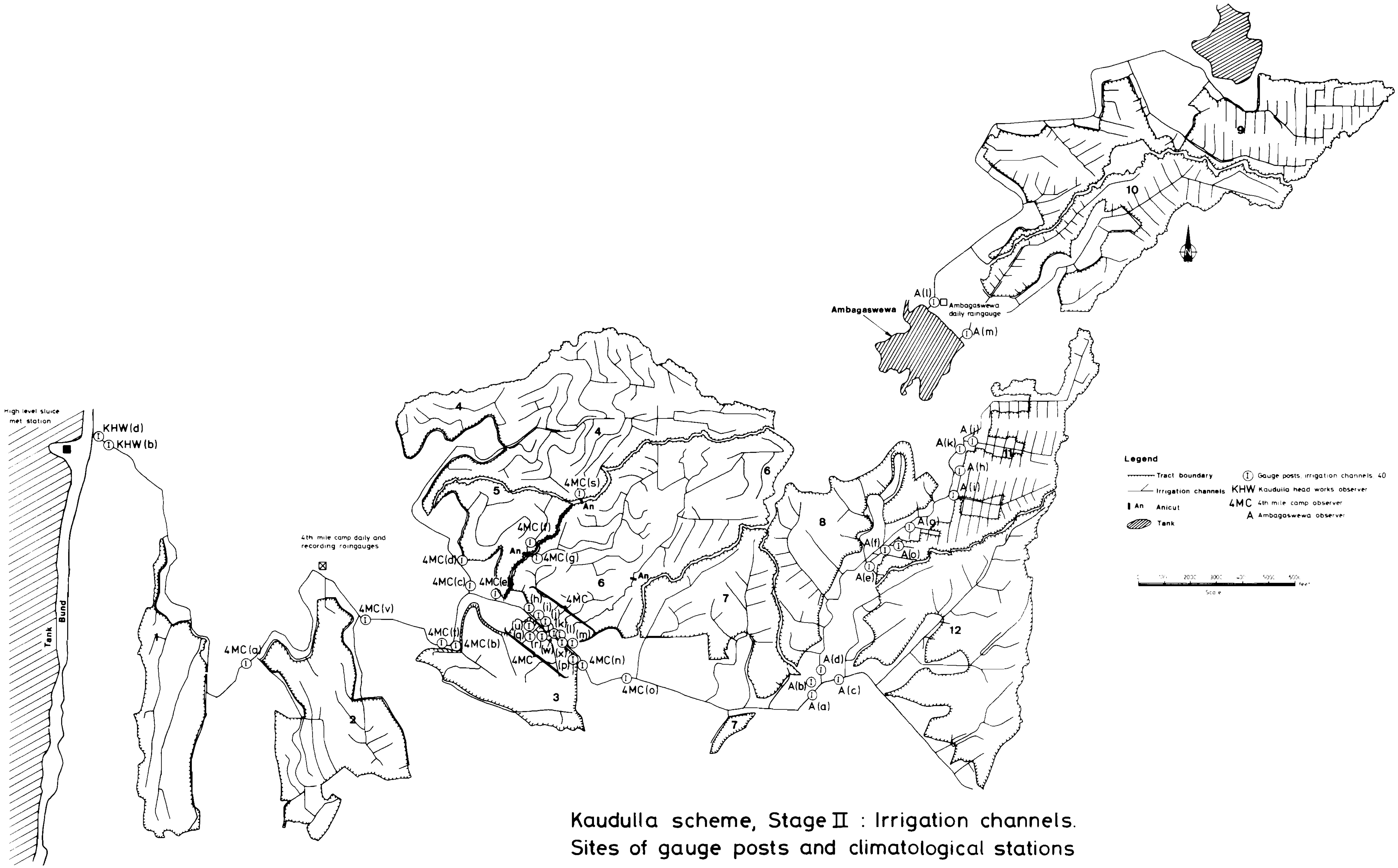
	Stage I	Stage II
Main and branch channels	8	13
Distributary and field channels	93	132

FIGURES



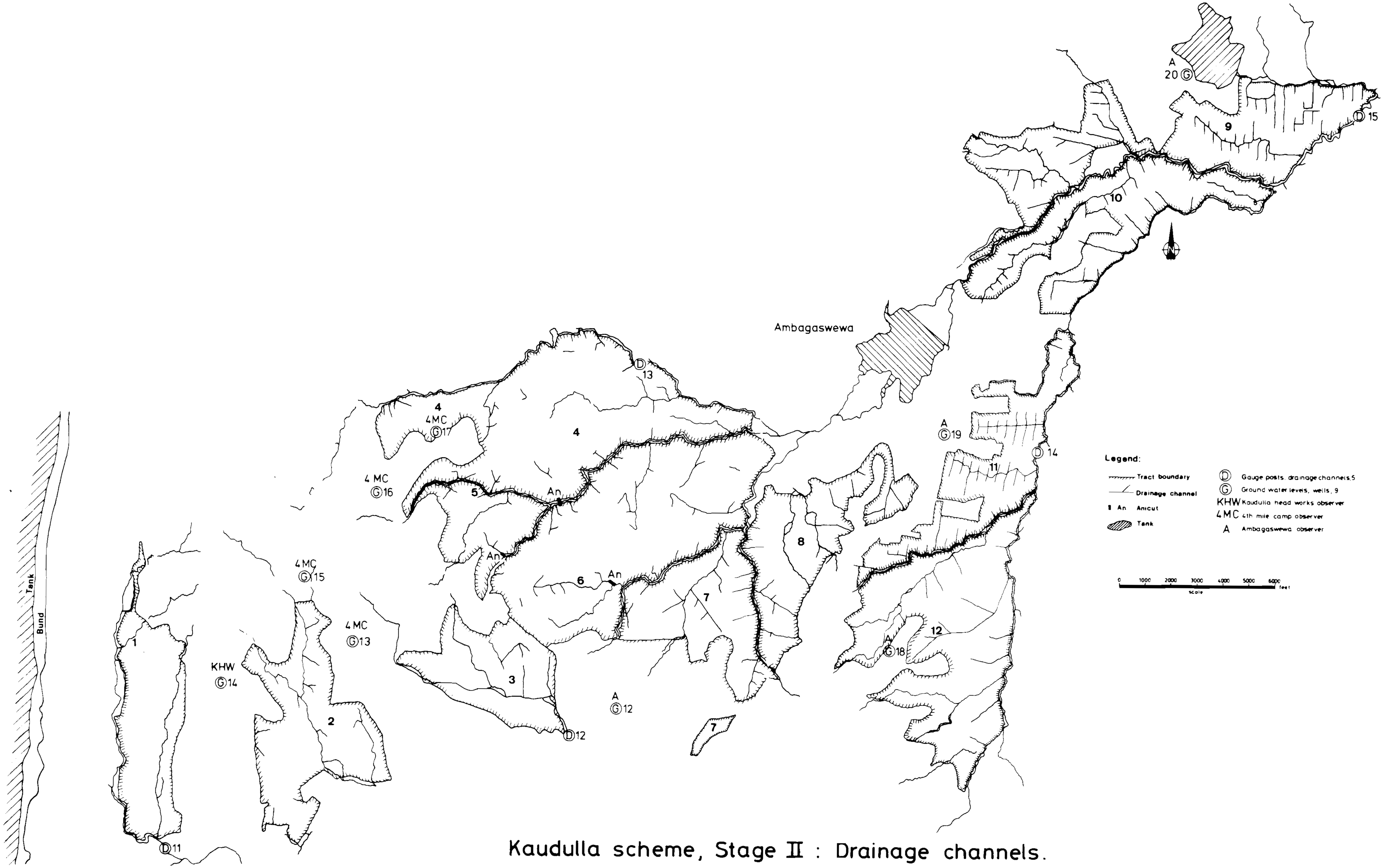
Kaudulla scheme, Stage I : Drainage channels.
Sites of gauge posts and wells

Fig 3



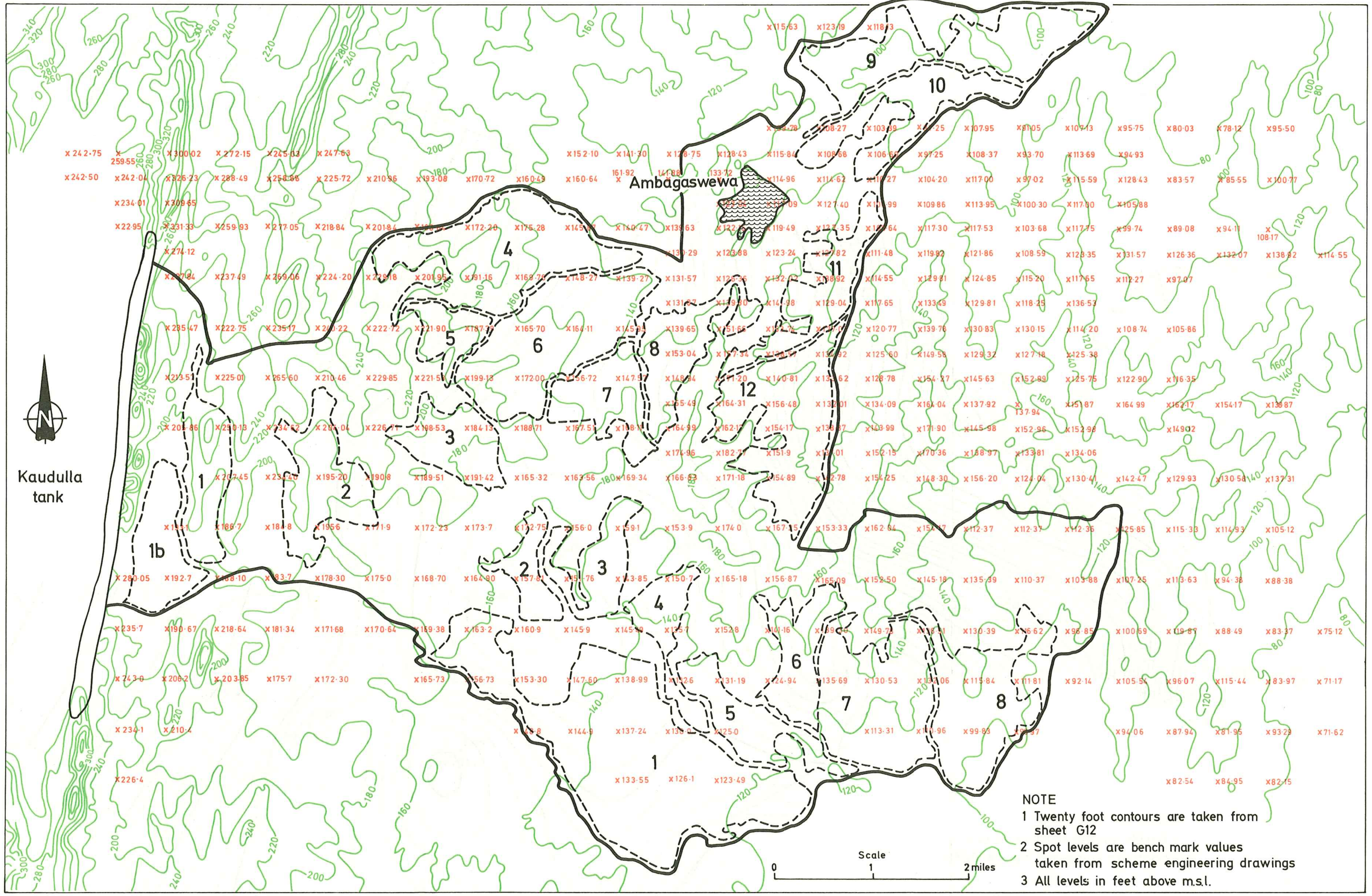
Kaudulla scheme, Stage II : Irrigation channels.
Sites of gauge posts and climatological stations

Fig 4



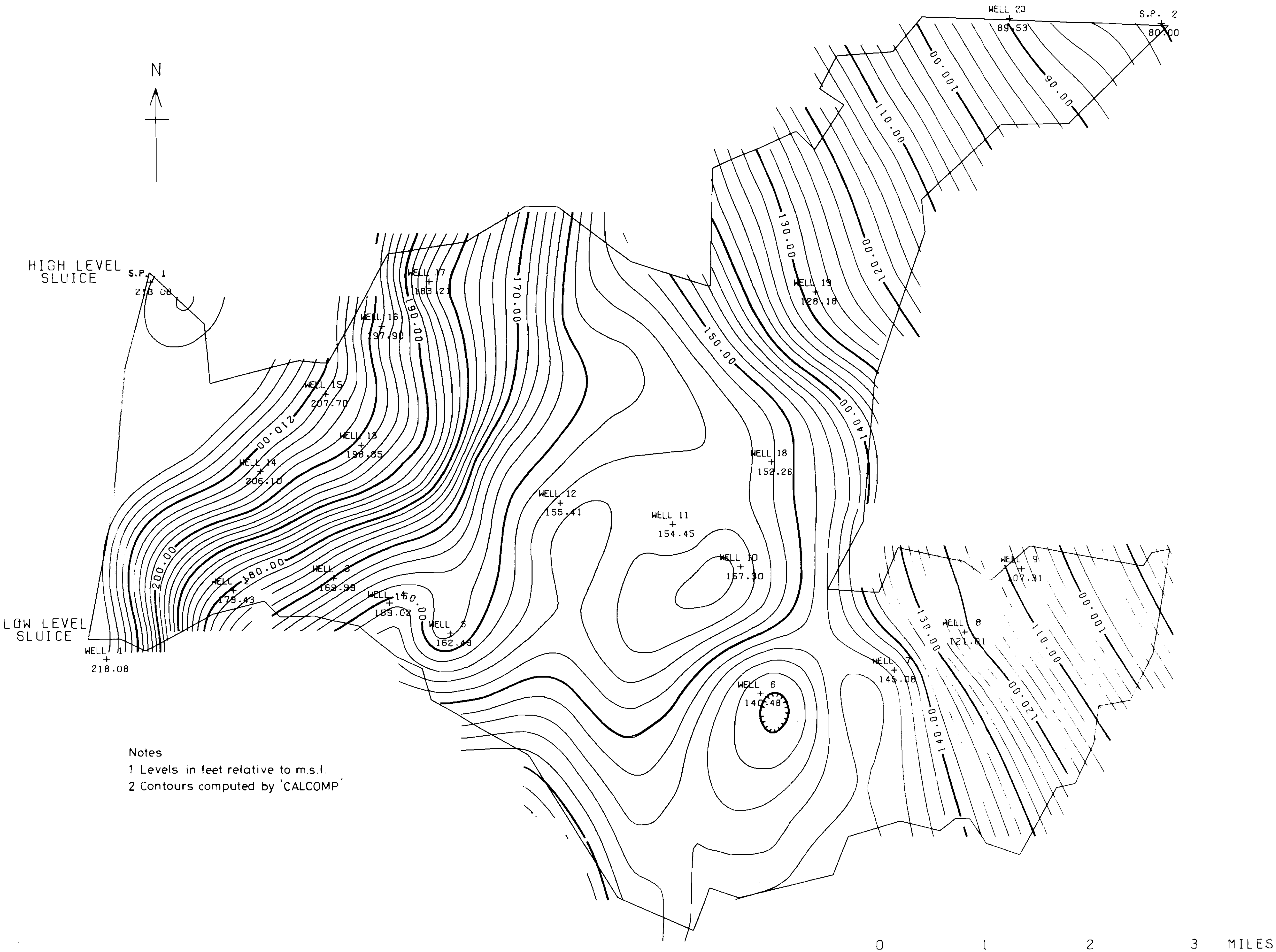
Kaudulla scheme, Stage II : Drainage channels.
Sites of gauge posts and wells

Fig 5



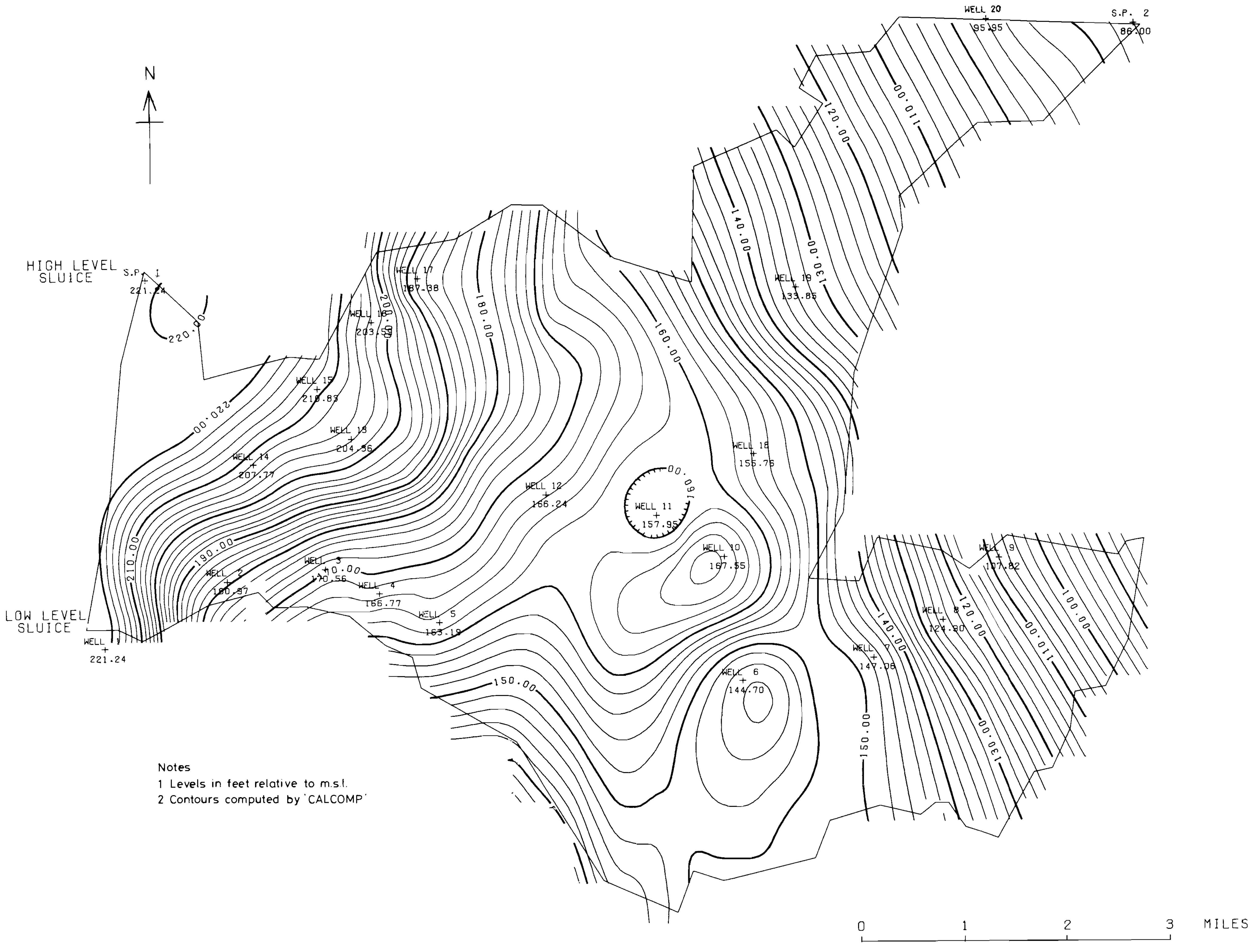
Kaudulla water management study
Plan of contours and spot levels

Fig. 6



Groundwater levels on 1st October 1978

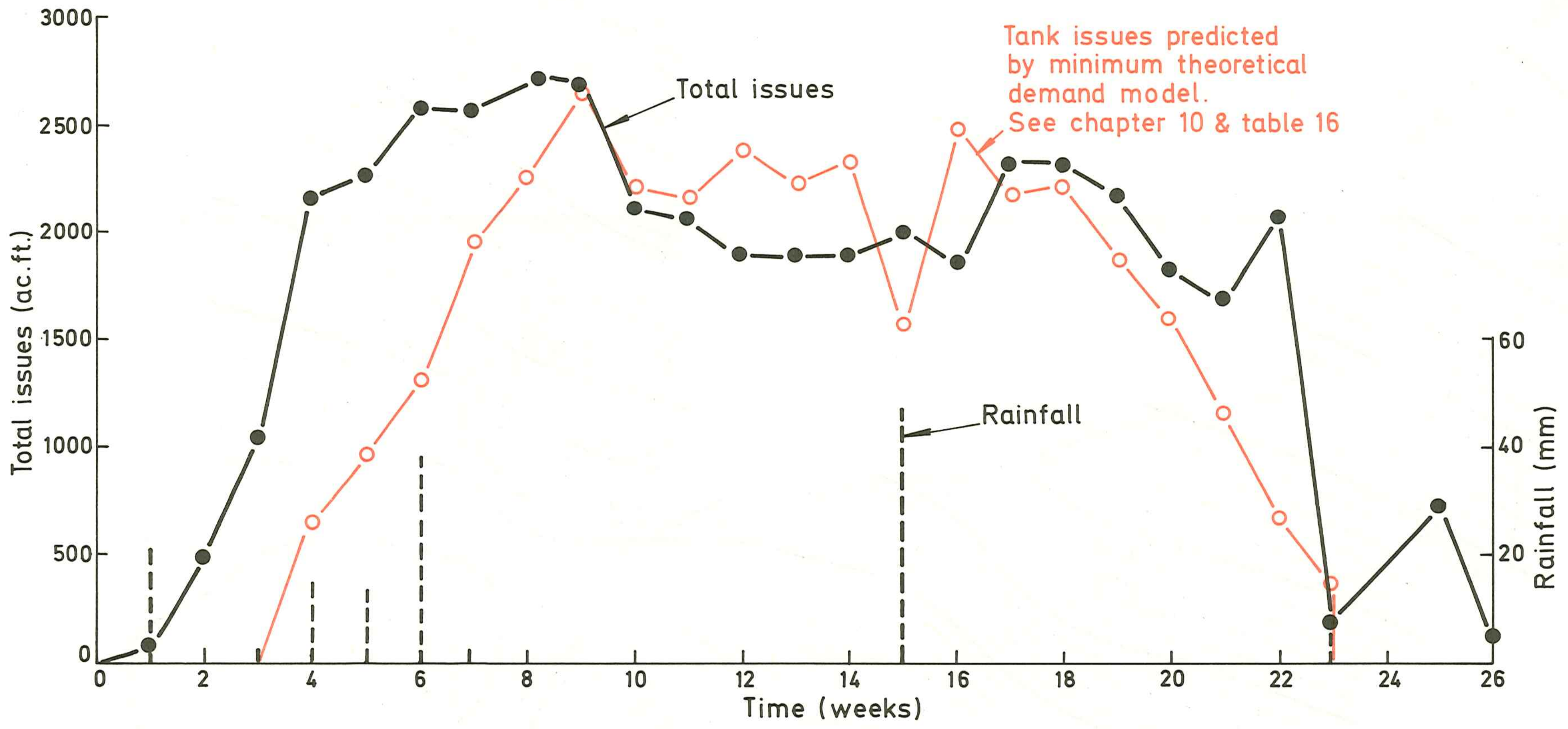
Fig 7



Notes
1 Levels in feet relative to m.s.l.
2 Contours computed by 'CALCOMP'

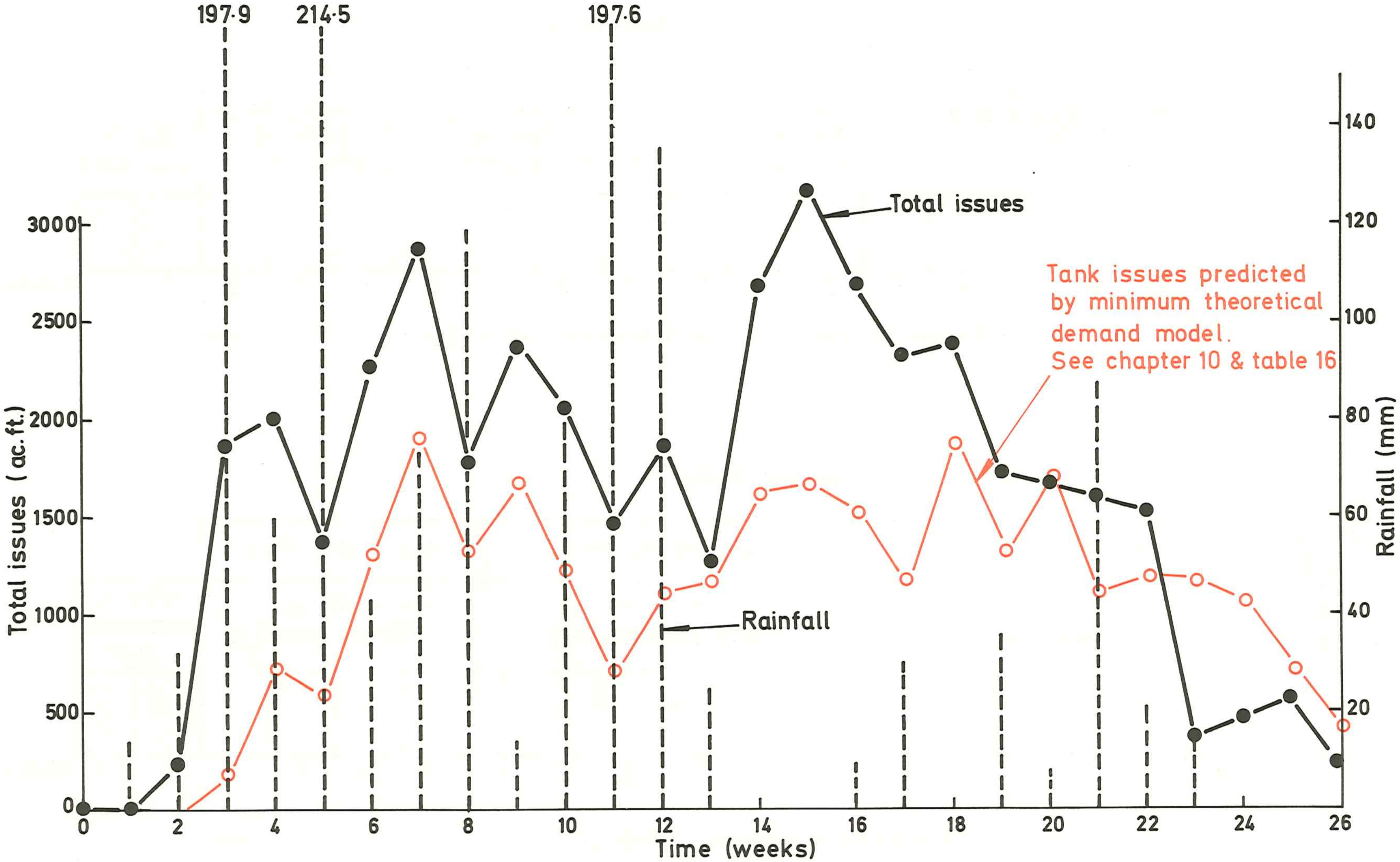
Groundwater levels on 1st April 1979

Fig 8



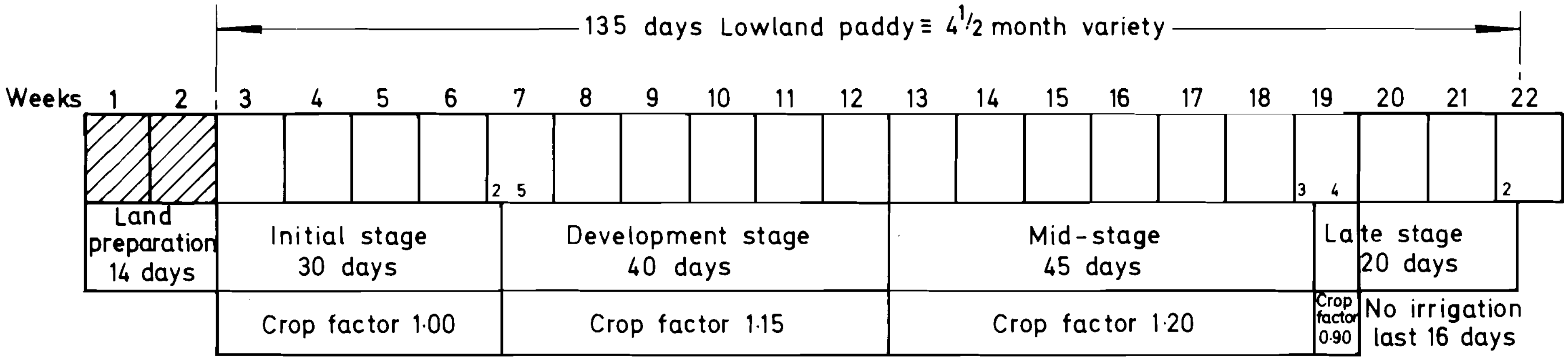
Weekly tank issues v. rainfall. Yala 1978

Fig. 9

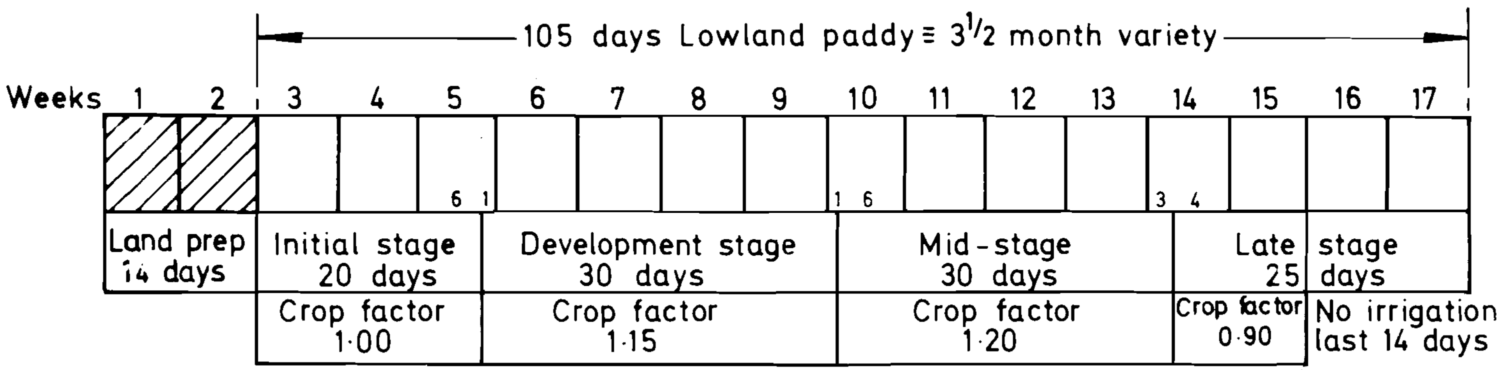


Weekly tank issues v rainfall Maha 1978/79

Fig.10



Maha season



Yala season

NOTE: These cropping patterns are based on those of reference 14

Definition sketches of crop patterns used in computer model

Fig 11

PLATES

PLATE 1 Gal Oya Spill radial gates

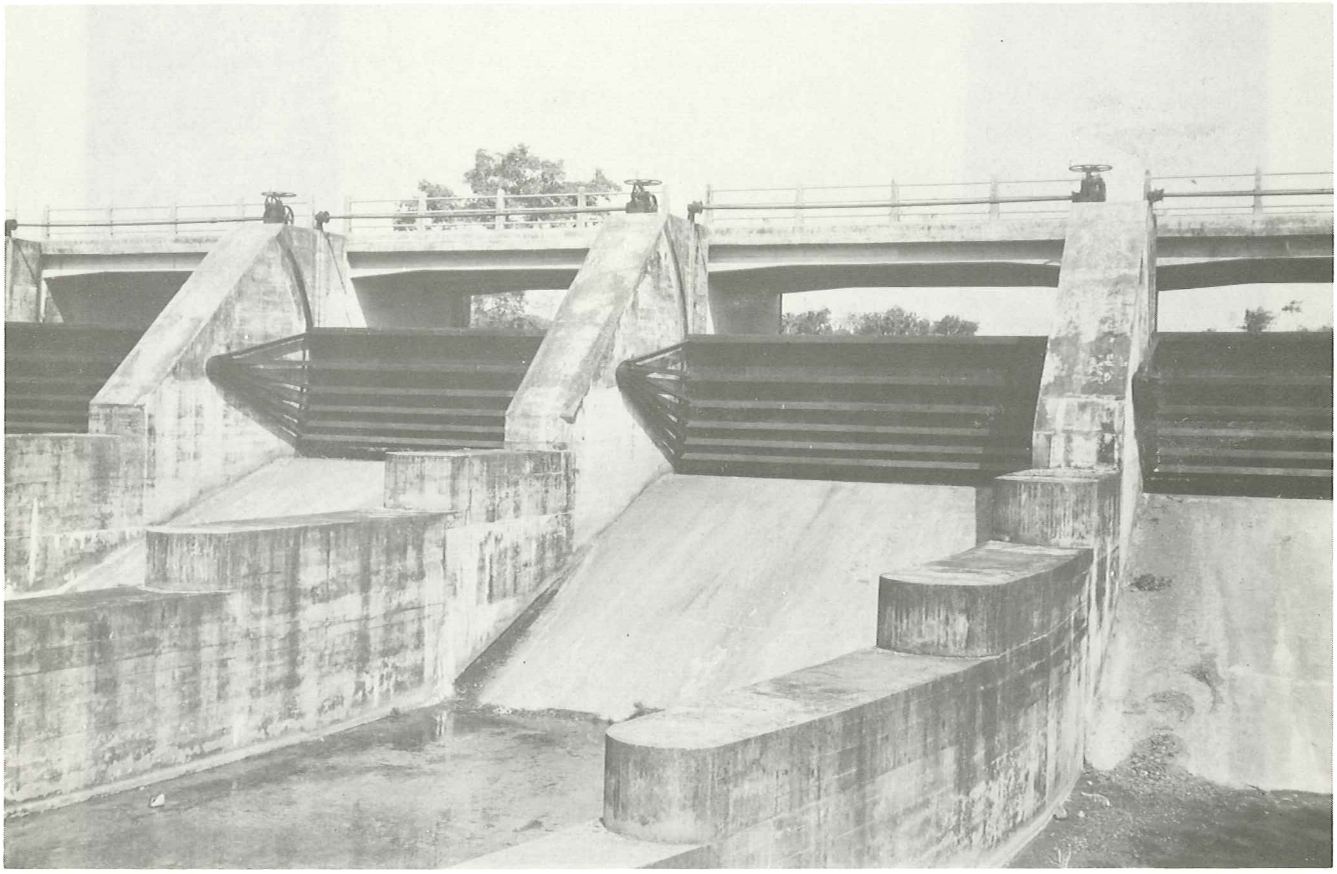


PLATE 2 Gal Oya Spill radial gates – Close-up

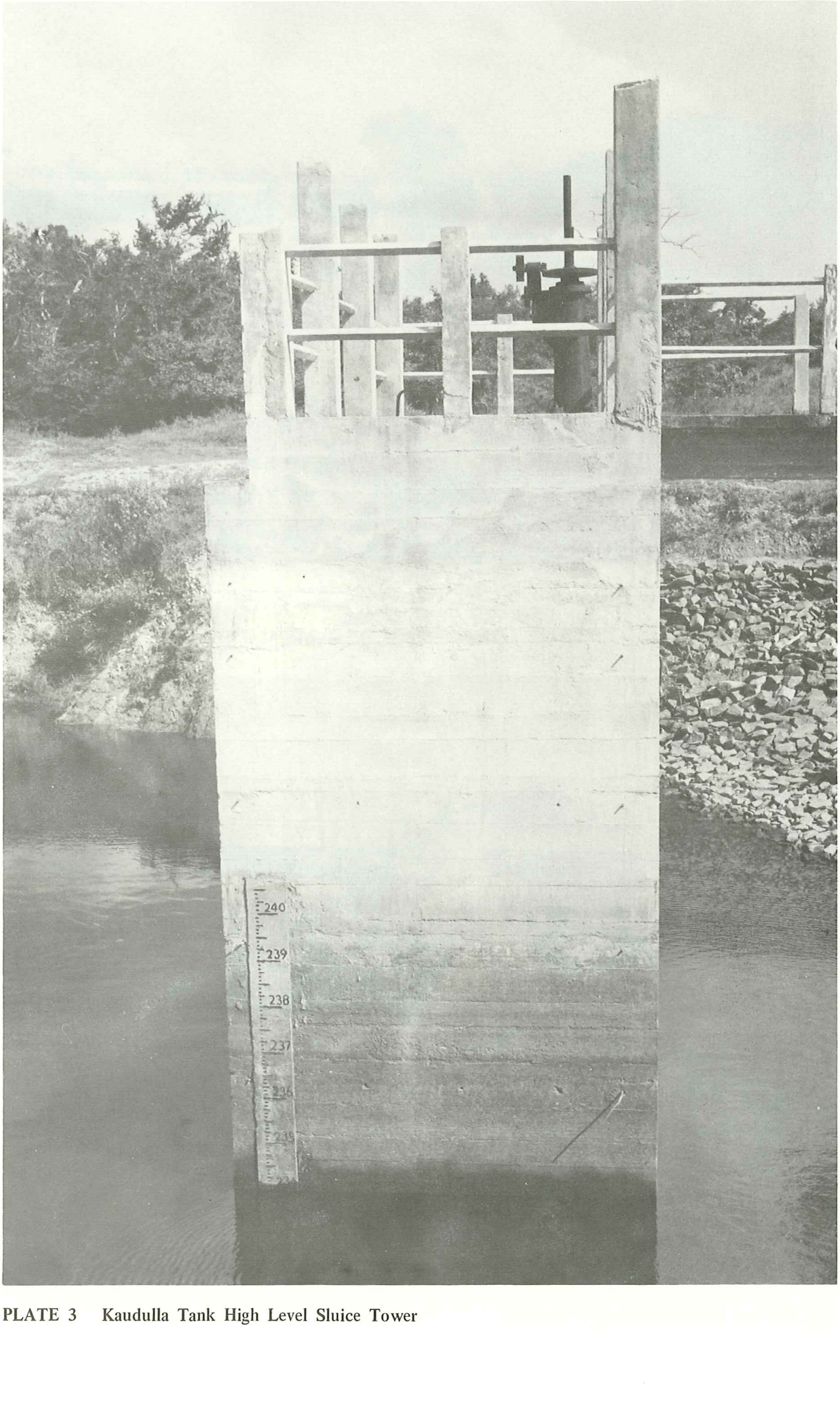


PLATE 3 Kaudulla Tank High Level Sluice Tower

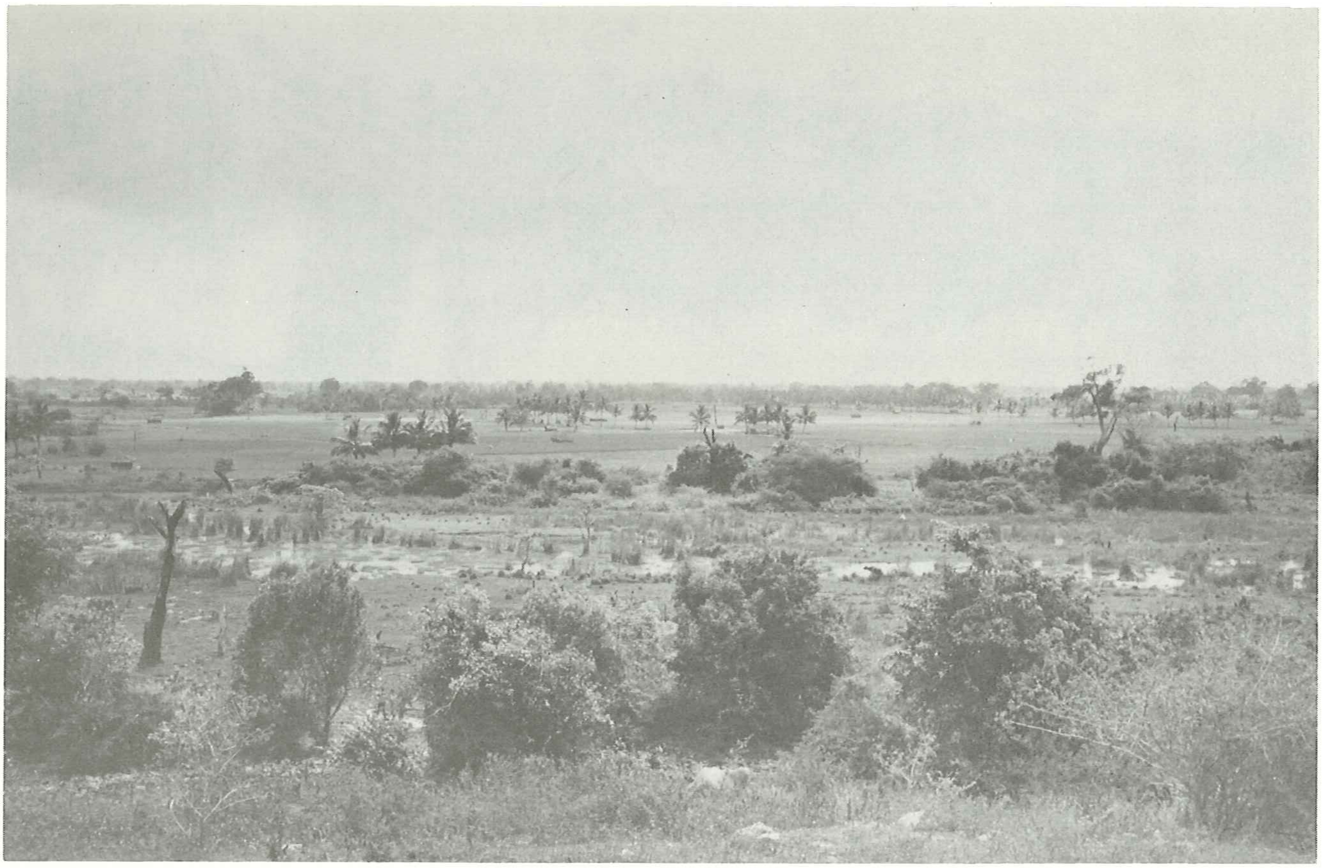


PLATE 7   Panorama of Tract 1B, Stage I taken from Kaudulla Tank bund

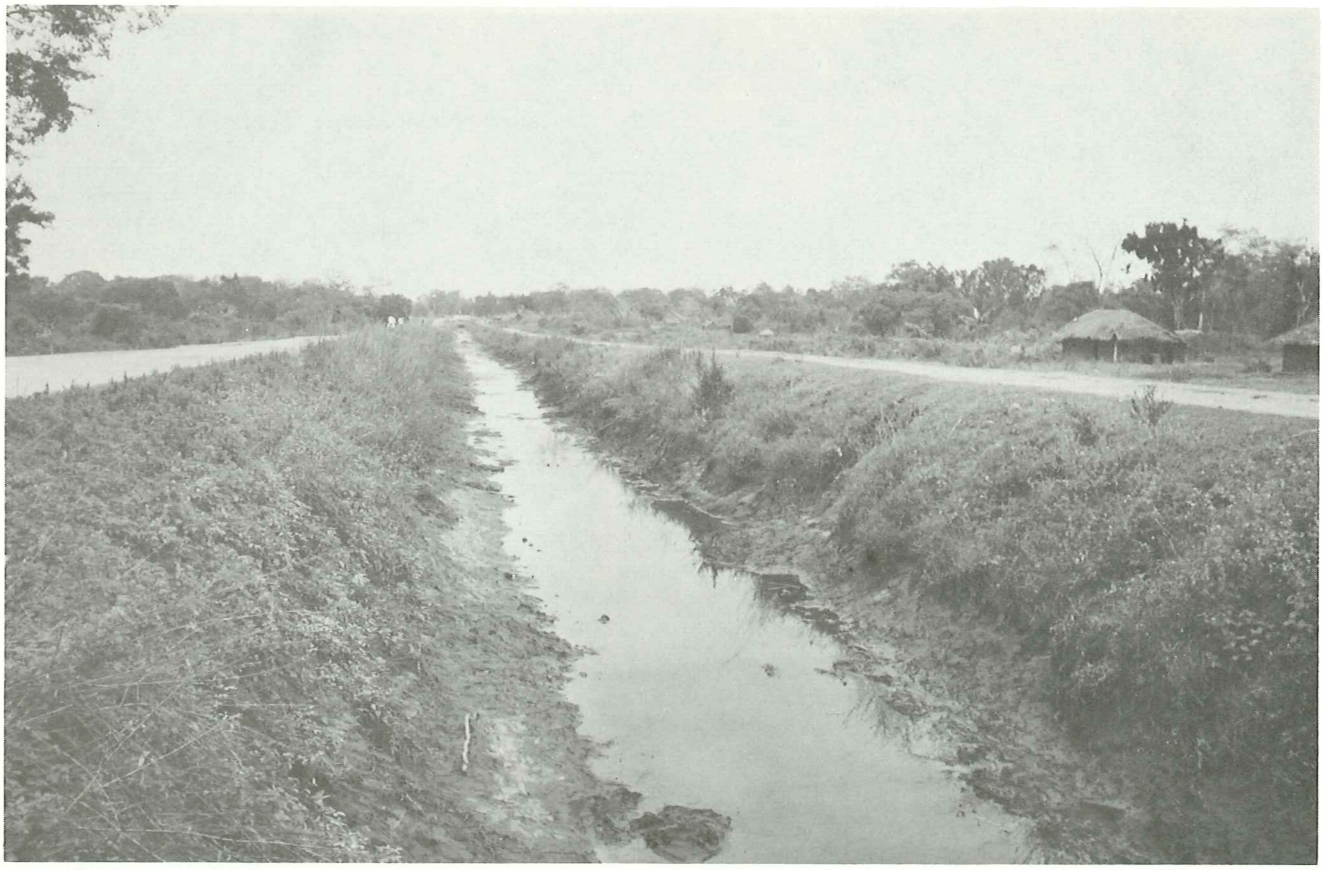


PLATE 8   Stage II Branch Channel 1, usual running level indicated by vegetation

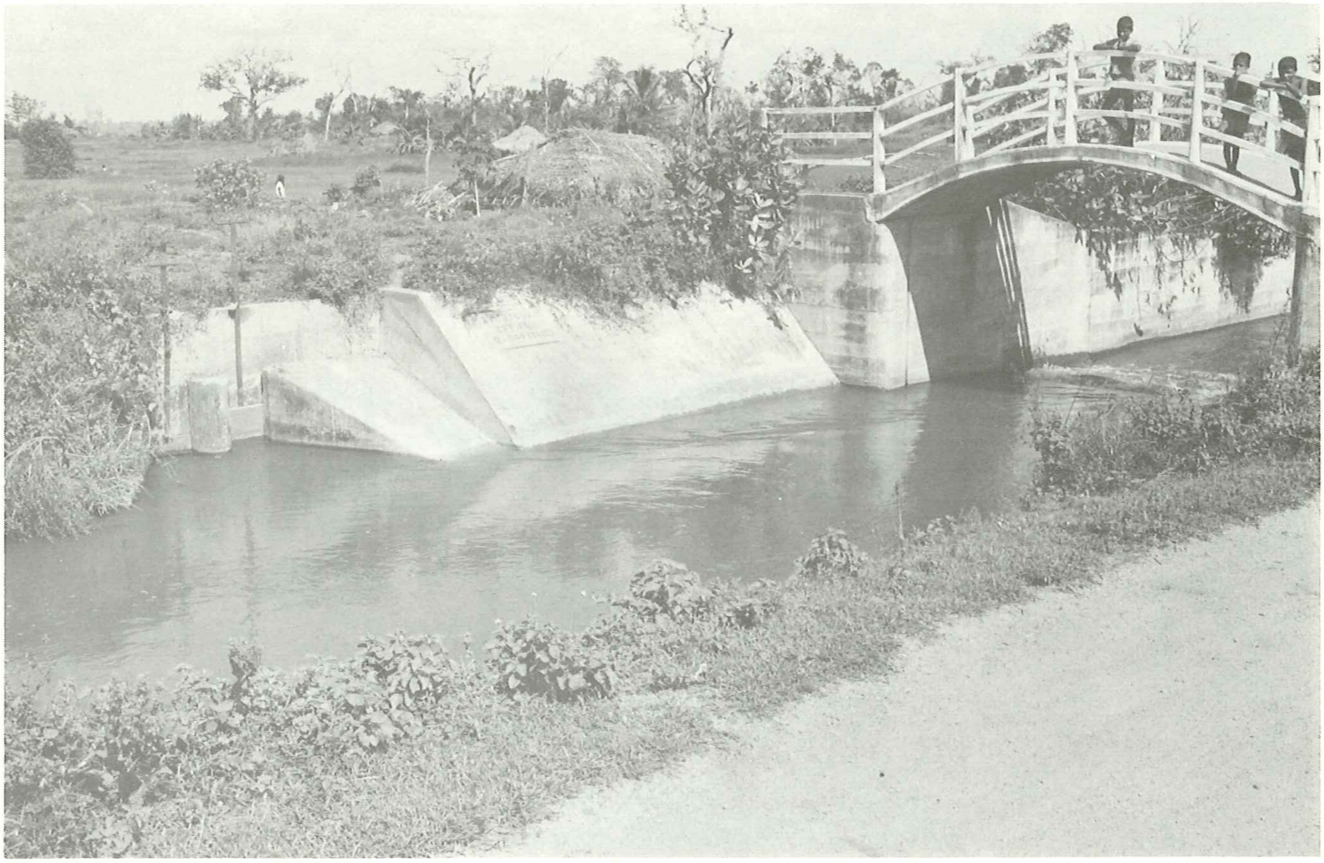


PLATE 9 Drop structure at 2 m 27 ch on Stage II Branch Channel 1 with offtake to Tract 6

PLATE 10 Gauge post 4MC(n), Stage II, Branch Channel 1

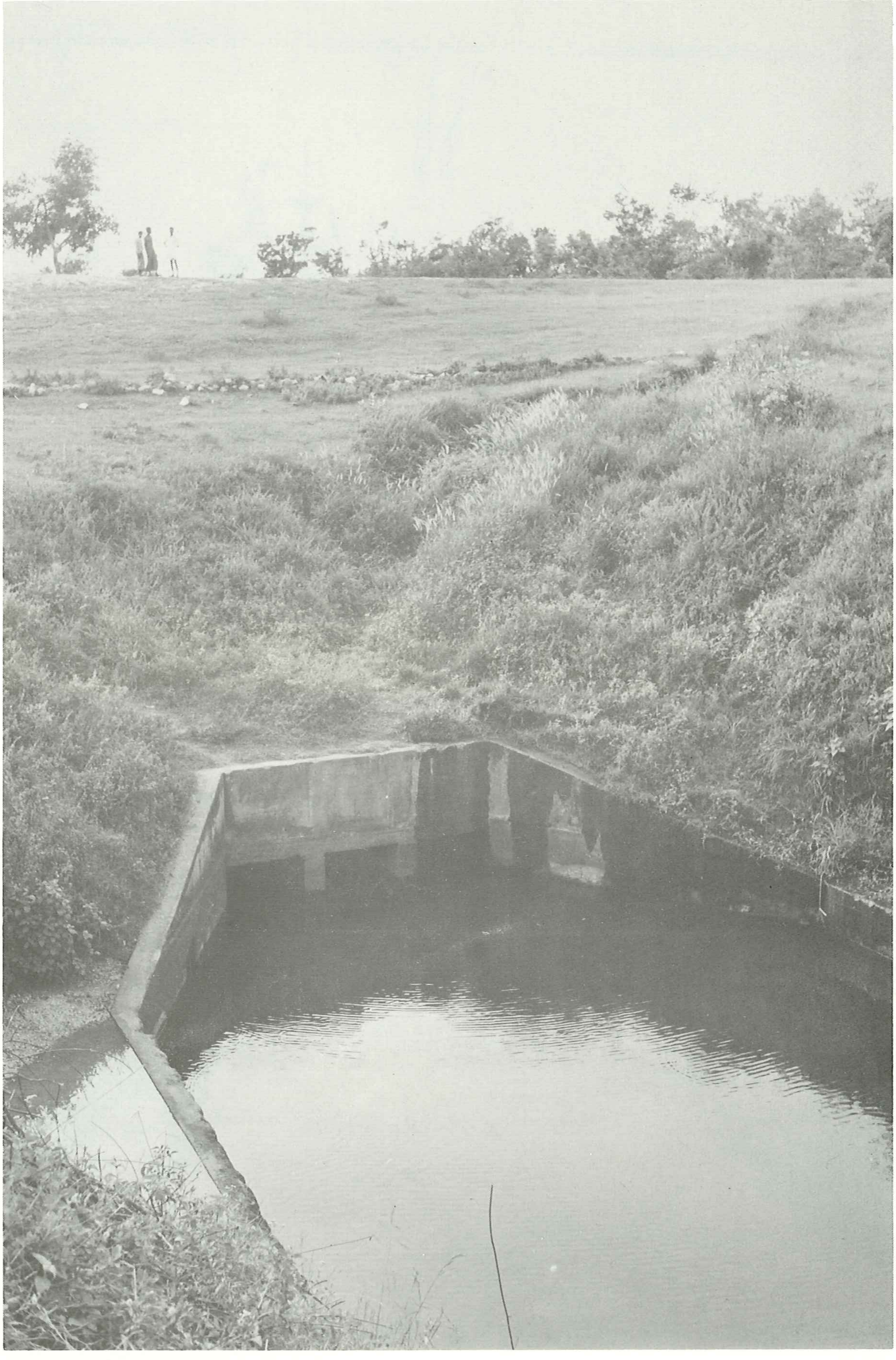


PLATE 4 Kaudulla Tank High Level Sluice Outlet

PLATE 5 Kaudulla Tank Low Level Sluice Tower

PLATE 6 Kaudulla Tank Low Level Sluice Outlet

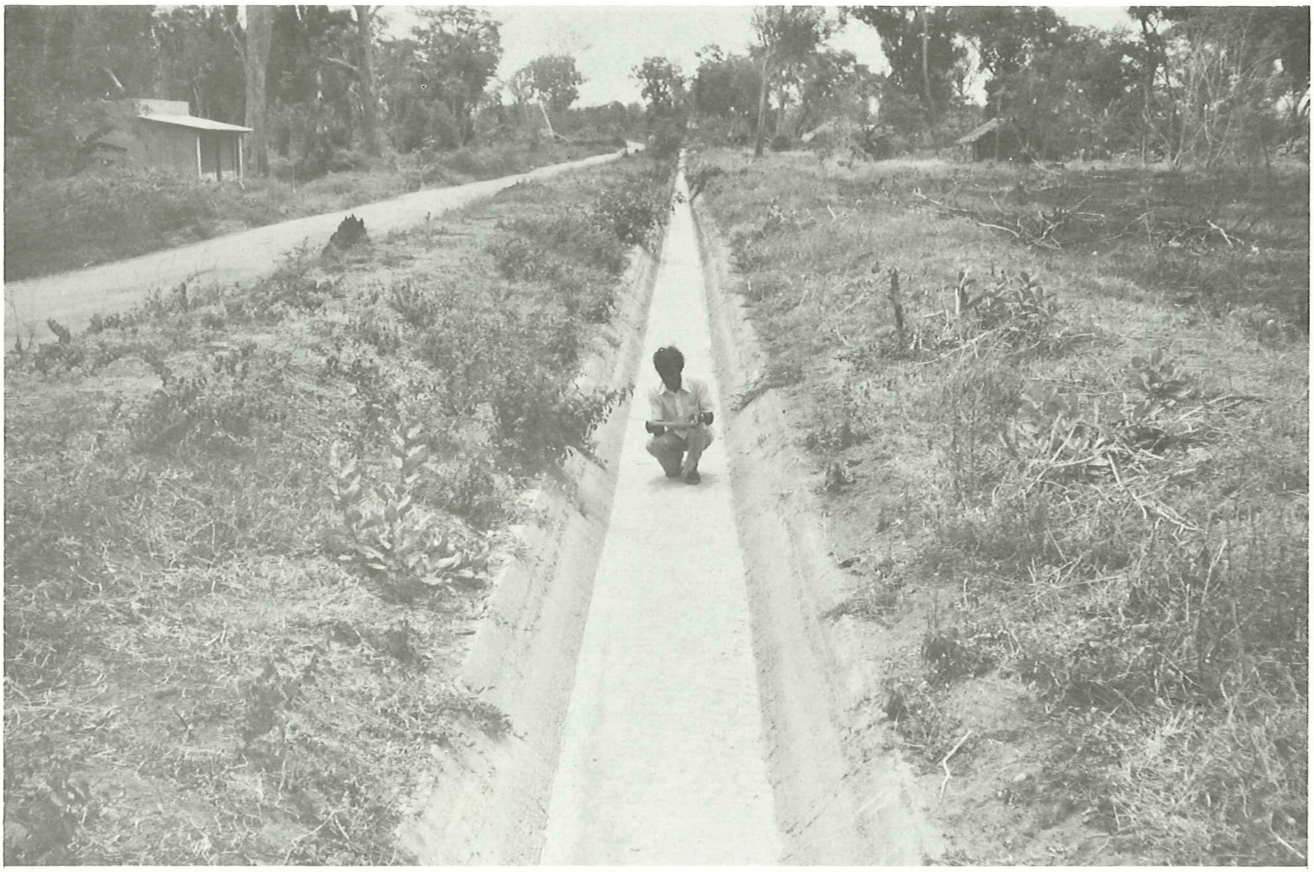


PLATE 11 Stage II Branch Channel 1A, concrete lined

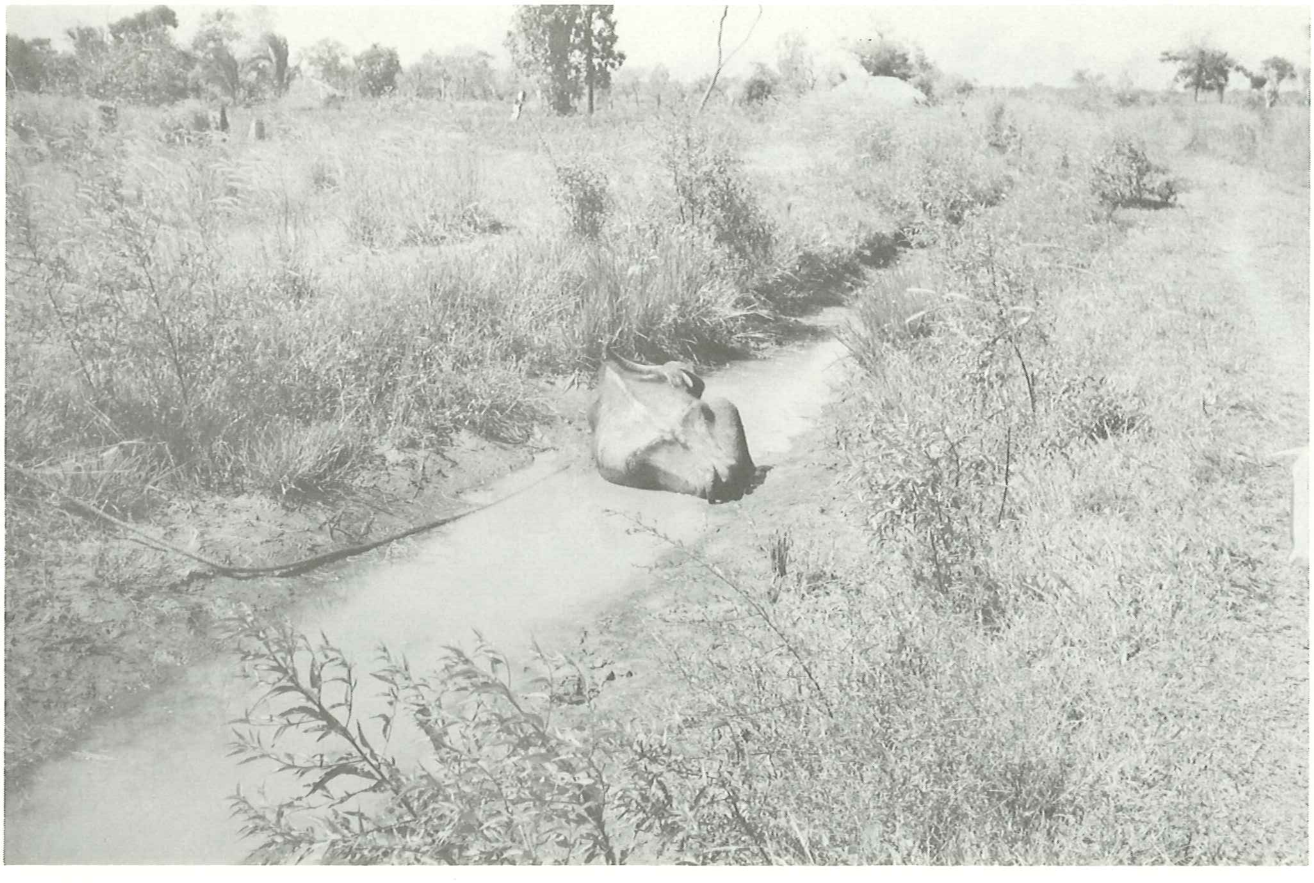


PLATE 12 Small channel in Tract 8 of Stage II

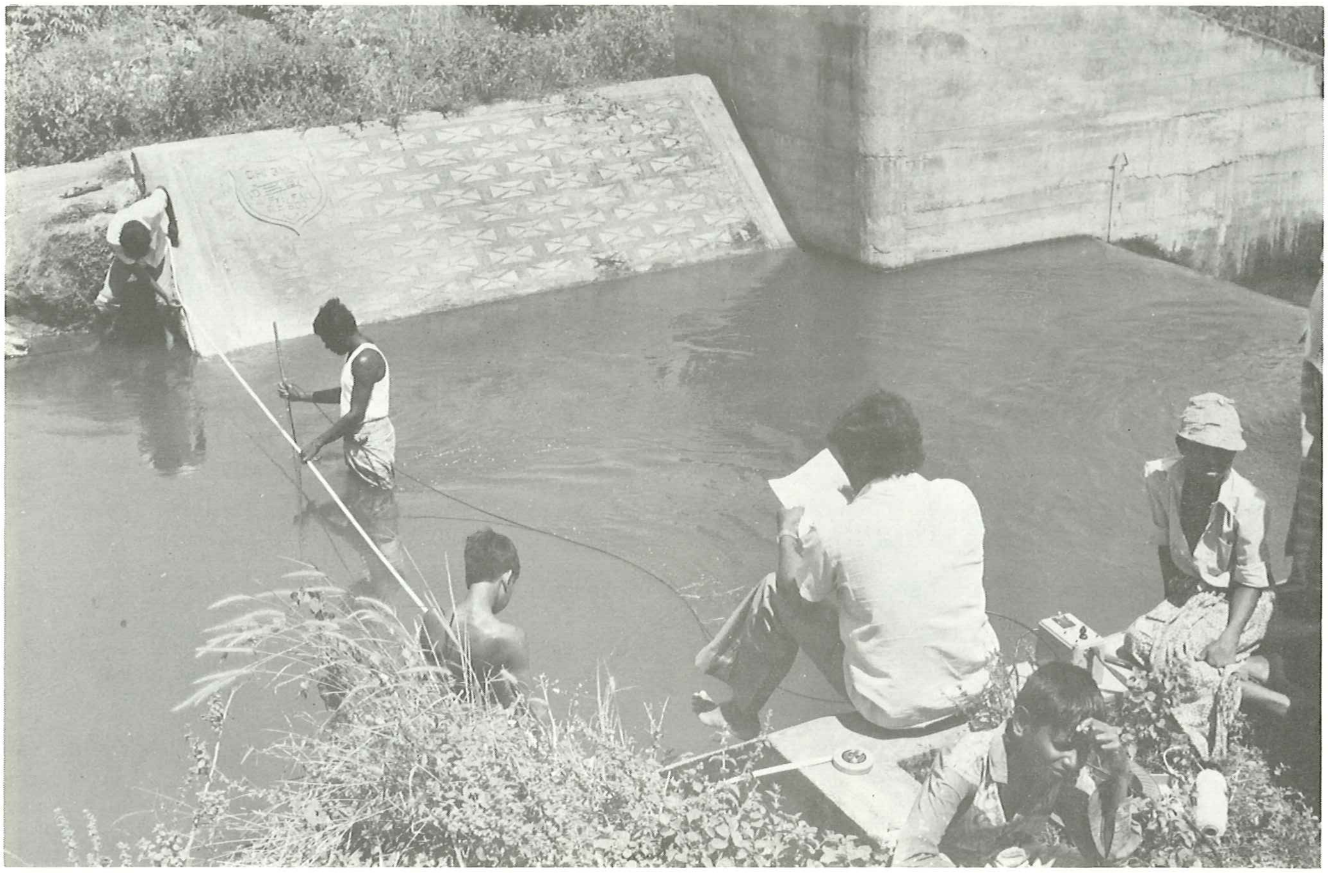


PLATE 13 Stream gauging at drop structure at 3 m 0 ch on Stage II Branch Channel 1

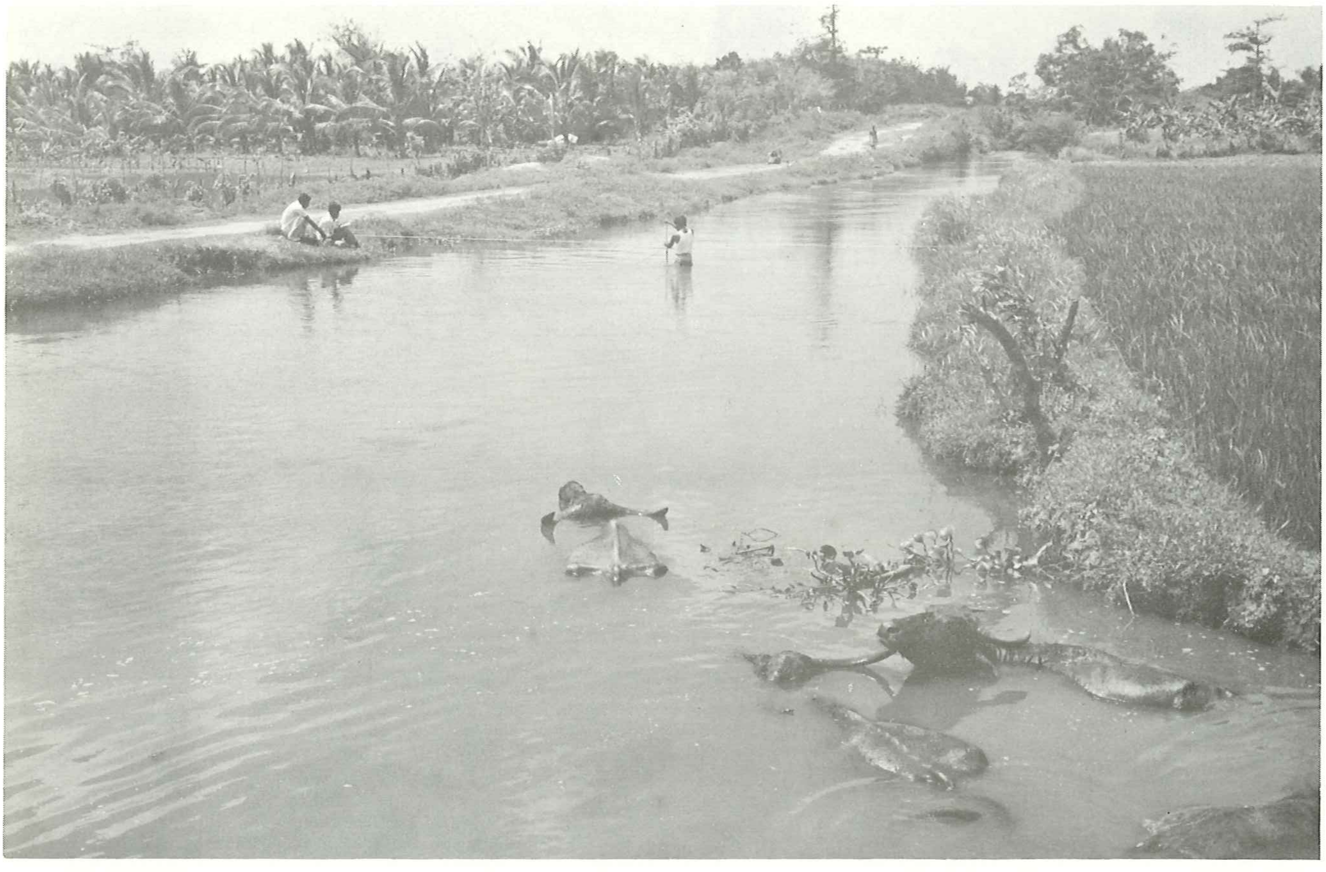


PLATE 14 Stream gauging at D(i) on Stage I main channel

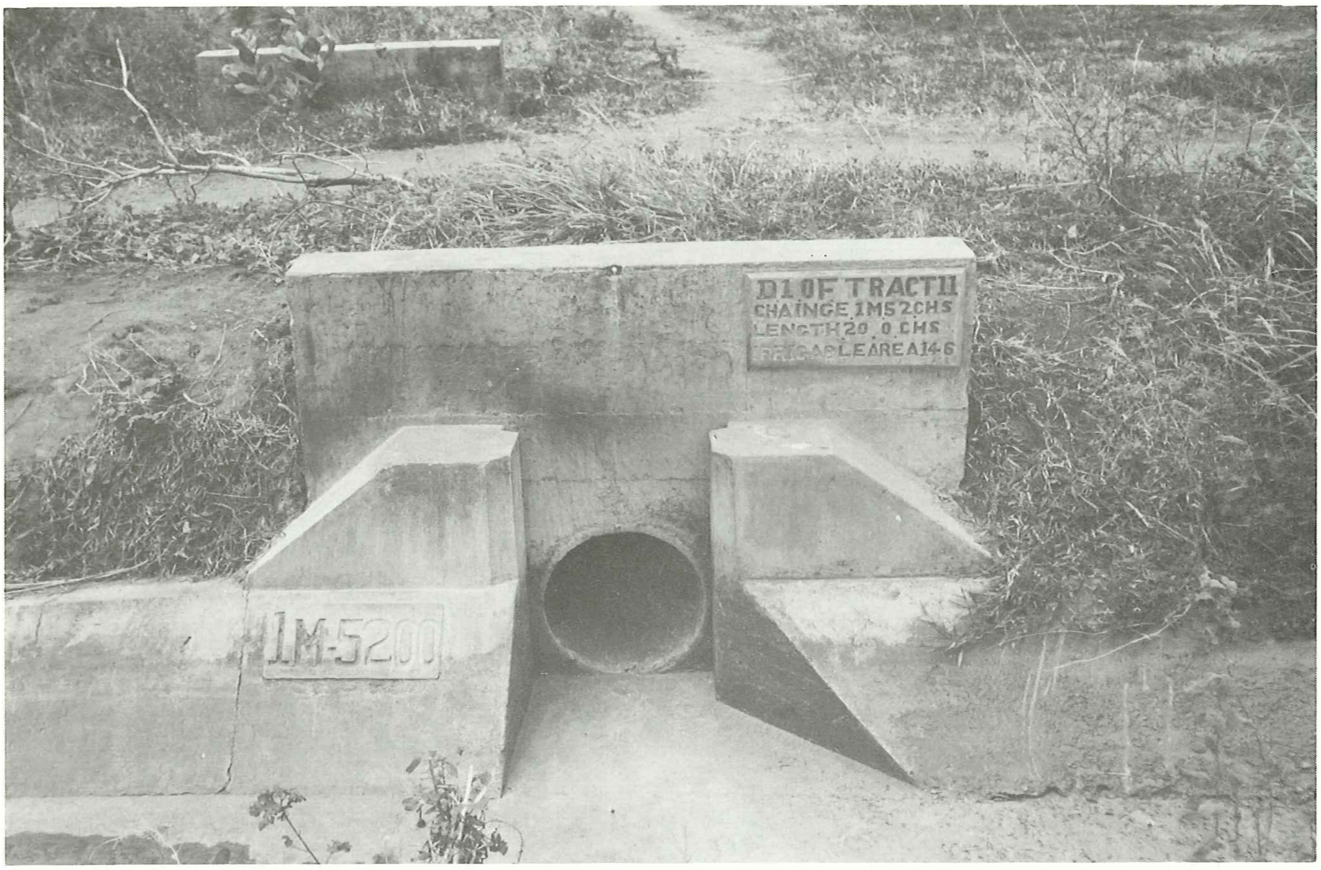


PLATE 15 Offtake from Branch Channel 1A to Tract 11 of Stage II

PLATE 16 Site for Drainage Post 15

PLATE 17 Paddy draining to intercepting distributary channel D2 of Tract 4, Stage II

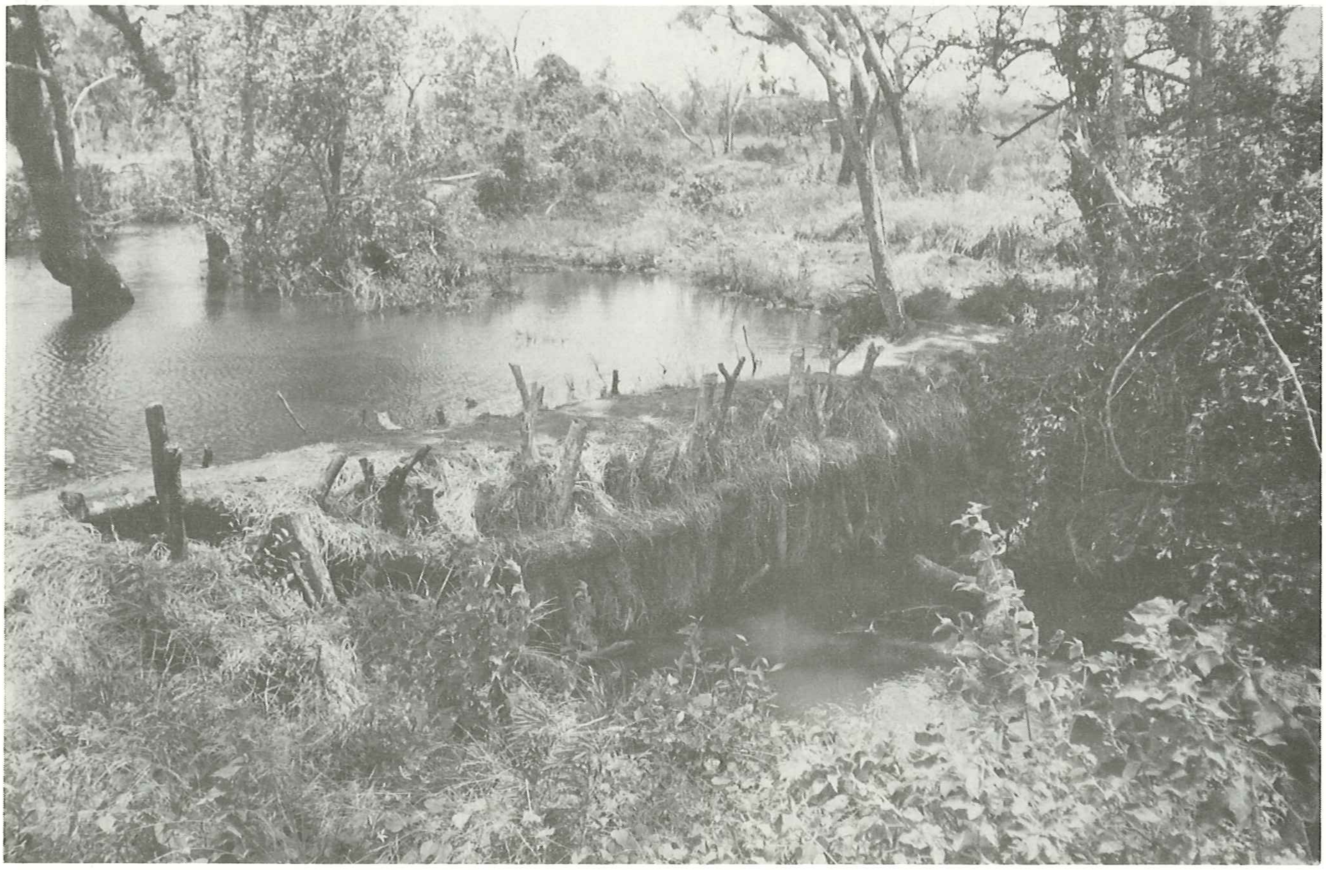


PLATE 18 Weir across stream to divert drainage water for re-use

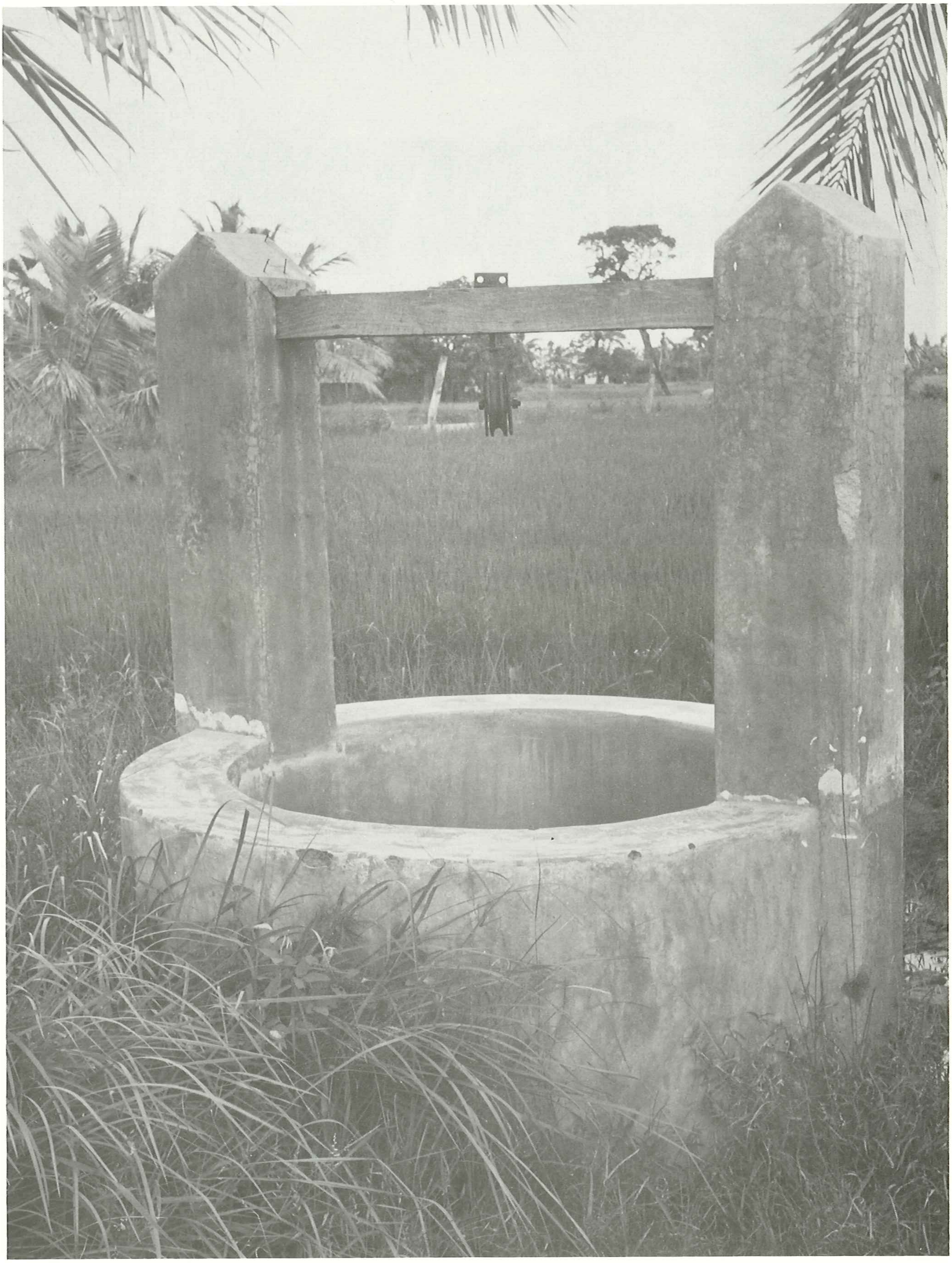


PLATE 19 Groundwater Observation Well

PLATE 20 Gal Oya Spill Daily Raingauge. Rim set at 4 feet following ID practice

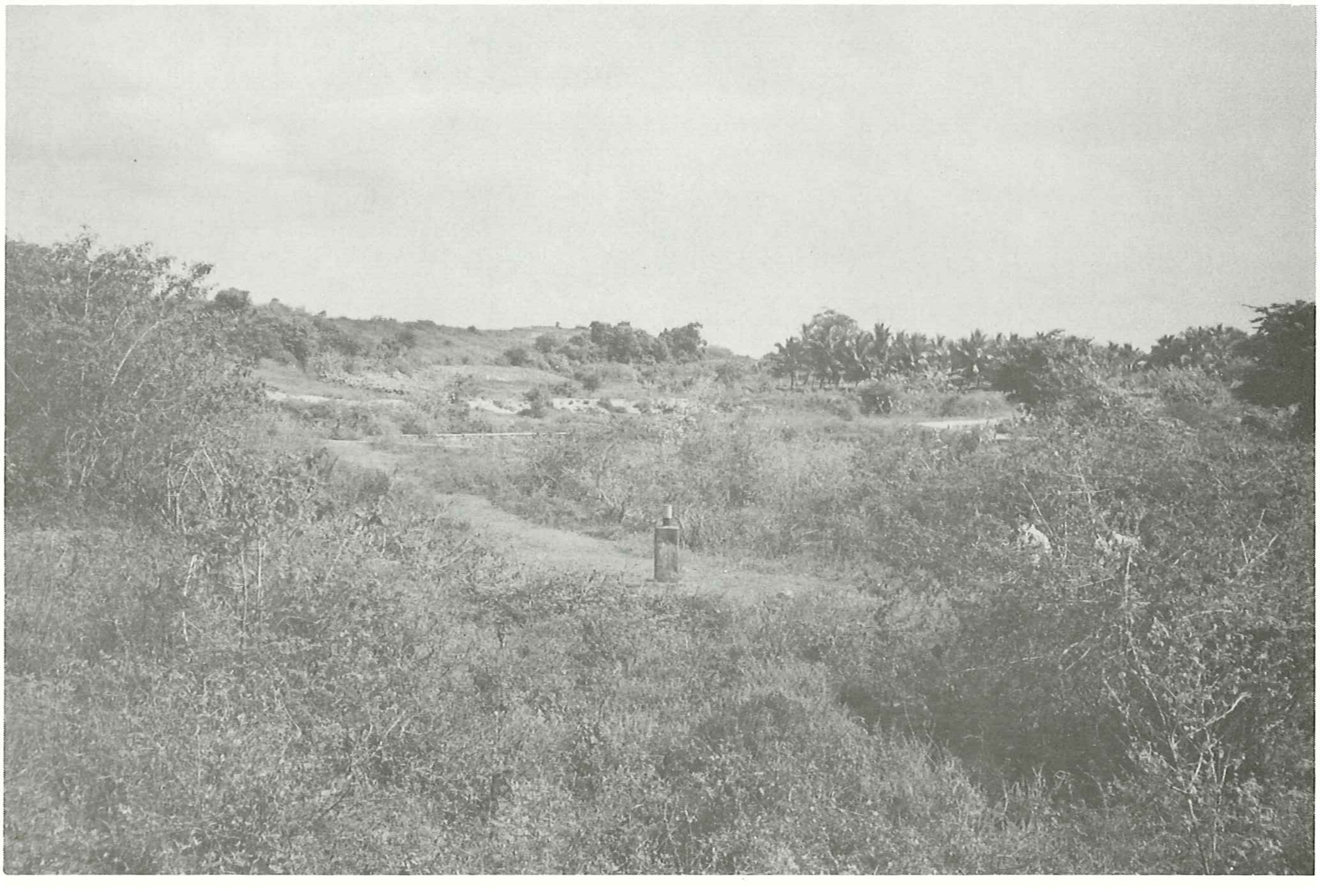


PLATE 21 Kaudulla Tank Low Level Sluice Daily Raingauge (original site)

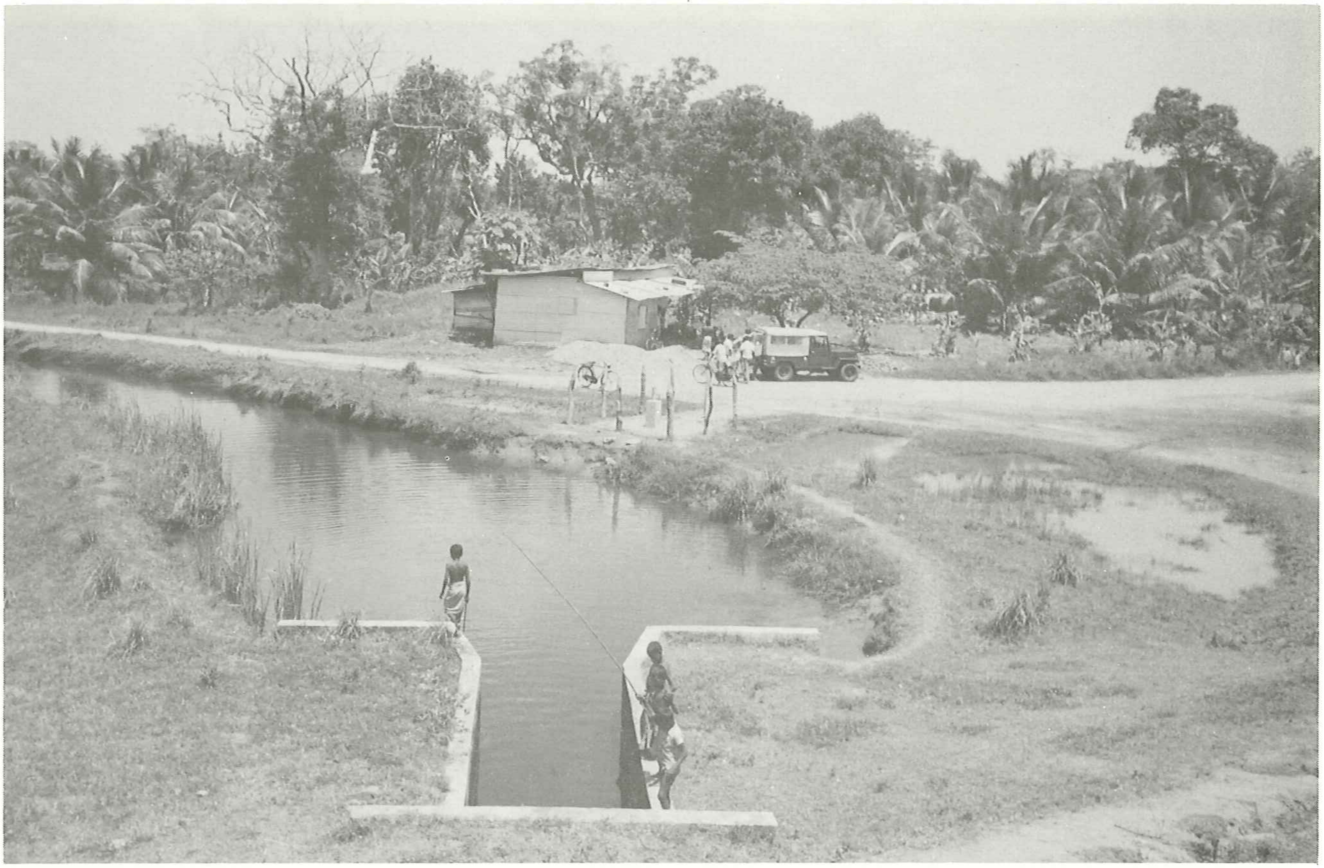


PLATE 22 Ambagaswewa Daily Raingauge, below LB sluice

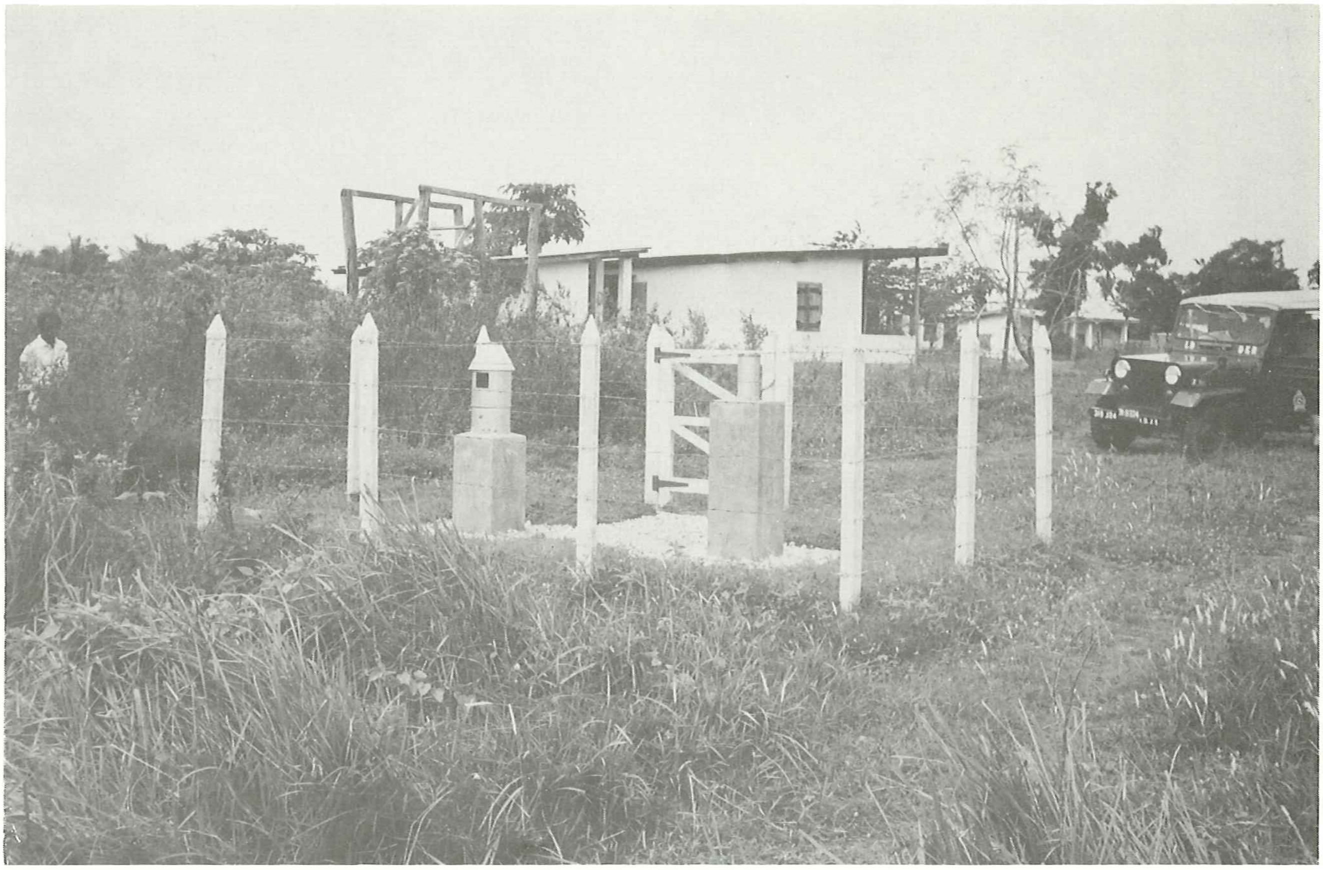


PLATE 23 Fourth Mile Camp Raingauge Station, showing daily and recording gauges

PLATE 24 Diyasenapura Meteorological Station

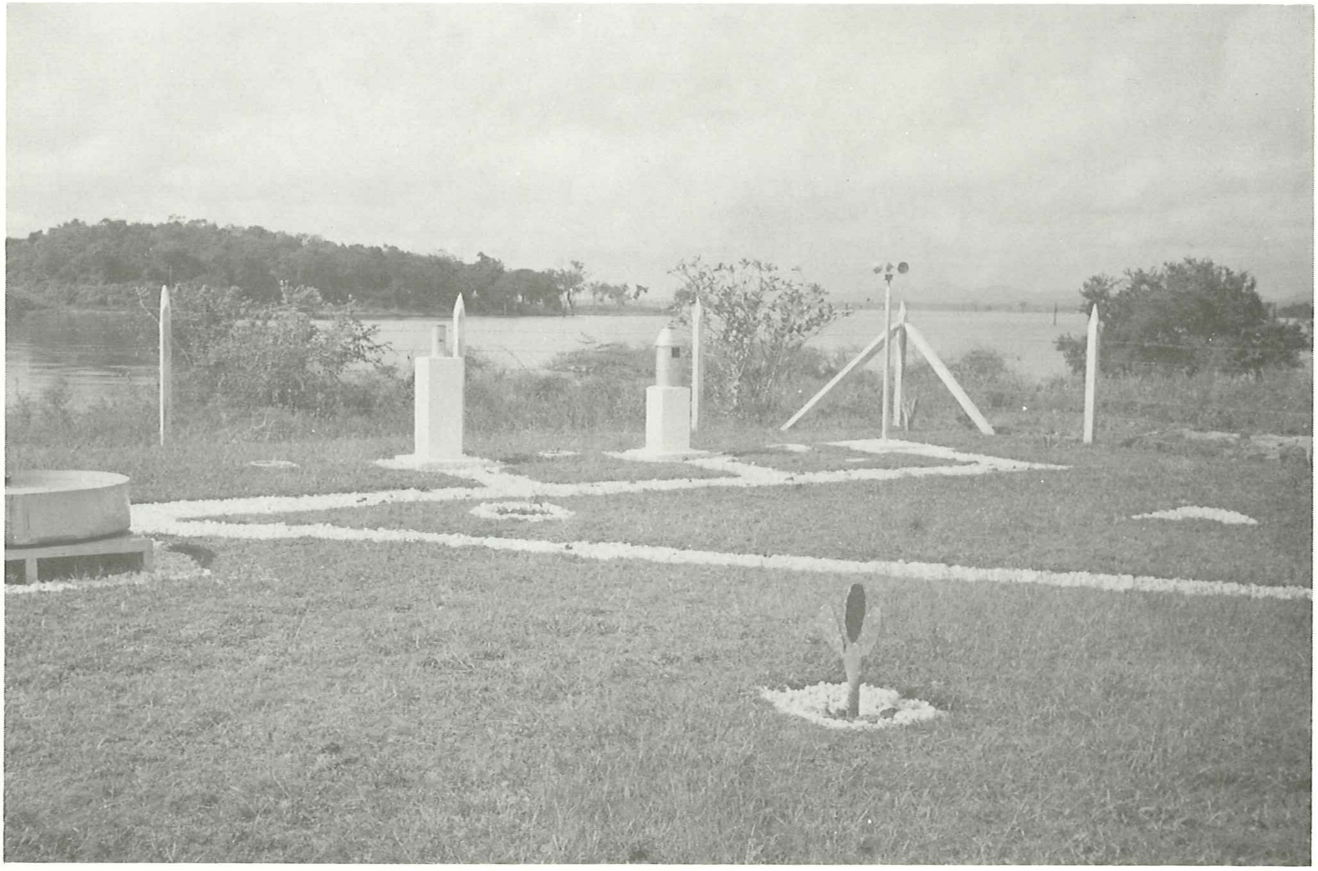


PLATE 25 Kaudulla Tank High Level Sluice Meteorological Station

PLATE 26 Field Ponding Test. Mr Karunatilake holding screw hook gauge

PLATE 27 Field Ponding Test, Stage I, Tract 2, showing hook gauge in position

PLATE 28 Ploughing during land preparation, Stage I, Tract 2

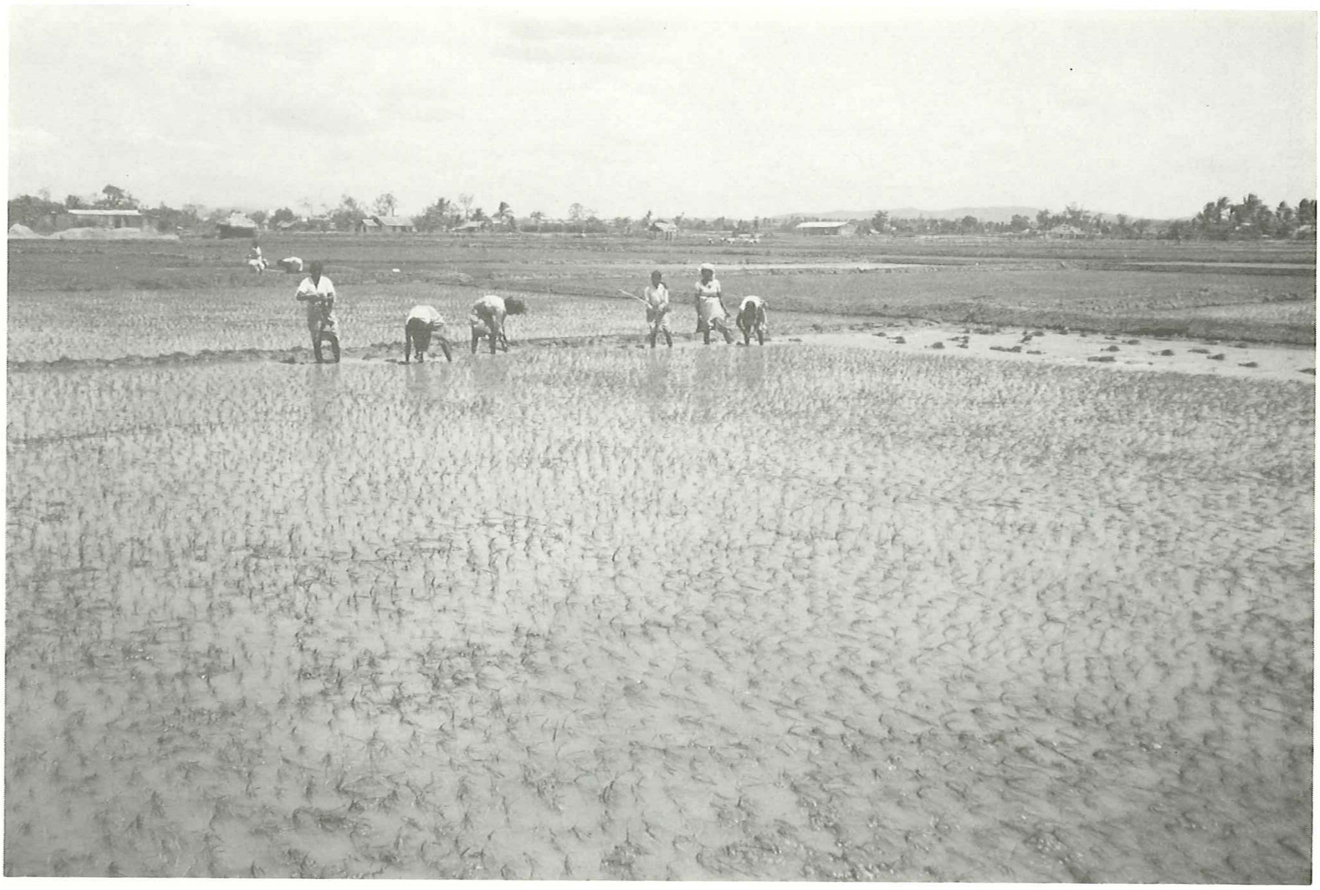


PLATE 29 Transplanting paddy, Stage I, Tract 2

PLATE 30 Paddy on Low Humic Gley Soil, Stage I, Tract 2

PLATE 31 Winnowing at a paddy threshing floor, Ambagaswewa

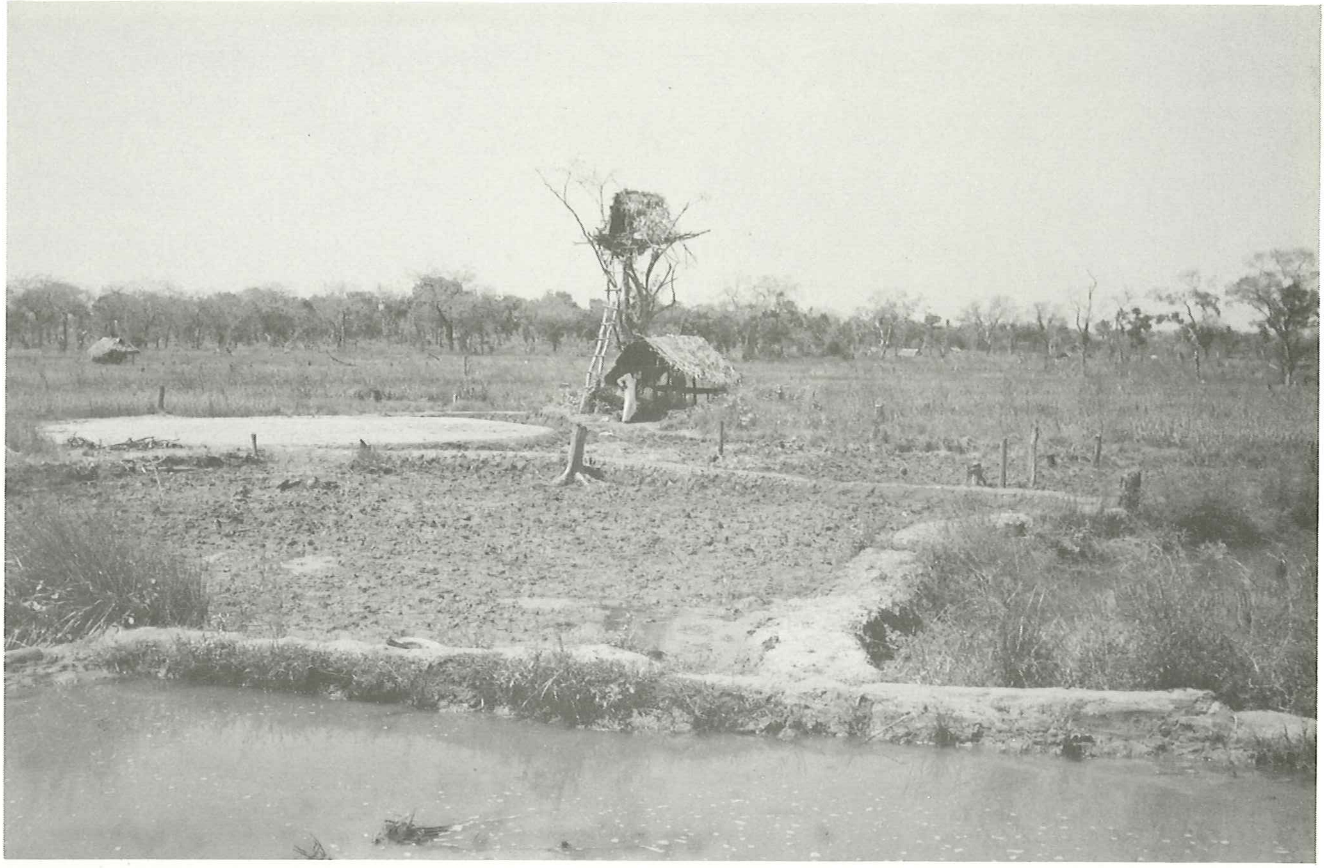


PLATE 32 New field at mudding stage, Stage II, Tract 11, March 1978

PLATE 33 Same field shortly before harvest, July 1978

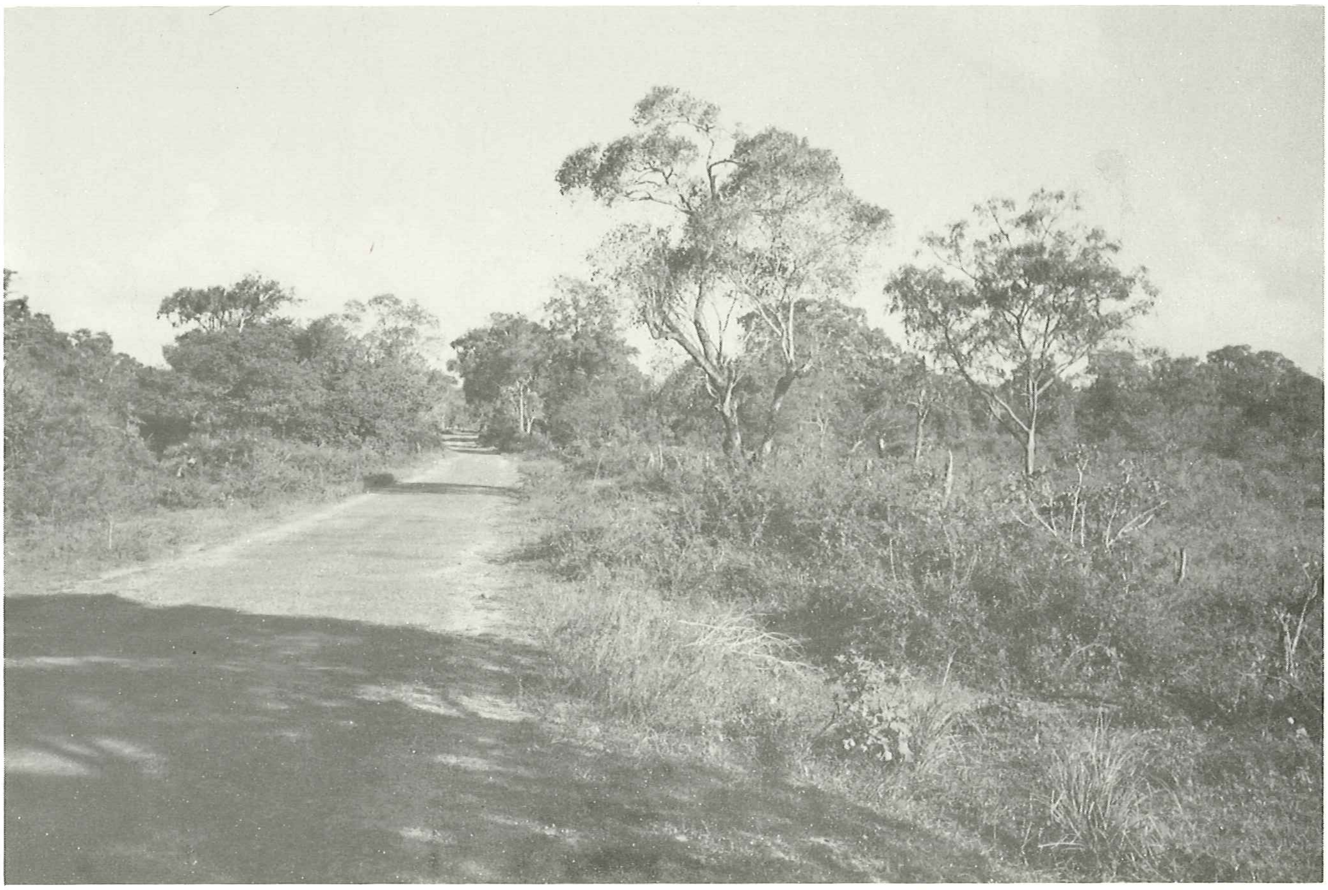


PLATE 34 Scrub forest near the Aggalawan Oya, Kaudulla Tank catchment area

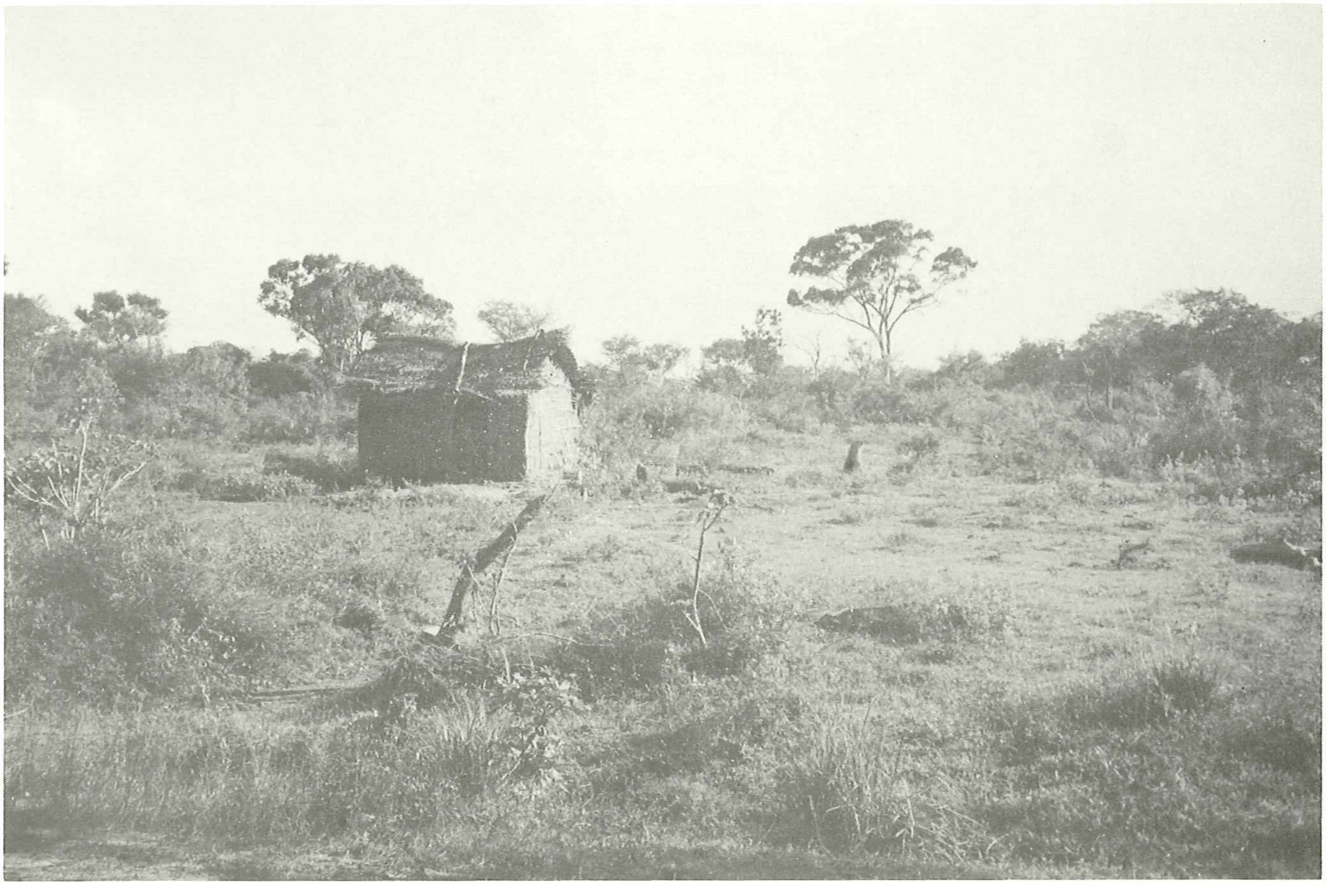


PLATE 35 Land reverting to scrub following chena (shifting) cultivation, Kaudulla Tank catchment area

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