DRAINAGE REQUIREMENTS IN THE MARKHAM VALLEY

ABSTRACT

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From the recent survey of the Markham Valley, information is presented that is relevant to possible drainage projects. The nature and extent of the poor drainage conditions are described, together with a discussion of the appropriate formulae for the calculation of field drainage spacings.

INTRODUCTION

POORLY drained lands occupy about 30,000 hectares in the Markham Valley. This is 27 per cent of the total area covered in a recent survey of soils and agricultural potential (D.A.S.F. Report) but represents 40 per cent of the non-gravelly soils which have better potential for arable cropping. Land drainage will be an important feature of any large scale agricultural development in this area which has as its goal the maximum productive utilisation of land in cropping activities.

The purpose of this paper is to draw together technical information made available by the recent survey that has relevance to possible drainage projects. This might be seen to have the combined utility of providing a preliminary appreciation of the type and magnitude of improvements required and of providing a framework for further investigations by identifying those aspects of importance to the designing of a drainage project.

Emphasis is given to two areas of the Markham Valley, namely the Erap-Rumu section and the neighbouring Rumu-Leron section (see *Figure* 1). By way of introduction to the discussion of drainage systems and their design, a summary is given of the nature and extent of the poor drainage conditions that are experienced in the Erap-Leron area. Background information on the selection of appropriate formulae for the calculation of field drain spacings is also provided.

1. *The nature and extent of poor drainage in the Erap—Leron area*

Surplus water on the valley floor is derived from four main sources.

(i) Direct rainfall;

(ii) Surface runoff from lands located upslope, especially the foothill catchments;

(iii) Seepage along the base of the piedmont, also derived mainly from foothill catchments; and

(iv) Radial subsurface flow and seepage from the main cross-valley streams.

It is not possible to estimate the relative contribution of each source to the condition of poor drainage. However, survey results have shown that large areas of land between the main rivers are subject to the wet conditions, commonly between December and May in most years.

The extent of poor drainage in the Erap-Leron area and the requirement for improvements for purposes of short-term cash cropping activities is indicated in *Table* 1. From this table it can be seen that of the total 39,000 hectares having some suitability for cropping in the Erap-Leron area at least 18,000 hectares (46 per cent) has a requirement for drainage if its productive potential is to be realised. A further 7,700 hectares (20 per cent) might be improved for cropping activities by stategically located drains or the improvement of natural drainage facilities.

The most common feature of poor drainage in the Markham Valley is the occurrence of ground water at shallow depth. Inundation, or very shallow flooding of the land surface, is also prevalent over extensive areas, especially following rains. Another important feature of poor drainage in the Erap-Leron area is the occurrence of highly alkaline soil conditions. Most soils in the Valley contain large amounts of free carbonates, and under poorly-drained conditions these dissolve to give calcium and

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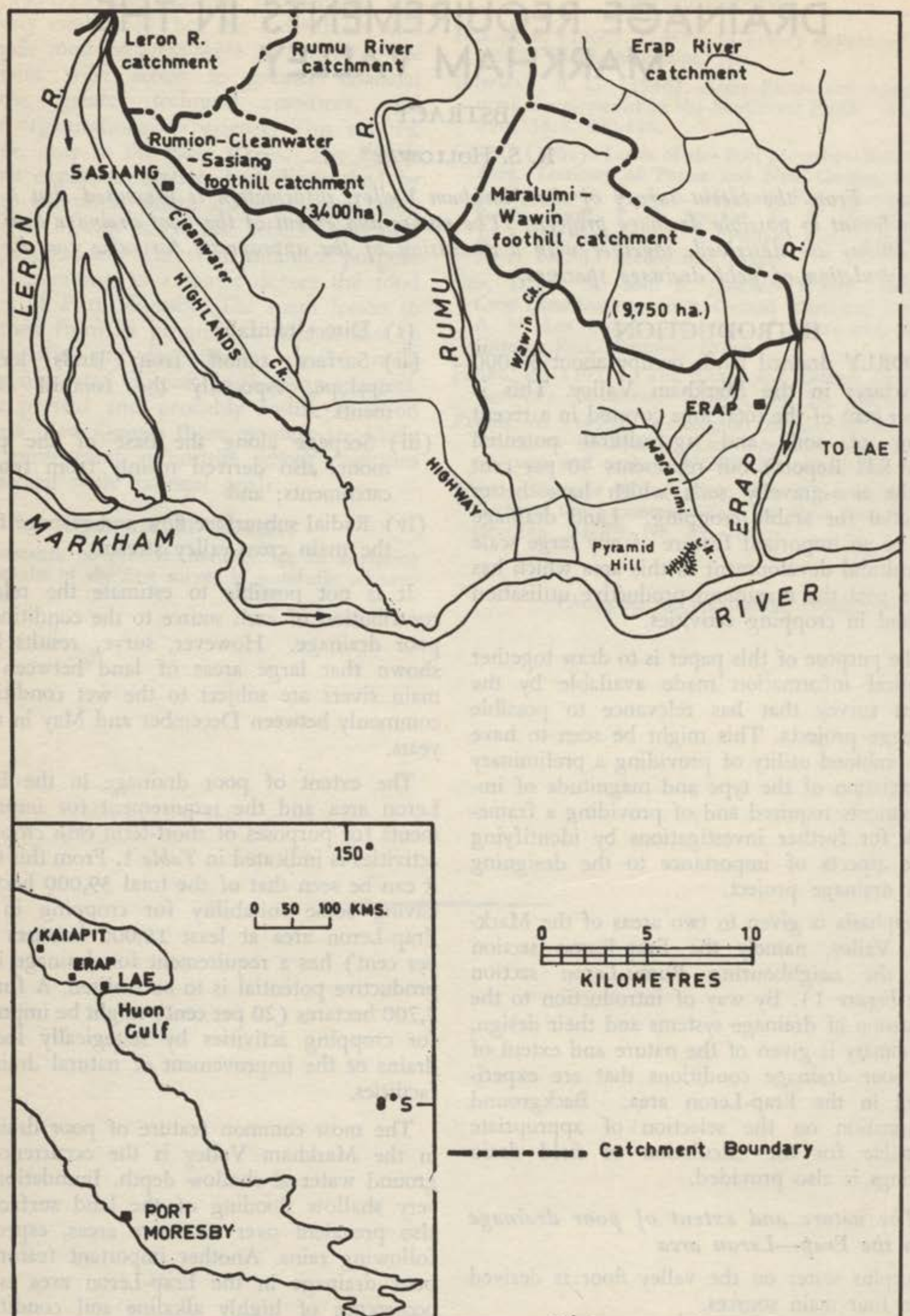

Figure 1.—**Sketch map of the Erap—Leron area of the Markham Valley, showing foothill catchments and major drainage lines.**

Table 1.—Classification of drainage requirements Erap-Leron

Sector	No requirement for drainage	Minor improvements may be necessary	Drainage required for row cropping	Not suitable for row cropping	Recommended not suitable for arable crops	TOTALS
Erap-Ramu (ha)	4,765	1,968	6,686	1,186	1,288	15,893
proportion (%)	30	12	42	8	8	100
Rumu-Leron (ha)	8,541	5,773	11,276	5,829	2,616	34,035
proportion (%)	25	17	33	17	8	100

magnesium bicarbonates. The calcium and magnesium ions displace sodium from the clay exchange sites, resulting in a build-up of sodium bicarbonate. In well-drained soils this sodium bicarbonate is readily leached, but under water-logged conditions it builds up and results in a serious pH rise, especially upon drying. Trace element availability is reduced in alkaline conditions and problems have been experienced with crop nutrition (e.g. rice).

The aims of drainage projects in the Markham Valley would thus be two-fold: firstly the removal of excess water, and secondly the creation and maintenance of soil conditions suitable for cropping.

2. *Selection of formulae for calculating spacings of field drains.*

Most drain spacing formulae have been developed on the basis of steady-state flow conditions i.e. continuous steady rainfall, discharged uniformly by drains and with a state of equilibrium between supply and discharge. It will be apparent that this situation does not occur in practice, especially where the poorly-drained condition derives from seasoned yet variable rainfall, surface run on and subsoil seepage. The non-steady state condition is characterised by rising and falling watertables such is common throughout most of the poorly drained lands in the Markham Valley. Despite this fact W.F.J. van Beers (1965) indicates that the use of a steady-state formula is in many cases entirely justified, especially since the hydrological constants are difficult to define with accuracy for non-steady state formulae.

In order to calculate the required drain spacing in a given hydrological situation, the required intensity of the drainage system should be known. This drainage intensity is given in quantitative terms by the drainage design criteria.

For a steady-state formula, the drainage design criteria for a given drain depth are the maximum permissible height of the ground water midway between the drains and the corresponding projected discharge. The design discharge (q) is determined by the mean rainfall distribution; the available hydraulic head (h) being determined by the depth of the drains and the minimum permissible depth of the ground water. The latter is an agronomic criterion and for arable cropping in the Markham Valley 0.5 m is considered to be a suitable value. For natural grassland and improved pastures a lower value might be acceptable, but since cropping rotations are a desirable feature of land use in the valley, the design should be based on the enterprise having the greater requirements.

For the non-steady formula the drainage intensity is determined by the required fall in the watertable over a chosen number of days, starting from a given unacceptable level.

One of the most important factors affecting the flow of ground water into a drainage system is the position of an impermeable layer (or 'barrier layer') with respect to the drains. Different drain spacing formulae are applied for different locations of the impermeable layer, and the first problem is thus to define the soil conditions so that the appropriate formula can be selected.

In general terms it can be stated that the deeper the impermeable layer, the smaller will be the horizontal resistance and the greater will be the radial resistance component of the total flow resistance which determines drain spacing. Also, the smaller the horizontal resistance factor, the greater can be the drain spacing for equivalent effectiveness in ground water removal.

There is insufficient deep soil data available from the Markham Valley to enable accurate definition of particular soil profile conditions in any given area. Drain spacing calculations have thus been undertaken for both extremes of the range of likely conditions.

METHODS AND RESULTS

1. *Estimation of surplus water derived from foothill catchments*

Water from the small foothill catchment on the northern side of the valley contributes to the condition of poor drainage on the valley floor because few of the streams have direct channel access across the valley to the Markham River. Most of the water from these streams goes underground on the piedmont and may re-appear in seepage zones at some point down slope, or may contribute directly in inundation of the surface at relatively low lying points in the landscape.

Rainfall records from Erap (20 yrs) and Sasiang (9 yrs) were used for the purpose of estimating the general magnitude of discharges from two such catchments:

(i) Maralumi-Wawin foothill catchments; and

(ii) Rumion-Cleanwater-Sasiang foothill catchment (see *Figure* 1).

Weekly totals of rainfall registrations from Erap and Sasiang were processed under 'WATBAL', (Keig and McAlpine 1969), a computer system designed by officers of CSIRO for the estimation and analysis of soil moisture regimes. Results provided an estimate of the amounts of surplus water after allowing for evaporation, transpiration and soil storage requirements (Appendix I.) These surpluses were determined on a weekly basis throughout the period of rainfall records.

Surpluses indicated for Erap and Sasiang were combined in order to judge the magnitude of discharges according to selected frequencies of occurrence (*Table* 2 volumns 1 and 2 A). An inspection of daily rainfall registrations at both stations enabled a probability estimate of surpluses on a daily basis according to amount. In these instances the surplus was taken to be 10-15 mm below the corresponding daily rainfall quantity (*Table* 2—columns 1 and 2 B). Discharge estimates given in *Table* 2 were obtained by directly relating these calculated surpluses to the area.

2. *Field drainage*

Calculation of theoretical spacing requirements for a range of conditions on agricultural land.

A. *Choice of formulae*

(a) Formula for calculating drain spacings in a homogeneous soil with impermeable layer at great depth

$$h = \frac{qL}{K} \ln \frac{L}{u}$$ (Ernst 1954, Toksoz and Kirkham, 1961; cited in van Beers, 1965).

h = height of the watertable above drain level midway between the drains (metres).

q = rate of rainfall or drain discharge per m^2 of area drained (m^3/m^2/day = m/day).

L = spacing of drains measured between centres (metres).

K = hydraulic conductivity (m/day).

ln = log..........., (2.3 $\log_{10}$ ....).

u = wetted perimeter of drain (metres).

Table 2.—Water surpluses and estimated discharges from foothill catchments

Frequency of occurrence (Years)	Surplus water	Discharge from catchment (millions of cubic metres): Maralumi—Wawin (area 9,750 ha)	Rumion—Cleanwater—Sasiang (3,400 ha)
		A. *Weekly*	
1 in 1	90 mm	8.8 per week	3.1 per week
1 in 5	110 mm	10.7	3.7
1 in 10	140 mm	13.7	4.8
1 in 20	190 mm	18.5	6.5
		B. *Daily*	
1 in 1	65 mm	6.3 per day	2.2 per day
1 in 5	85 mm	8.3	2.9
1 in 10	105 mm	10.2	3.6
1 in 20	125 mm	12.2	4.3

This is a steady-state formula and can be considered as representing the soil condition presenting the least problems for effective drainage. It has been used in calculating the spacings required on Soil type A as shown in *Tables* 3 through 6.

(b) Formula for calculating drain spacings in a homogeneous soil with an impermeable layer at shallow depth (less than $\frac{1}{4}$ of the distance between the drains)

$$h = \frac{qL}{8K_1D_1} + \frac{qL}{K_1} \ln \frac{Do}{u}$$

(Ernst 1954; cited in van Beers 1965).

K_1 = hydraulic conductivity in layer of thickness D_1 (m/day).

Do = thickness of layer for which the radial resistance is calculated. Water level to layer of different permeability (metres).

D_1 = average cross-section for the horizontal component. (D_1 = Do + 0.5 h) (metres).

Other parameters as described above.

This also is a steady-state formula and has been applied in this current work to represent the most difficult conditions expected in the Markham Valley. It has been used to calculate spacings on Soil type B in *Tables* 3 through 6.

(c) Formula for calculating drain spacings for transient flow conditions in a soil with an impermeable layer at shallow depth (less than $\frac{1}{4}$ of the distance between the drains).

$$j = \frac{VL^2}{\pi^2 KD}$$

(Glover/Dumm, 1954; cited in van Beers, 1965).

where $D = Do + \frac{ho + ht}{4}$.

j = reservoir coefficient (in days). Incorporates main hydrological properties of a given situation.

V = volume fraction of pores drained at a falling watertable. This can be estimated by $V = \sqrt{K}$, where K is in cm/day and V is expressed in ratios by volume.

ho = midpoint watertable height at beginning of drainout period (metres).

h_t = midpoint watertable height at end of drain-out period (metres).

Other parameters as described above.

Table 3.—Spacing required for the drainage of soils having moderate permeability (3 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains: 0 m	0.5 m	0.75 m	1.0 m
0.004 metres/day (5n in. per month)	A	150	114	90	66
	B	78	60	51	40
0.008 metres/day (10 in. per month)	A	90	66	52	38
	B	54	42	35	28
0.016 metres/day (20 in. per month)	A	52	38	30	22
	B	37	29	24	19
0.024 metres/day (30 in. per month)	A	38	26	22	18
	B	30	23	19	15

Table 4.—Spacing required for the drainage of soils having moderately rapid permeability (8 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains: 0 m	0.5 m	0.75 m	1.0 m
0.004 metre/day (5 in. per month)	A	340	255	200	143
	B	130	100	84	67
0.008 m/day (10 in. per month)	A	200	143	115	83
	B	91	70	59	47
0.016 m/day (20 in. per month)	A	115	83	67	47
	B	63	49	41	33
0.024 m/day (30 in. per month)	A	83	60	47	35
	B	51	39	33	26

This is a non-steady state formula and has been used to enable comparison of results from the steady-state formula for different

Table 5.—Spacing required for the drainage of soils having rapid permeability (15 cm/hour) using ditches 1.5 metres deep (metres)

Amount of water to be removed per unit area (q)	Soil type	Depth to watertable midway between drains			
		0 m	0.5 m	0.75 m	1.0 m
0.004 metres/day (5 in. per months)	A	600	440	345	245
	B	150	134	116	93
0.008 m/day (10 in. per (month)	A	345	245	190	140
	B	122	98	82	65
0.016 m/day (20 in. per month)	A	190	140	108	77
	B	85	66	57	45
0.024 m/day (30 in. per month)	A	140	98	77	57
	B	70	55	46	37

Table 6.—Spacing required for field ditches 1 metre deep to draw watertable 0.5 metres below land surface (metres)

Permeability	Soil Type	Amount of water to be removed (m/day)			
		0.004	0.008	0.016	0.024
Moderate 0.72m/day (3 cm/hour)	A	60	34	20	16
	B	38	26	17	13
Moderately rapid 1.92 m/day (8 cm/hr)	A	132	76	42	32
	B	65	45	31	24
Rapid 3.60 m/day (15 cm/hr)	A	230	128	71	52
	B	91	63	43	35

drainage conditions. It has been used in the calculation of drain spacings required on Soil type A and Soil type B is shown in *Table* 7.

B. *Parameter values*

(a) Height of watertable above drain level midway between the drains, h (meters). Drain spacings were calculated for drain depths of 1.5 m and 1.0 m using the steady-state formula.

Four values of h were applied, as follows:—

Drain depth	h values	Watertable depth
1.5 m	1.5 m	0.0 m (surface)
1.5 m	1.0 m	0.5 m
1.5 m	0.75 m	0.75 m
1.5 m	0.5 m	1.0 m
1.0 m	0.5 m	0.5 m

For the transient flow formula two drain depths were also used. Values for ho and ht were taken as follows:—

Drain depth	Value ho	Value ht	Watertable depth
1.5 m	1.5 m	1.0 m	0.5 m
1.0 m	1.0 m	0.5 m	0.5 m

Table 7.—Required spacing of field ditches to lower the watertable from the surface to 0.5 metres in stated period of time (metres)

Permeability	Soil type*	Time required to lower watertable by 0.5 metres at end of wet conditions			
		Drain depth = 1.5 metres		Drain depth = 1.0 metres	
		5 days	10 days	5 days	10 days
Moderate 0.72 m/day (3 cm/hr)	A	70	120	45	80
	B	45	64	35	52
Moderately rapid 1.92 m/day (8 cm/hr)	A	105	170	65	115
	B	58	83	46	67
Rapid 3.60 m/day (15 cm/hr)	A	130	210	85	150
	B	68	97	55	80

*In this case Soil Type A does not have an impermeable layer 'at great depth', but at 20 metres below the base of the drains. This enables a spacing correction to be applied to the transient flow formula (van Beers, 1965). Results however, can be realistically compared with those determined for Soil Type A according to the steady-state formulae.

In both cases the watertable depth refers to the vertical distance from soil surface to ground water at a point midway between the drains, and under transient flow conditions this depth will prevail at the end of the drainout period.

(b) Drainage coefficient, q (metres per day, or more completely m^3/m^2/day. Rainfall data from eight stations in the valley reveal average monthly totals ranging from less than 30 mm to greater than 350 mm depending on time of the year and station location. Wet season conditions commonly range between 120 mm and 250 mm per month. In the Markham Valley the poorly drained condition also arises because of surface run-on from land located upslope, and from sub-surface seepage from minor catchments and the main rivers. The relative contribution of the various sources cannot be estimated, but it is reasonable to assume that the seepage and run-on components are highest in those areas classed as poorly and very poorly drained on the maps accompanying the report of the recent survey of soils and agricultural potential (D.A.S.F. Report).

Drain spacing calculations were made for four values of q, as follows:—

q value	mm. per month	Approx. inches per month
0.004 m/day	120	5
0.008 „	240	10
0.016 „	480	20
0.024 "	720	30

(c) *Hydraulic conductivity, K (metres per day)*

The auger-hole method of determining average permeabilities (van Beers 1970) was applied to a limited number of soils in the Markham Valley. Results suggested that the classes moderate and moderately rapid (0.48 to 3.0 m/day) are most common and that the slow categories (less than 0.12 m/day) are rare. In the absence of detailed permeability data for specific soil types, three values of K were chosen and computations for drain spacings made for each condition.

K value	permeability rate	permeability class
0.72 m/day	3 cm/hour	moderate
1.92 m/day	8 cm/hour	moderately rapid
3.60 m/day	15 cm/hour	rapid

(d) *Drain dimensions*

Depth of drains, and the wetted perimeter (u) are also important determinants of drain spacing. Drain dimensions are dependent on soil engineering factors and economic considerations. Deeper drains allow wider spacing but are more costly to establish and maintain. Drain spacings in this paper have been calculated for two different drain sizes: 1.5 m (u = 1.0 m) and 1.0 m (u = 0.6 m).

(e) *Depth to impermeable layer for determination of D, Do & D_1*

Results of ground water drilling on river fans in the Markham Valley reveal that water occurs in porous beds lying immediately above relatively impermeable layers. A number of such layers is commonly encountered at any one drilling site. Limited deep augering information obtained during the recent land resources survey suggests a very complex inter-relationship between coarse, medium and fine textured materials in different geomorphic locations in the valley. Detailed survey work will be necessary in order to identify profile hydrological characteristics for site-specific drain spacing determinations.

Drain spacing calculations have been made using two assumptions with respect to the depth of an impermeable layer: viz. 3.7 metres (approx. 12 ft); and 'at great depth'. Allowances are made for drain depth in the calculation of D values where these are required by the drain spacing formula.

C. *Results of calculations to determine spacings of field drains*

The spacings indicated in *Tables* 3 through 7 represent both extremes of the range of likely soil conditions. Soil type A is assumed to be homogeneous and has no impermeable layer within the top 20 metres. Soil type B on the other hand is assumed to have an impermeable layer at shallow depth, 3.7 metres.

3. *Field drain design capacity and rainfall surpluses at various locations*

Drain spacing requirements as determined by steady-state formulae are based on assumptions as to the amount of water to be removed by the drains (q). This drainage coefficient is expressed in metres per day which is the same as cubic metres per square metre of area drained per day.

Calculations have been made to test the adequacy of different design capacities of the field drain system in coping with water surpluses expected at various locations in the valley.

Rainfall records from seven stations were processed by 'WATBAL' and week by week estimates of water surpluses were determined after having allowed for evaporation, transpiration and soil storage (see Appendix I). Surpluses thus derived were compared with the amounts of water removed under three possible design discharges of the field drain network. The three values used were 0.004, 0.008 and 0.016 metres per day. These are the same as were applied in calculating drain spacings in part 2 above.

For purposes of the calculations, a week was considered to be a "high watertable week" if the surplus for that week exceeded the design discharge. Similarly, high watertables were said to occur for at least two weeks if the total amount of surplus in two consecutive weeks exceeded twice the design discharge. Results are shown in *Table* 8.

DISCUSSION

The estimates of quantities discharged from the foothill catchments as shown in *Table* 2 are only approximate. Although run-off collection and recession times are expected to be fairly short in these catchments, the use of daily surpluses for calculating daily discharges could well over-state the peak flow. Weekly values should be more in line with actual conditions. On the other hand rainfall in the foothill catchments is known to be higher than that over the valley centre. The use of Erap rainfall data as the major component of the surplus estimates thus to some extent under-states the magnitude of the surpluses at all frequency levels.

Figures in *Table* 2 demonstrate that large amounts of water are discharged onto the valley floor from the foothill catchments. This suggests that a drainage project for agricultural development in these areas should include in its basic design, facilities for the efficient collection and disposal of water from these sources.

Table 8.—**Occurrence and duration of high watertables between drainage ditches**

	Station	Estimated occurrences per 10 years according to duration in weeks			
		>1 week	>2 weeks	>3 weeks	>4 weeks
Drainage system designed to remove 0.004m/day (110 points per week)	Erap	23	4	1	1
	Sasiang	65	23	12	6
	Leron	56	18	8	4
	Kaiapit	151	59	30	18
	Mutsing	86	34	18	10
	Gusap	103	38	19	11
	Dumpu	116	46	26	15
Drainage system designed to remove 0.008m/day (220 points per week)	Erap	12	2	1	0
	Sasiang	35	12	5	2
	Leron	24	5	2	1
	Kaiapit	101	35	19	12
	Mutsing	52	16	10	6
	Gusap	51	14	8	3
	Dumpu	66	25	12	10
Drainage system designed to remove 0.016m/day (440 points per week)	Erap	1	0	0	0
	Sasiang	9	1	0	0
	Leron	5	1	0	0
	Kaiapit	28	7	2	1
	Mutsing	12	2	0	0
	Gusap	10	0	0	0
	Dumpu	8	0	0	0

1. *Surplus Disposal System*

Planning for the location and design of channels in the Markham Valley environment will be a complex exercise. Water levels in the disposal channels for instance should be maintained below the desired ground water level on the neighbouring arable land. In determining this level in the disposal channel a possible criterion might be the ninth decile of daily discharges during the months January to March. If this level was made equal to the desired ground water level on the nearby cropping land there would be little risk of lateral dispersion of water and salts.

Another important factor in channel design is land gradient. Information obtained during the recent survey of land resources has enabled a contour map to be prepared covering all the poorly drained land located between the Erap and Leron Rivers. Estimates of gradients can be obtained from these maps and used by engineers in the preliminary stages of drainage investigations. Field traverse data are available for poorly drained zones west of the Leron River, but contour maps have not been prepared. In general terms the land gradient is about 1.0 per cent near the base of the piedmont and reduces gradually to about 0.3 per cent close to the Markham River.

Channel design will need to take into account a critical velocity of flow. This is the speed at which the material of the bed and banks is not quite set in motion. It depends on the soil type (mainly texture) and the degree of protection (by vegetation). Under conditions of high discharge, considerable quantities of silt and sand will be suspended in the water. Design specifications will be of major importance in determining how much of this material will be transported through the system, and how much will be deposited within the drains and thus necessitate expensive maintenance work.

A further aspect in channel design is the inclination of side slopes. For example, collection drains near the base of fans will receive considerable water by seepage. Side slopes must be designed flatter to allow for this, and mechanical properties of the soil will need to be investigated. Also, if cattle have access to the drain or if there is a roadway along the edge of the channel, flatter side slopes will be required. On the other hand the large variations in flow from week to week and season to season will enable dense grass cover to establish on the channel banks and this will enable a slightly steeper design of side slopes. Soil texture variations especially near the base of the piedmont will mean the choice of flatter slopes on channel banks than would be required for channels located in the finer textured basin sediments.

In general terms the steeper the hydraulic gradient and channel side slopes, the less earth moving will be required and the cheaper will be the construction of the surplus disposal system. Given the constraint of critical velocities however, as can be expected in the Markham Valley environments, the permissible hydraulic gradient decreases with increasing discharge.

By application of the Manning formula (Appendix II) and taking into account the factors mentioned above, two suggestions concerning disposal design can be made.

(a) Channel design might be expected to alter along its length from a shallow, board vegetated waterway with a flood levee on the downslope side near the base of the piedmont, to a progressively deeper channel with steeper side slopes closer to the Markham River.

(b) A surplus disposal system for the Rumion-Cleanwater-Sasiang catchment could comprise two collection drains and one main channel. Collection drains could originate in the vicinity of map units 156 and 130 (D.A.S.F. Report), and some modification of Cleanwater Creek would be necessary to facilitate the removal of water.

Surplus disposal from the Maralumi-Wawin catchment on the other hand should comprise at least two main cross-valley channels rather than one. This would reduce the requirements for extensive modification of the existing Maralumi Creek channel. One system worth investigation would be the channelling of Wawin Creek from the base of its fan in a south-westerly direction into the Rumu River, or alternatively in a south-easterly direction for outfall into the Markham River near the western end of Pyramid Hill. Maralumi Creek could then be modified to become a disposal channel for collection drains located near the base of the piedmont and extending from map unit 17 in the north-east and the vicinity of map unit 41 in the north-west (D.A.S.F. Report).

From *Table* 2 it can be seen that large differences can be expected between normal wet season flow and peak flow requirements. This suggests that a composite channel cross-section might be cheapest, and the use of flood levees might also be considered. Further, the requirement of the surplus disposal system to cope with occasional high discharges poses problems for this system's integration with a field drainage network. Field drainage outfall into a main disposal channel would need to be located sufficiently downslope to prevent the banking back of water at periods of high discharge. Alternatively, or in addition, separate outfall points to the Markham or other rivers should be considered.

2. *Field Drainage*

The field drainage network would be required to remove excessive rainwater and subsurface seepage. A primary objective would also be to maintain the net movement of water in a downward direction through the soil so that chemical limitations for agriculture will be minimised. This downward movement will result in the leaching of sodium and bicarbonate ions, the main causes of nutritional problems in crops grown in these areas. Whilst bicarbonates will continue to come into solution it is thought that their concentration in equilibrium with calcium and magnesium ions will not cause nutritional problems to the same degree as when sodium is present.

Crops vary in the extent to which they can tolerate wet conditions, or soil and ground water alkalinity. Peanuts and sugar cane for instance will not grow whilst watertables are near the surface (cf. rice). On the other hand rice will not tolerate the strongly alkaline soil conditions such as is known to occur in the area between the Erap and Leron Rivers (cf. grain sorghum). It is clear that in order for engineers to be able to make a decision on drainage system design, it will be necessary to specify the purpose for which the land will be required.

For known agronomic requirements with respect to watertable depth, the most important factors determining the appropriate spacing of field drains are the amount of water to be removed, soil permeability, presence and location of a 'barrier' layer and the drain dimensions. Assuming that a drainage project in the Markham Valley would be designed with an adequate surplus disposal capacity, it is then possible to use the results of *Table* 8 as a rationale for selecting a design capacity in the light of agronomic requirements. This can be seen to vary for different locations in the valley. For example, at Erap an appropriate design capacity might be $q = 0.004$ metres per day, whereas in the Cleanwater area (Sasiang) a similar order of control might require a design capacity closer to $q = 0.008$ metres per day. Similar control in the vicinity of Mutsing, Gusap and Dumpu might be achieved with a design capacity of $q = 0.011$ metres per day, and at Kaiapit, 0.016 metres per day.

The drain spacings indicated in *Tables* 3 through 7 demonstrate clearly the importance of hydraulic conductivity. Detailed tests will be needed to enable the selection of suitable values for different soil units. It will also be necessary to investigate the drainage condition and water movement in the soil at depth. For all soil types the presence of an impermeable layer within the top 15 metres or so can have an important effect on drain spacing. In the case of an impermeable layer at very shallow depth, say 4 metres, twice as many drains might be required for efficient water removal in the Erap-Leron area than if the soil has no relatively impermeable layers.

Drain dimension is another important aspect. Deeper drains permit wider spacing as can be seen from *Table* 7. The choice of drain depth depends mainly on economic factors but also on the position of suitable soil layers, the level of available outlets and the salt content of the ground water.

Results from *Tables* 3 to 8 enable a generalised statement to be made concerning the spacing of field drains. In the Erap-Rumu area for instance, assuming a design discharge of 0.004 metres per day, and a drain depth of 1.5 metres, it should be possible to place drains at a distance up to 100 metres apart on the finer textured soils having moderate permeability. On medium textured soils about 160 metres would be satisfactory and on the rapidly permeable or moderately well-drained soils distances up to 300 metres could be used. For the area between the Rumu and Leron Rivers rainfall records indicate a higher design discharge for field drains although the requirement for surplus disposal is not as high as in the Erap-Rumu area. Using $q = 0.008$ and drains 1.5 metres deep it would appear that drains should be placed about 70 metres apart on clay-loam and clayey soils, about 120 metres apart on the loamy soils and 200 metres apart on the sandier sites.

CONCLUSIONS

A. *Surplus Disposal*

1. Large quantities of water are discharged onto the valley floor from foothill catchments along the northern margin of the valley. In this paper an example has been made of two such catchments: the Maralumi-Wawin (located between the Erap and Rumu Rivers) and the Rumion-Cleanwater-Sasiang foothill catchment (between the Rumu and Leron Rivers). A system for the collection and disposal of this water would be an essential component of any drainage project which aims to release for cropping purposes a large proportion of the seasonally poorly drained land.

2. The design of surplus disposal systems for the Markham Valley environment will require detailed investigations. Basic information is already available on land gradients in the Erap-Leron area and the results of climatological analyses also in hand will assist in the selection of normal and peak flow design requirements. Fieldwork will be needed to determine the distribution of discharges along the mountain front and to relate actual flows to measured rainfall (both on site and at stations with longer records).

Other important factors to be investigated include the water levels of disposal channels in relation to groundwater in neighbouring crop land, velocities of flow and channel cross section features such as side slope inclination, composite sections and the use of levees.

3. Preliminary estimates of discharge and capacities of surplus disposal channels suggest that two cross-valley channels may be required in the Erap-Rumu area, and that one would be sufficient in the Rumu-Leron area. Calculations also suggest that channel design might be expected to change from shallow vegetated waterway near the base of the piedmont to a propressively deeper channel with steeper side slopes nearer the Markham River. Since large differences are expected between normal and peak flow requirements of the disposal channels, the use of composite channel sections and flood levees needs investigation. There may also be problems for the integration of field drainage systems because of the risks of flooding arable land at times of high discharge in the disposal channels.

B. *Field Drainage*

4. Surplus water from direct rainfall and soil chemical conditions necessitate a field drainage system being implemented in conjunction with a surplus disposal system if large areas of poorly drained land are to be cropped during December to May inclusive.

5. Climatological and soil survey investigations have enabled some general statements to be made on the order of drainage required on different soils and at different locations in the valley. Climatological work for instance has shown that the design capacity will change from place to place along the valley. Soil survey has indicated a range of hydraulic conductivities for different soils and the distribution of poorly drained lands. It has also shown the extent of areas most severely affected by excessive bicarbonates and sodium. Interpretation of this work in terms of the reclamation (drainage) requirement however, is limited by the lack of specific data on hydraulic conductivity, and lack of information on water movement (soil characteristics) at depths between 1.5 metres and about 15 metres.

6. Detailed investigations into agronomic requirements and economic factors in addition to the abovementioned engineering factors will be needed before a field drainage system or total drainage project can be designed for any particular area of the Markham Valley.

ACKNOWLEDGEMENTS

Suggestions given by Mr D. Legger, Dr M. J. Knight, Mr J. M. Brigatti and Mr A. McGrigor of D.A.S.F. Land Utilization Section are acknowledged. Thanks are also due to Mrs G. Keig and Mr J. R. McAlpine of CSIRO for their guidance in computer processing.

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(Accepted for publication November, 1973.)

APPENDIX I

DETERMINATION OF WATER SURPLUSES*

1. ***Parameter values***

(*a*) Rainfall (NRAIN)—weekly totals of station registration.

(*b*) Evaporation (EVAP)—estimated from mean maximum temperature daylength and vapour pressure data by method of Fitzpatrick, 1963.

(*c*) Maximum soil moisture storage (MAXST)—100 mm.

(*d*) Transpiration (PETCF)—constant potential rate of 80 per cent of weekly evaporation.

(*e*) Actual evapotranspiration (AETCF)—100 per cent of potential rate until soil storage falls below 50 per cent of maximum. Then 50 per cent of potential rate.

2. *Method*

a) Water demand for week N, ($NDMD_N$):

$$NDMD_N = AETCF_N \times PETCF_N \times EVAP_N$$

b) Soil moisture storage for week N, ($NSTR_N$):

$$NSTR_N = (NSTR_{N-1} + NRAIN_N) - NDMD_N$$

Note: If $NDMD > NSTR_{N-1} + NRAIN_N$ then $NSTR_N = O$

c) Surplus water for week N, ($SPLS_N$):

$$SPLS_N = NSTR_N - MAXST,$$

when $NSTR > MAXST$

Recorded $NSTR_N$ value for the subsequent week of estimate = MAXST.

* Source: Keig, G., & McAlpine, J.P. (1969).

APPENDIX II

FORMULA FOR CALCULATION OF DISPOSAL CHANNEL CROSS SECTION*

For vegetated and rough-bed channels the empirical formula of Manning is appropriate:

$$V = K_M R^{2/3} S^{1/2} \; ; Q = V A$$

V = average velocity of flow (m/sec.)

K_M = a coefficient related to bed roughness ($m^{1/3}$ sec.)

R = hydraulic radius of cross-section (m)

S = gradient of channel (dimensionless)

Q = discharge (m^3/sec.)

A = cross sectional area of flow (m^2)

* Source: Int. Inst. Land Recl. Impr., (1964).

Printed and published by E. C. Awo, Government Printer.
Port Moresby.—8380/12.74.