SPECIFICATIONS FOR ENGINEERING A DRAINED AND AERATED ROOT ZONE TO PREVENT WATERLOGGING

Greg Hamilton and Ian Foster
Agriculture WA, South Perth

Introduction

Broad scale studies (Anon. 1989 & McFarlane et al., 1992) indicate that seasonal waterlogging is an extensive and costly problem in the western and southern sections of the WA agricultural area. These studies have estimated that 1 million hectares are affected in a 'wet' year, with an attendant loss of income worth $ 156 million.

Simulation modelling is perhaps the best way to improve our understanding of complex systems where the consequences are either unforeseen or poorly understood. Such modelling, however, can only provide new perspectives on a problem, it cannot solve the problem. Experience has shown that, when models are based on fundamental mechanisms, the perspectives produced often identify very good directions for research and thus hasten the development of improved soil and water management practices (Hillel, 1977).

Our objectives in undertaking this modelling exercise were to:-

a) study the waterlogging process to:
   - gain a better appreciation of the extent of agricultural land and the prone to waterlogging;
   - obtain the basis for an improved costing of production lost from waterlogging;
   - generate a capacity to predict the occurrence of waterlogging for given soils and locations; and
   - identify the better treatments to control waterlogging:

b) study the drainage process to:
   - understand what soil conditions and drain spacings would be required to prevent waterlogging;
   - assess whether the requisite conditions were practically achievable.

In addition, the literature on soil management was reviewed to identify those practices capable of creating and maintaining the soil conditions required for drainage and the prevention of waterlogging

This paper outlines the analyses undertaken and the root zone specifications needed for waterlogging to be prevented on texture contrast soils in Western Australia.

Methods

a) Waterlogging modelling

A one-dimensional daily water balance model was constructed in which the key assumptions are:

- Waterlogging occurs at air-filled pore space < 8% (Wesseling, p. 18 *In* van Schilfgaarde 1974).]
- Drainage to the groundwater system is effectively zero.
- When the A-horizon reaches a moisture content of 0.20 mm^3/mm^3, water drains into the B-horizon at 1 mm/day until a recharge of 20 mm is reached.
- Infiltrating rainfall redistributes in a 24 hr period
- All rain infiltrates up to the total absorption capacity of the soil profile.
- Maximum water absorption capacity of the A-horizon is its total porosity minus 0.03 mm^3/mm^3 entrapped air, plus 5 mm surface detention. A-horizon bulk density is 1.5 g/cm^3.

- All rain in excess of this storage capacity is assumed to runoff.
- Potential evaporation from a wet soil is $0.8E_{pan}$.
- Bare soil evaporation applies until August 31. Thereafter transpiration rates are adjusted relative to soil moisture content and E_{pan}, according to the Denmead & Shaw relationship (1962).

Bare soil evaporation was calculated by the equation of Gardner and Hillel (1972) using a diffusivity function derived from Hillel (1977, pp. 81, 83 & 84). This equation is

$$E_{soil} = \frac{D(\theta) . \theta_{Zw} . \pi^2}{4 Z_w}$$

where: E_{soil} is bare soil evaporation *(mm/day)*; $D(\theta)$ is soil-water diffusivity relationship *(mm^2/day)*; θ_{Zw} is the average soil-water content of the A-horizon *(mm^3/mm^3)* and Z_w is A-horizon depth *(mm)*.

Historical rainfall and pan evaporation data have been used, from 1907 to 1996. The model was run for:

(a) *sand over clay soils* with 100 mm, 200 mm and 300 mm depths of A-horizon; and
(b) *loam over clay soils* with 100 mm, 200 mm and 300 mm depths of A-horizon, for
(c) 33 locations in the southern and western agricultural area of WA.

The frequency of waterlogging on a given day of the year for particular soil types and locations is derived from this analysis. The model also predicts daily changes in soil-water content.

b) Drainage modelling

The Glover equation (van Schilfgaarde, 1974) was used to predict the time taken for a water table (WT) to fall a given distance for the range of soil conditions and drain spacings presented in Table 1, where:

$$t = \frac{L^2 . f_d . \ln [4m_o / \pi . m]}{\pi^2 . K . D}$$

and: t = time (h); L = distance between drains (m); f_d = fractional drainable porosity; m_o = mid-point of initial water table height (cm); m = final midpoint height of water table (cm); K = saturated hydraulic conductivity (cm/h); D = average initial depth of water table to be drained (cm).

Table 1. Soil properties and drain spacings/bed widths used in drainage calculations

Soil property/drain dimensions	Unimproved soil	Improved soil
Bulk density	1,500 kg/m^3	1,400 kg/m^3
Drainable porosity at - 10 cm suction	0.01	0.05
- 20 cm suction	0.01	0.05
Saturated hydraulic conductivity	20 mm/h	50 mm/h
Bed heights	12 cm	13 cm
	24 cm	26 cm
Drain spacing/Bed widths	1.5 m	1.5 m
	2.0 m	2.0 m
	3.0 m	3.0 m
	10.0 m	10 .0 m

Results

The waterlogging model illustrates the dramatic effect of individual rainfall events on soil moisture content, particularly when evaporation is low. When evaporation is between 1mm & 2mm/day, waterlogging is determined by the amount of rainfall and the number of wet days per month, which average 15 days or more in June, July and August. Waterlogging frequency does not decline until September-October when evaporation increases and rainfall decreases (Figure 1.).

The historical frequencies of daily waterlogging on varied soil types (Figures 2) illustrate that (i) shallow A-horizon soils are highly prone to waterlogging in the WA winter; (ii) soils with deeper A-horizons are *marginally* less prone to waterlogging; (iii) the frequency and duration of waterlogging is less in drier sections of the agricultural area; (iv) there is little difference in waterlogging frequency between sand and loam topsoils.

Maps of isolines of daily frequency of waterlogging for the south west section of the agricultural area illustrate (Figure 3.) that June, July and August are the most prone to waterlogging, with July having the highest frequency. These modelling results, when overlain by soil maps of shallow texture contrast soils clearly illustrate that very large sections of the agriculture area are regularly affected by waterlogging.

The results of the drainage analyses (Figure 4.) show that when a 2 day drainage time is used as the minimum time to lower a water table, soil in poor condition requires drains spaced at ~ 1.5 m apart: for soil in good condition, drains may be spaced at ~ 4 m.

Of greater importance, however, is the fact that although the water table may have fallen the required distance, the small drainable porosity does not provide enough air space for plants to avoid suffer the physiological stresses of waterlogging - the soil remains saturated by capillary forces.

A review of published R&D work on the soil physical benefits of no-tillage practices (Table 2.) indicates that the hydraulic conductivity and aeration properties required for water tables to drain rapidly and aerate the soil can be achieved.

Table 2. Changes in soil properties with no-tillage practices

Location, soil physical properties	**Source (ref.)**	**Duration (years)**	**Tillage practice**	
			District practice	**No-tillage**
Ginninderra, ACT	6.	8		
• Hydraulic conductivity (mm/h)			16	54
• Total Porosity (%)			47	54
Tatura, VIC	1.	6		
• Macropores (%)			3	15
Cowra, NSW	9.	6		
• Hydraulic conductivity (mm/h)			14	65
• Total porosity			37	43
Grafton, NSW	5.	14		
• Hydraulic conductivity (mm/h)			28	187
• Total porosity (%)			47	54
• Macroporosity (%)			12	15

Conclusions

- Deepening the topsoil by whatever method may diminish waterlogging in the short term, but without drainage to maintain unsaturated conditions, loosened soil will quickly subside and approach the original, dense waterlog-prone condition.
- Without tillage and traffic, no-tillage crop establishment can create and maintain good soil physical conditions.
- Soil in good condition can have drains spaced as wide as 4 m apart and still avoid waterlogging. In these circumstances machinery track widths can be the determinant of drain spacing.
- Tractors, being the major implement with the narrowest track width mostly determine drain spacing. Commonly this is 1.8 m or 2.0 m.
- Assuming crop rotations allow sustainable and good weed and disease control, it is possible to engineer root zones that will prevent waterlogging.

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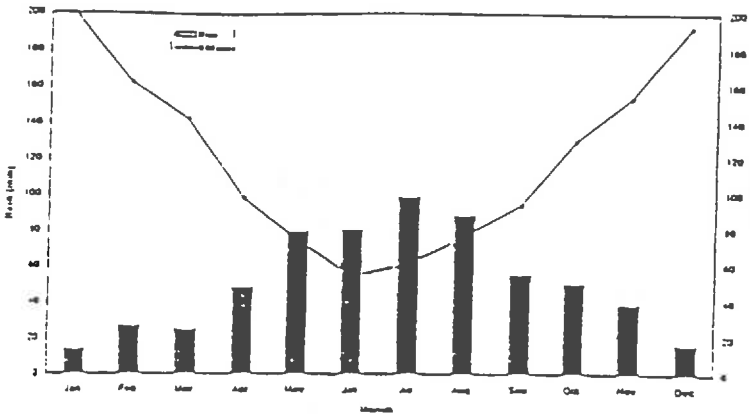
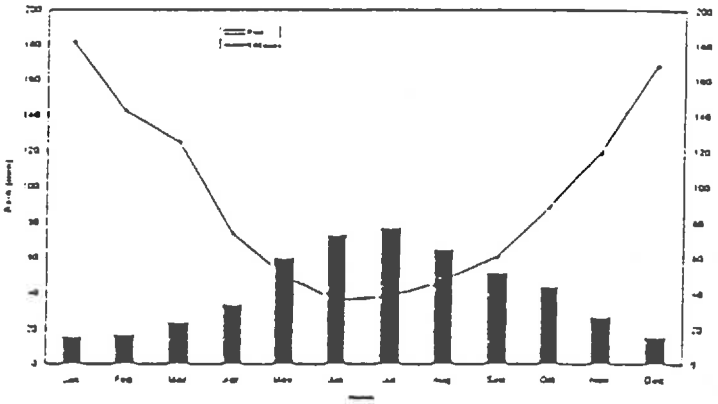
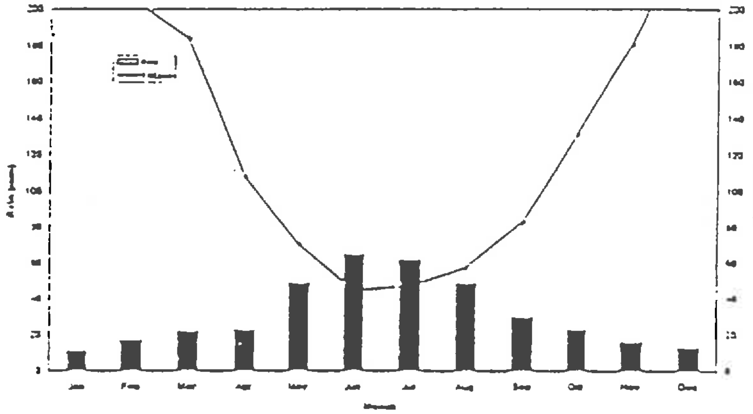
a) Esperance



b) Cranbrook



c) Corrigin



d) Wagin

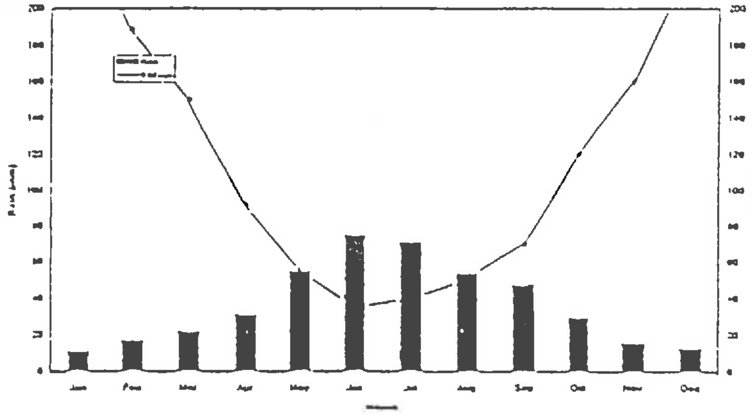
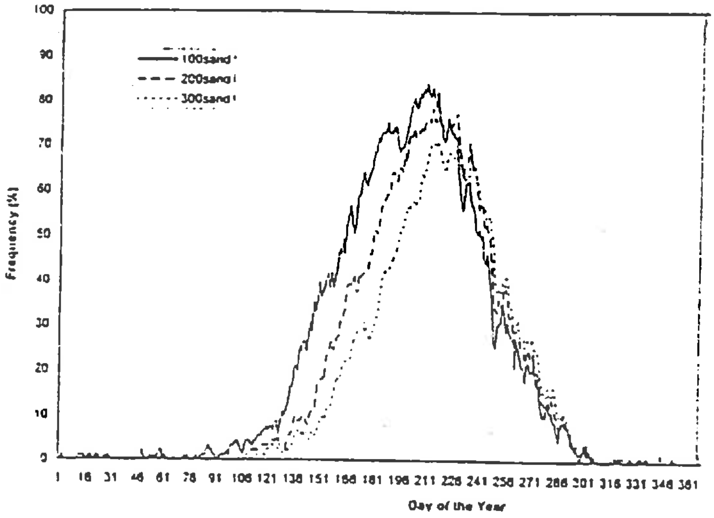
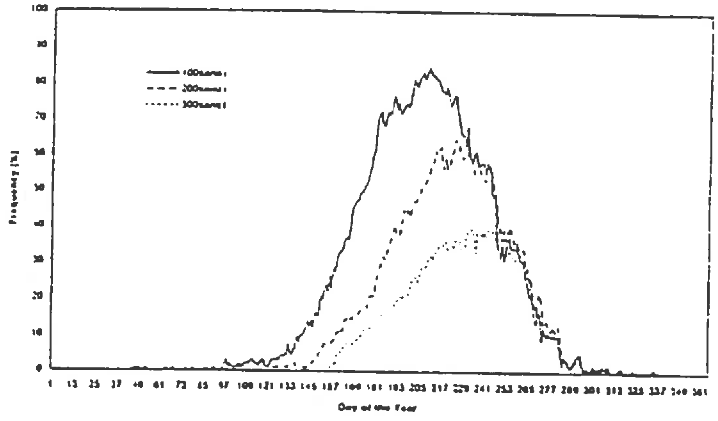


Figure 1. *Long term average rainfall and (0.8) pan evaporation data illustrating the coincidence of winter dominant rainfall with the winter trough of evaporation. The locations shown and the amount of excess rain over evaporation at each site are: (a) Esperance - 80 mm; (b) Cranbrook - 103mm; (c) Corrigin - 35mm; (d) Wagin - 80mm.*

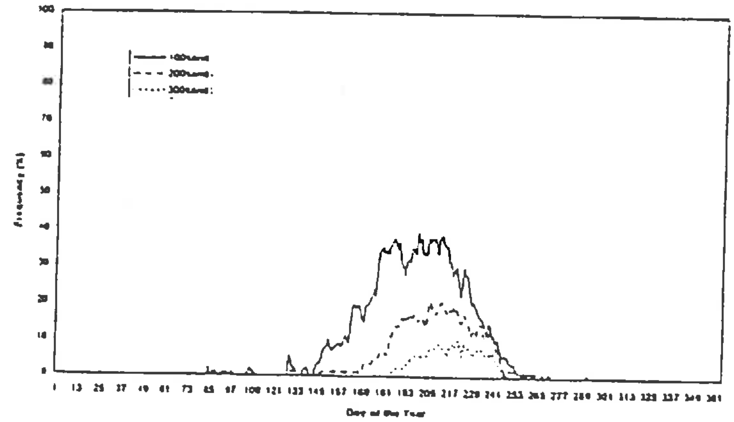
a) Esperance



b) Cranbrook



c) Corrigin



d) Wagin

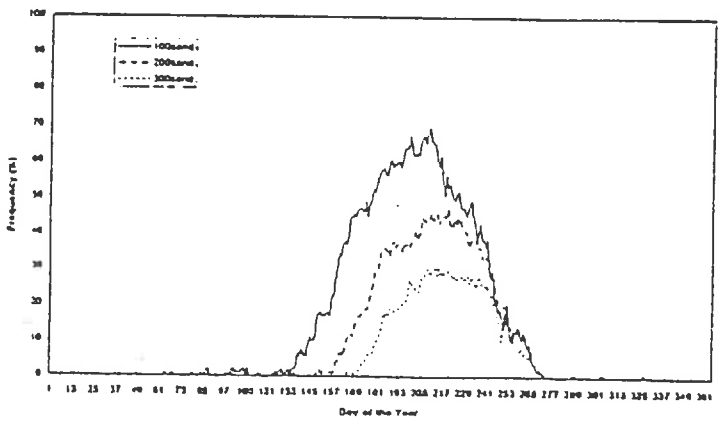


Figure 2. *Predicted daily frequency of waterlogging for sand-over-clay soils with 100mm, 200mm and 300mm depths of sand, for (a) Esperance; (b) Cranbrook; (c) Corrigin; (d) Wagin.*

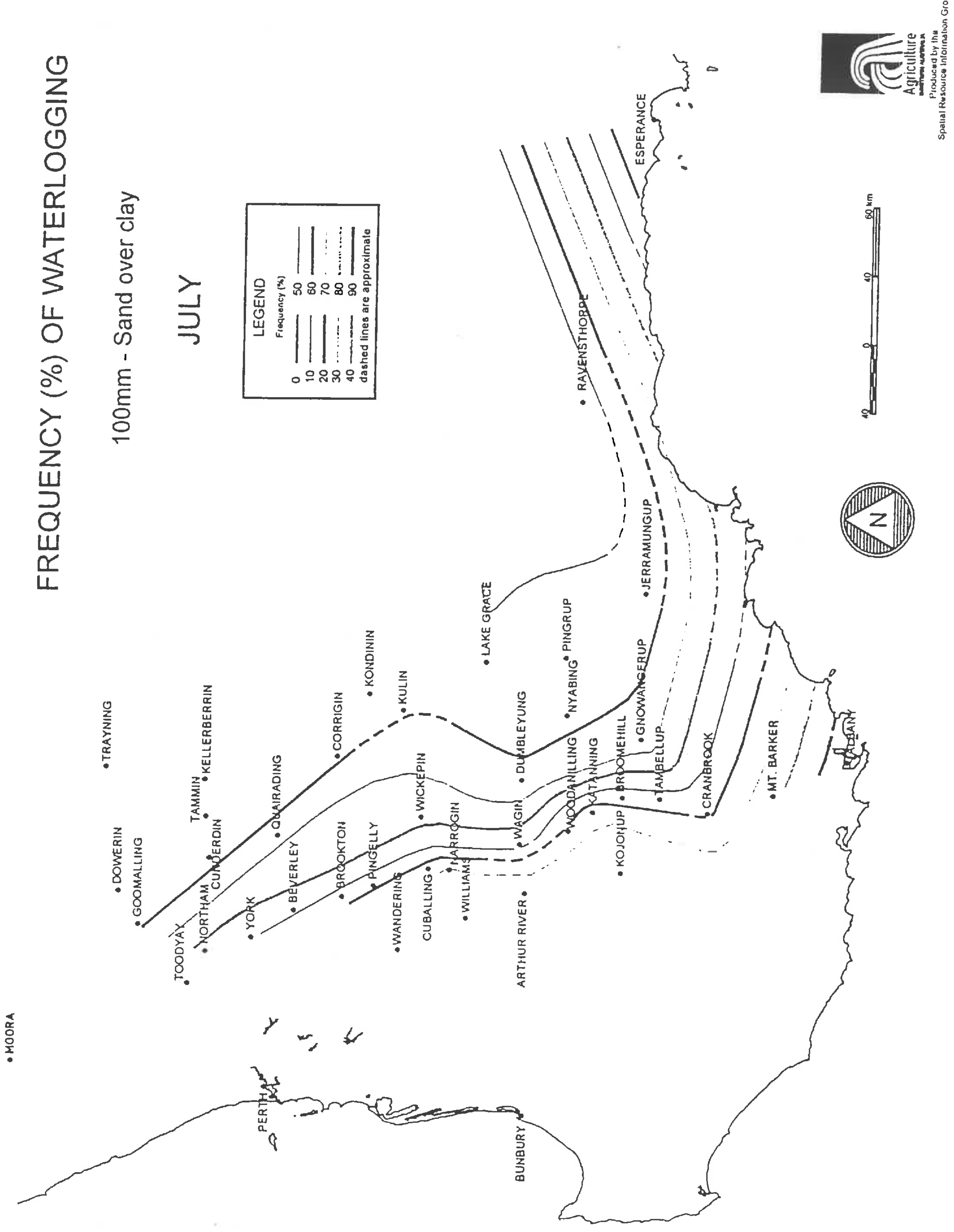


Figure 3. One of a series of maps showing lines of the same frequency of daily waterlogging over much of the WA agricultural area. The data shown are the waterlogging frequency for July 31, for a shallow (100mm) depth of sand-over-clay soil.

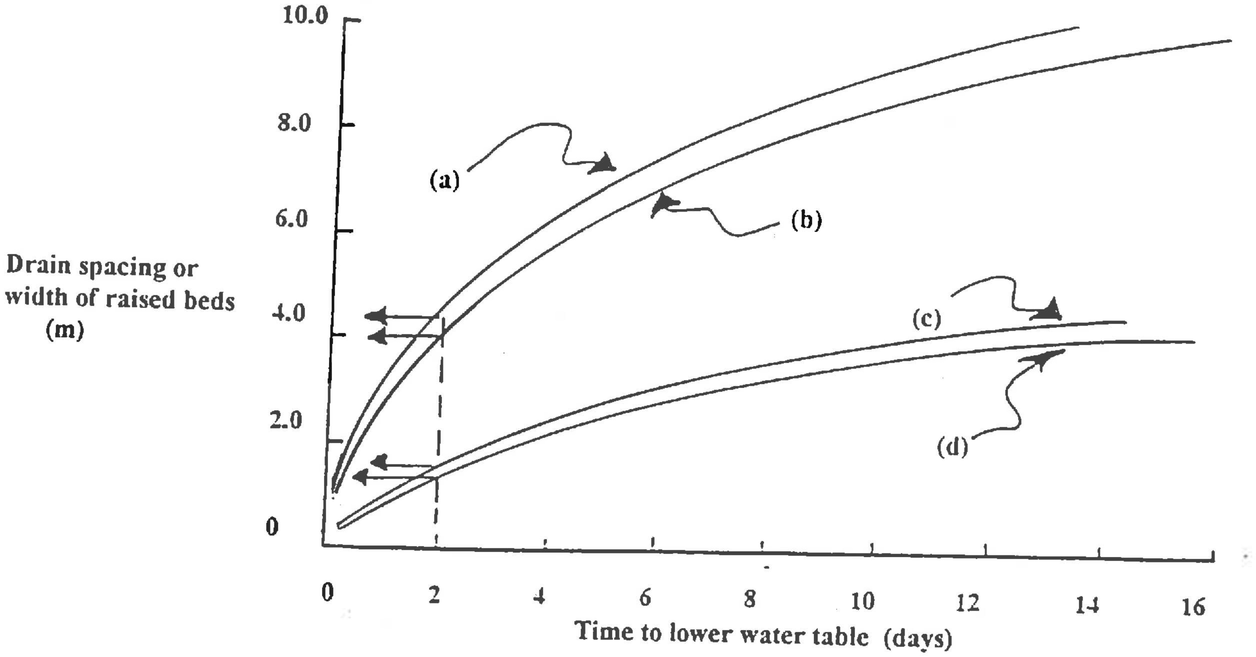


Figure 4. *Relationship between time to lower the water table from the surface of saturated soil and the spacing of drains (or width of raised beds) for: (i) a soil in an improved condition with two bed heights, 13 cm and 26 cm - curves (a) and (b); and (ii) a soil in an unimproved condition with two bed heights, 12 cm and 24 cm - curves (c) and (d).*