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Tree clearing and dryland salinity hazard in the Upper Burdekin Catchment of North Queensland

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Abstract

This paper provides experimental data on the effect of tree clearing, introduction of perennial *Stylosanthes* based pastures, and the use of native grasses on the water balance of a red earth soil in the Upper Burdekin Catchment near Charters Towers. The water balance simulation models SWIM and PERFECT are used to extend the results and estimate deep drainage for this and other soils in this tropical environment. The analysis illustrates that the soil/climate interaction in the wet/dry tropics has a similarity with the winter-dominant rainfall zone where vegetation change can substantially increase deep drainage beyond the root-zone. Salt distribution in the soil/landscapes of the Upper Burdekin suggests that there is a salinity hazard, should a significant shift in the water balance occur as a result of tree clearing. Therefore, in the Upper Burdekin Catchment of North Queensland, indiscriminate tree clearing is a hazardous form of land management and should only proceed after the risks of dryland salinity have been evaluated and shown to be negligible.

Additional keywords: soil water balance, deep drainage, dryland salinity hazard, Burdekin Catchment.

Introduction

It is recognised that inappropriate tree clearing over the past 200 years has contributed to much of the dryland salinity which is now widespread in southern Australia. In the woodlands of the seasonally wet/dry tropics of Australia, however, tree clearing is still seen as an important land management tool to increase production in the beef cattle industry. Therefore, an urgent need exists to evaluate the long-term risk of dryland salinity associated with tree clearing in the wet/dry tropics if we are to avoid the salinity problems that plague the winter-dominant rainfall zone of southern Australia.

The catchment above the Burdekin Falls dam is referred to as the Upper Burdekin and roughly corresponds with Dalrymple Shire. This shire occupies an area of 68 000 km^2 and is within the seasonally wet/dry tropics. The climate is characterised by a summer (November–April) wet season during which 80% of the annual rainfall occurs (500–1600 mm). Whilst the annual potential evapotranspiration is large (2000–2500 mm/year), the concentration of the annual rainfall over 5–6 months results in rainfall sequences that favour rapid filling of the soil water store and the opportunity for water to drain beyond the root-zone if the vegetation is unable to extract the water.

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The native vegetation is largely intact and is typically mid-high to tall, open eucalypt woodland with native perennial grasses. The predominant land use is grazing by beef cattle. To date, only 2% of the shire has been cleared, but tree clearing is becoming an important grazing land management option around Charters Towers and in the south of the shire where about 10% of the land has been cleared. Highly erodible soils are widespread and land degradation and woody weed infestation are major problems facing the grazing industry (De Corte *et al*. 1991).

Tree clearing is seen as an important land management tool to increase production in the beef industry in the shire (Dalrymple Landcare Committee 1989). By replacing timber with grass, animal production and profitability in eucalypt woodlands can increase, and there are a number of suitable legumes and grasses available for introduced pasture production systems (McIvor 1989). However, attention has been drawn to the salinity hazard and the unattractive economics of replacing trees with native grass (Gillard *et al*. 1989; Williams and Chartres 1991). Often the enthusiasm for tree clearing as a land management tool in these wet/dry tropics results from a view that salinisation as a consequence of tree clearing will be restricted to the temperate and Mediterranean regions of Australia (Burrows 1991). This view results from a failure to appreciate the nature of the water balance in the seasonally wet/dry tropics and the strong leaching environments that can be present (Coventry and Williams 1984).

This paper presents both experimental data and water balance simulations to show that, in these seasonally wet/dry tropics, tree killing can result in significant increases in water movement beyond the root-zone. Further, it will document the current information on salt levels in the soil and groundwater in the region and indicate that there is a potential salinity hazard associated with land clearing in the Upper Burdekin.

Measurement and analysis

Water balance measurements

Experiments to measure the comparative water balance of eucalypt woodland, native grasses, and *Stylosanthes* pastures with suboptimal and adequate P nutrition were conducted at 'Redlands', 45 km west of Charters Towers in the Upper Burdekin Catchment. The soils at Redlands are an association of red earths (Paleustalf) and yellow earths (Haplustalf). The experiments with *Stylosanthes* have been described previously (Probert and Williams 1985, 1986). In an area of eucalypt woodland on deep red earth (Coventry 1982) with a slope of $<0\cdot5$%, 2 replicated areas of woodland, native grasses, and *Stylosanthes scabra* cv. *Seca* pastures, at 2 rates of P application, were established with neutron meter access tubes installed to a depth of 450 cm. The native grass and legume areas were created by killing the trees and applying legume seed and fertiliser to a grid of plots (5 by 5 m^2) over the area where trees were killed. The area of killed trees was approximately 80 by 60 m. The woodland areas where measurements were made were within 30 m of the tree-killed areas. The plots of native grass and legume pasture grass plants were not grazed but were mown annually, and most biomass was left on the plot except in very high (>10 t/ha) legume plots. Rainfall and pan evaporation were recorded at the Redlands homestead (1 km from site), as was rainfall on the site. The water content distribution to 450 cm was measured with a neutron meter each month from October 1979 to May 1982. During this period there was no evidence of significant runoff because of the high hydraulic conductivity of the surface soil, and its low relief and large roughness associated with the tussock grasses (Williams and Bonell 1988). The soil moisture characteristic for the red earth was measured on soil cores (75 mm diameter by 50 mm height) sampled from the surface and from deep pits. The saturated hydraulic conductivity was measured using the *in situ* auger hole method (Talsma and Hallem 1978) and infiltration rings (Talsma 1969). At depths where no data were available, the soil moisture characteristic was estimated from texture and bulk density (Williams *et al*. 1992).

Simulation analysis

The SWIM simulation model (Ross 1990) was used to analyse these experimental data to yield estimates of actual evapotranspiration (AET), runoff (RO), deep drainage (DD), and profile water storages (S) for the profile water balance, which can be written as

$$P = \mathrm{AET} + \mathrm{RO} + \mathrm{DD} + \Delta S \tag{1}$$

where P is precipitation and ΔS is the change in soil profile water store. The PERFECT simulation model (Littleboy *et al*. 1989) was used in conjunction with SWIM to extend and generalise to other soils and rainfall patterns over the long-term. The soil hydraulic properties used in PERFECT were drawn from studies on red earths and neutral red duplex soils in the Upper Burdekin.

The experimental data used in the SWIM analysis were for 6 months from 1 January to 16 July 1980 (Day 199). The distribution of water content on 14 January (Day 14) was used to initialise the model. Comparisons between predicted and measured water contents were made on 14 February (Day 45), 17 March (Day 76), 17 April (Day 107), and 16 July (Day 199).

Table 1. Soil and vegetation properties for red earth and neutral red duplex soil used in PERFECT analysis

See Littleboy *et al*. (1989) for details of these parameters in the PERFECT simulation model
Rooting depth for trees 500 cm, for grass 150 cm

Parameter	Trees		Grass	
	Red earth	Duplex	Red earth	Duplex
Drainable porosity (mm)	170	40	67	21
PAWC (mm)	380	350	140	130
K_{sat} (mm/day)	120	24	120	24
Curve number	70	80	70	80

Both SWIM and PERFECT were then used to investigate the effect of soil properties on the comparative water balance of woodland and native grass vegetations. The SWIM comparisons were established using 1980 rainfall and pan evaporation for 'Redlands', while the long-term comparisons were completed using PERFECT and 100 years of rainfall data for Charters Towers. The soil and vegetation properties used in PERFECT and SWIM are given in Tables 1 and 2. The red earth soil used in the PERFECT analysis was not from 'Redlands' but was representative of red earths which were part of the regional survey by De Corte *et al.* (1991). The purpose of the PERFECT analysis was to confirm the effect of vegetation change on the water balance for contrasting soils over long periods of time.

Soils, geology, and groundwater

CSIRO Division of Soils, in collaboration with the Queensland Department of Primary Industries (QDPI) and the National Landcare Program (NLP), conducted a survey of the soil and land resources of the Dalrymple Shire; 2000 sites were described as part of this survey, of which 1000 were sampled to 2 m and analysed for pH and electrical conductivity (EC) on 1:5 soil:solution extracts.

A regional GIS database has been collated from available sources which includes the digital Atlas of Australian Soils (1:2M); digital geology of Australia (1 : 2·5M; NRIC); grid digital elevation model and drainage (1 : 1M; AUSLIG); point observations and measurements of pH and electrical conductivity (EC) on soils from the current Dalrymple survey; Groundwater Resources of Queensland map (1 : 2·5M) including data on aquifers, salinity levels, and borehole data for depth, EC, and major ions (QDPI, Water Resources).

Table 2. Properties of red earth, sandy red earth, and yellow podzolic soil and vegetation properties used in SWIM analysis

See SWIM manual (Ross 1990) for detailed explanation of parameters; θ_s is saturated water content, b and Ψ_e are the slope and air entry parameters for the Campbell model of the soil moisture characteristic, and K_s is saturated hydraulic conductivity. Estimates of parameters were based on experimental measurements (Probert and Williams 1985, 1986)

Soil					Vegetation		
Depth (cm)	θ_s (cm^3/cm^3)	b	Ψ_s (cm)	K_s (mm/day)	Property	Trees	Grass
Red earth					Xylem potential (m)	250	150
0–15	0·34	3·9	12	960			
30–250	0·31	10·0	8	120	Max. root density (cm/cm^3)	5	5
250–450	0·30	10·0	5	72	Max. PET intercepted	0·8	0·6, 0·2[A]
Sandy red earth					Depth (cm) where root density = 37% max.	200	30
0–450	0·34	3·9	12	960			
Yellow podzolic							
0–45	0·44	5·4	2	720			
45–75	0·37	7·4	48	240			
75–450	0·33	16·0	60	24			

[A] When grass alone 0·6; when with trees 0·2.

This GIS database for the catchment was used to produce the distribution of the soils through which significant deep drainage may occur following clearing (see Fig. 7); the distribution of groundwater salinity levels, and bores with depth and salinity data (see Fig. 8); and the geology and its relationship to the soil profiles exhibiting significant salinity (see Fig. 9).

Results

Comparative water extraction of woodland, native grasses, and perennial legume

The rainfall from 14 January (Day 14) to 16 July (Day 199) 1980 at Redlands was 401 mm whilst the pan evaporation for the same period was 772 mm. If both runoff and deep drainage are small, then the sum of rainfall and change in profile water store is a measure of water use. This crude estimator is shown in Fig. 1 for woodland, perennial legume at high and nil P application, and native grass during this period of wet/dry season. It is clear that the woodland uses more water than the native grass and the nutritional condition of the perennial legume has a significant influence on its water use. To illustrate this further, Fig. 2 shows the change in soil water content from 14 February (Day 45) to 16 July (Day 199) 1980 under woodland, native grass, and fertilised perennial legume. There is 156 mm more water lost from the woodland than from the native grass. We also see that the woodlands appear to extract water down to about 3·5 m whilst the native grasses fail to change the water content below 2 m. At high levels of P fertilisation, the perennial legume is closer to the woodland than the native grass in the form of its water extraction.

Figure 3 presents detailed water content decreases under the 4 land use systems from 17 March to 17 April 1980. In a period when the vegetation was dependent on the soil store (rainfall was only 3·4 mm), native grasses failed to change the water content below 2 m whilst the woodland was able to change the soil water content beyond 3·5 m. Again, the perennial legume at high levels of P

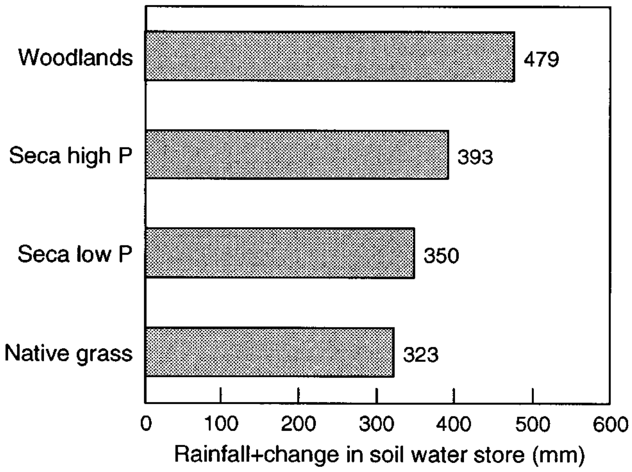

Fig. 1. Sum of rainfall and change in the soil water store for woodland, perennial legumes, and native grass at 'Redlands' from 14 February (Day 45) to 16 July (Day 199) 1980. This provides a first-order approximation of the loss of water as evapotranspiration if both deep drainage and runoff are small.

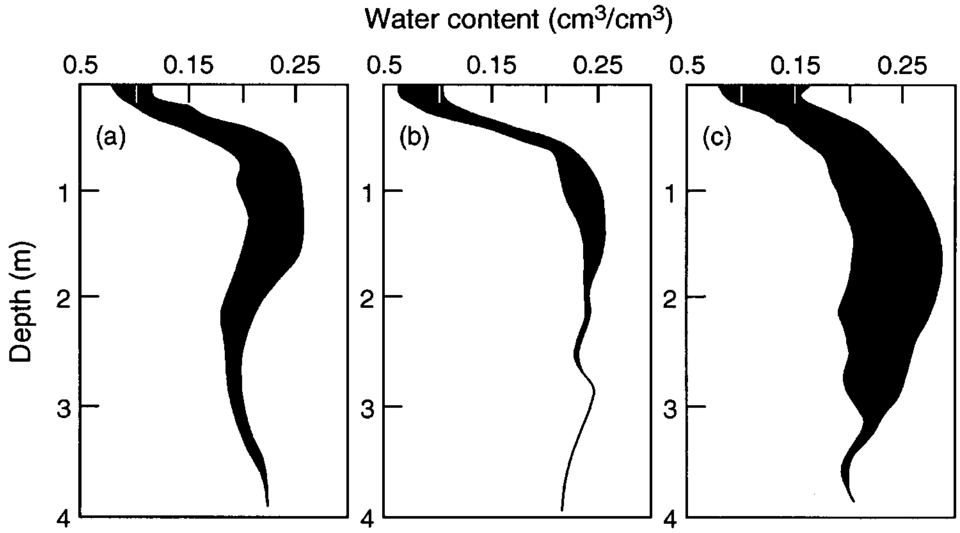

Fig. 2. Change in soil water storage (ΔS) as a function of depth at 'Redlands' from 14 February (Day 45) to 16 July (Day 199) 1980 under fertilised perennial legume, native grass, and woodland. (*a*) Seca (ΔS = 137 mm); (*b*) native grass (ΔS = 67 mm); (*c*) woodland+native grass (ΔS = 223 mm).

application reduced water content in a manner more similar to the woodland than the native grasses, although little water was extracted from below 3 m.

Whilst these data provide clear evidence of changes to the woodland water balance, they cannot provide estimates of deep drainage. Given the soil hydraulic properties and the vegetation characteristics, along with the rainfall and evaporation, SWIM was used to estimate both AET and DD for native grass and woodland consisting of a mix of trees and native grass. To gain confidence in the predictions provided by SWIM using the limited soil and plant parameters available, it is critical to compare the observed and predicted water content distribution beneath both woodland and native grass.

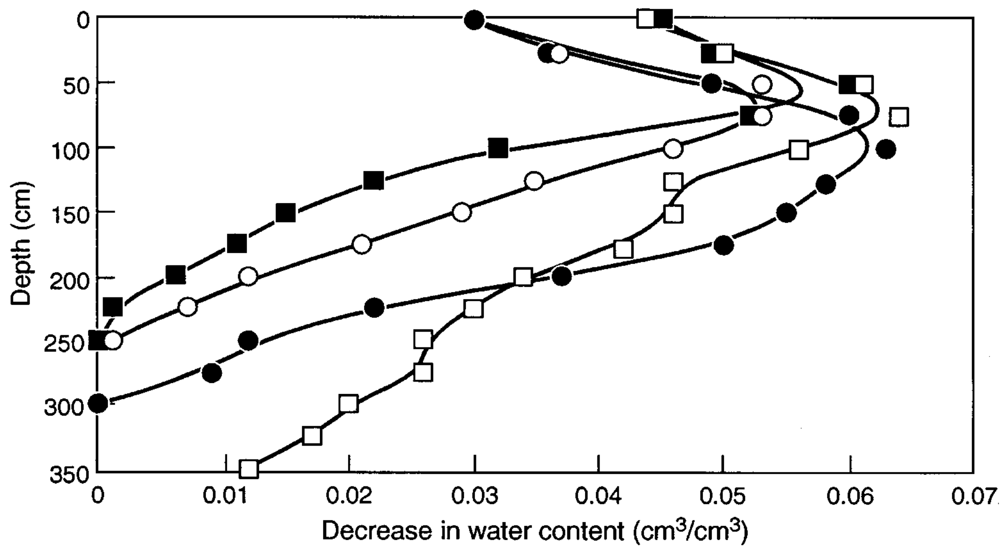

Fig. 3. Decrease in water content as function of depth under woodland, P fertilised and unfertilised perennial legume, and native grass (■, grass; ○, legume, low P; ●, legume, high P; □, Woodland).

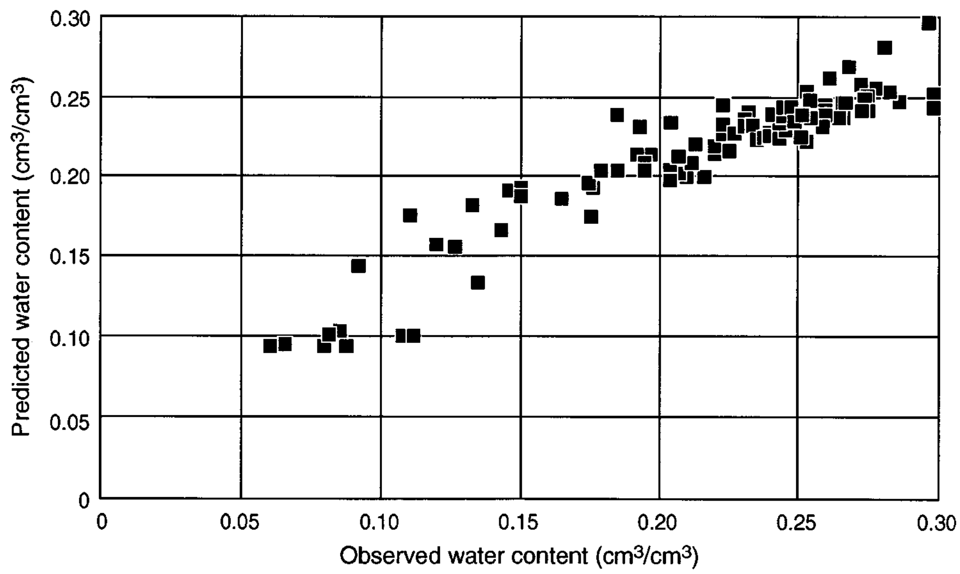

Fig. 4. Comparison of observed and predicted soil water contents for both woodland and native grass for Days 45, 76, 107, and 199 at 12 depth intervals to 360 cm on red earth.

In Fig. 4, the observed and predicted water contents for 12 depth intervals from 10 to 360 cm at observation Days 45, 76, 107, and 199 are shown for both woodland and native grass. The agreement is acceptable, particularly at the higher water contents where drainage from the profile will be most likely to take place. Comparisons of predicted and observed total profile water store (S) and change ($\mathrm{d}S$) in the profile water store indicated agreement within 10 mm for the native grass. At Days 45 and 76, the predicted, total profile store was in poor agreement for the woodland; however, by Days 107 and 199, agreement was good and similar to that for the native grass.

The water content distribution observed and predicted to a depth of 360 cm under native grass and woodland is shown in Fig. 5. The agreement between the simulation and the observation is acceptable and gives some confidence to the estimates of AET and DD provided by the simulation model. However, it should be noted that while the agreement between observed and predicted values is encouraging, the accuracy of the partitioning between AET and DD cannot be critically evaluated without independent estimates of AET. From other work (Williams and Bonell 1988), there is evidence that these soils can surface-seal under native grass and poor management. This would result in increased runoff and less deep drainage, but there was no evidence of significant runoff for the period of our study.

The purpose of this analysis is not so much the estimation of the absolute magnitude of DD, but rather the relative difference between the DD for the woodland and the native grasses after the trees have been killed. Figs 4 and 5 give a clear indication that differences in DD estimates between these 2 systems using SWIM are sensible and can be used with confidence.

Results of an analysis over a depth of 360 cm using the soil properties in Table 2 are given in Table 3. All analyses using SWIM were for a depth of 360 cm. Over this 5 months in 1980, deep drainage beyond 360 cm was increased from 18 mm under the woodland to 50 mm where the trees were killed. It is important to note that the large difference in AET (131·1 mm over 185 days) was not found in increased deep drainage but in a large increase in the profile water store. The implication for recharge in subsequent years is a factor to note.

Two questions require resolution: are these experimental results restricted to this particular rainfall sequence, and are the experimental findings restricted to this particular soil and vegetation system?

Extension of the experimental findings to other soils and to other rainfall seasons

To investigate these issues, SWIM was used to predict the water balance by using the same rainfall and evaporation data but with 2 different soil systems that are found in the catchment.

Table 4 indicates that, in this seasonally wet/dry tropical environment, the increase in deep drainage beneath 360 cm when trees are removed from the woodland is not specific to the red earth soil. A similar pattern exists for lighter textured soils and for texture contrast soils with relatively low permeability B horizons. This was confirmed further when PERFECT was used to extend our findings to other rainfall years in this environment. In Table 5, the water balance for a neutral red duplex and a red earth soil has been calculated for both woodland and grass only at Charters Towers using the rainfall for the 100 years 1889–1988.

The data in Table 5 indicate that the replacement of trees with grass will usually result in an increase in deep drainage in the Charters Towers environment. The results for the experimental measurement and the SWIM analysis conducted in 1980, which indicated a significant increase in deep drainage following tree removal, appear not to be site- or season-specific. During 1980, rainfall for Charters Towers (660 mm per year) was near average. For that year, the PERFECT model predicted deep drainage under grass to be about 70 mm. This

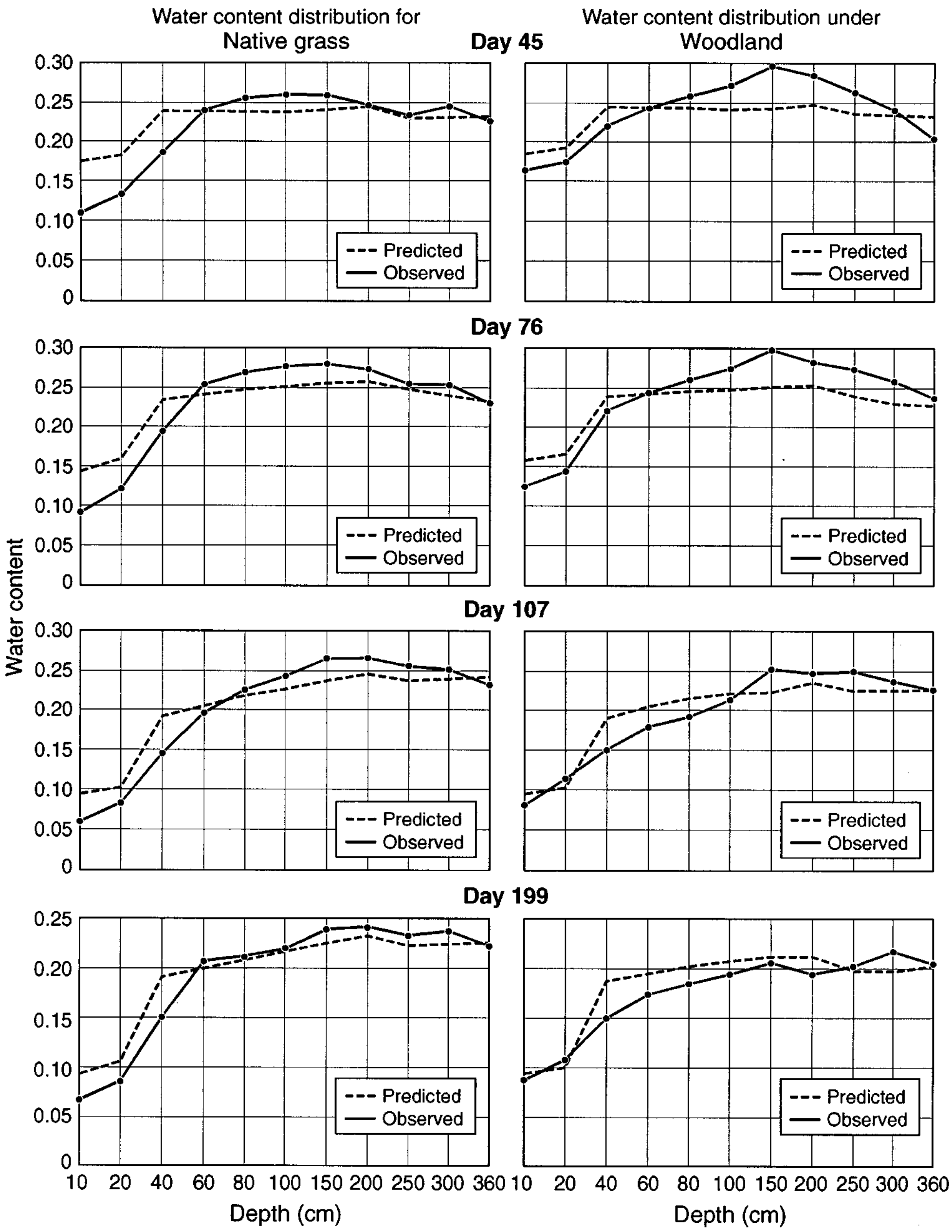

Fig. 5. Predicted and observed estimates of soil water content distribution with depth at Days 45, 76, 107, and 199 for woodland and native grass on red earth.

Table 3. Comparative water balance (mm) to 360 cm for woodland and native grasses on red earth at 'Redlands' from January to July 1980 using SWIM

P, precipitation; RO, runoff; DD, deep drainage beneath the root-zone; AET, actual evapotranspiration; *S*, the depth of water stored in the profile

Parameter	Water balance at day: 14	45	76	107	134	150
			Woodland			
P	0	154·9	289·6	293·8	311·6	400·6
RO	0	0	0	0	0	0
DD	0	3·2	9·2	14·6	16·8	18·3
AET	0	161·5	292·0	375·2	427·3	541·6
S	862·2	852·4	850·5	765·9	729·3	702·6
			Native grass			
P	0	154·9	289·6	293·8	311·6	400·6
RO	0	0	0	0	0	0
DD	0	7·2	13·3	28·2	38·3	50·5
AET	0	130·9	240·8	290·2	324·6	410·5
S	819·2	835·9	854·6	794·4	767·7	758·4

Table 4. Comparative water balance (mm) to 360 cm for red earth, sandy red earth, and yellow podzolic soils under woodland and native grass using the 'Redlands' rainfall and evaporation for January–July 1980 using SWIM

Vegetation	*P*	AET	RO	DD	d*S*
		Red earth			
Woodland	401	541	0	18	159
Grass	401	410	0	50	60
		Sandy red earth			
Woodland	401	640	0	118	357
Grass	401	357	0	238	194
		Yellow podzolic			
Woodland	401	628	0	73	300
Grass	401	454	0	150	203

Table 5. Predicted water balance (mm) for trees and grass on a neutral red duplex and a red earth soil at Charters Towers using 100 years of rainfall data (1889–1988) using PERFECT

% F, percentage of years in which deep drainage can be expected

Vegetation	*P*	AET	RO	DD	%F
		Red earth			
Trees	660	625	20	15	17
Grass	660	552	34	74	66
		Neutral red duplex			
Trees	660	619	40	1	4
Grass	660	561	91	8	42

is of the same order as our independent estimate of 50 mm reported in Table 3 for the 199-day period of the same year. The 1980 experimental result, when set in context of 100 years of rainfall, appears to be near the average in terms of deep drainage, and is not a special circumstance.

The predictions of deep drainage for the red earth under trees and grass for 100 years using PERFECT are shown in Fig. 6. These long-term predictions indicate the marked effect that tree clearing can have on both the frequency and magnitude of deep drainage in the seasonally wet/dry tropical environments.

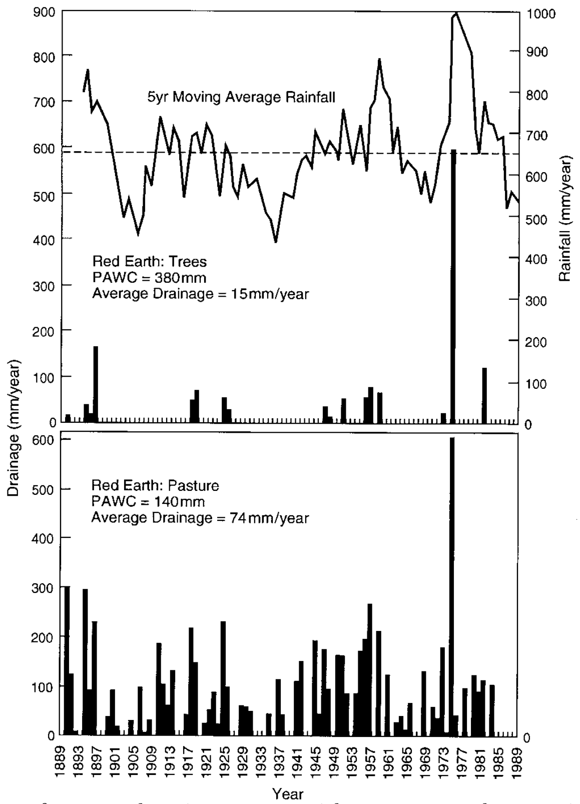

Fig. 6. Comparison of trees and native pasture without trees on the magnitude and frequency of deep drainage in a red earth at Charters Towers for 100 years (1889–1988).

The PERFECT analysis predicts that the frequency of occurrence of deep drainage will increase from 17 to 66% for the red earth and from 4 to 42% for the neutral red duplex when trees are removed from the woodland. While the absolute magnitude of the deep drainage will be soil- and vegetation-dependent, the relative magnitude of the increase appears to be 2–3 times that under woodland. It is the relative change in the magnitude of deep drainage, along with the depth and hydraulic properties of the regolith, that determines the time taken for clearing to influence local and regional groundwater. A small absolute, but large relative change in deep drainage after clearing can have important long-term environmental consequences.

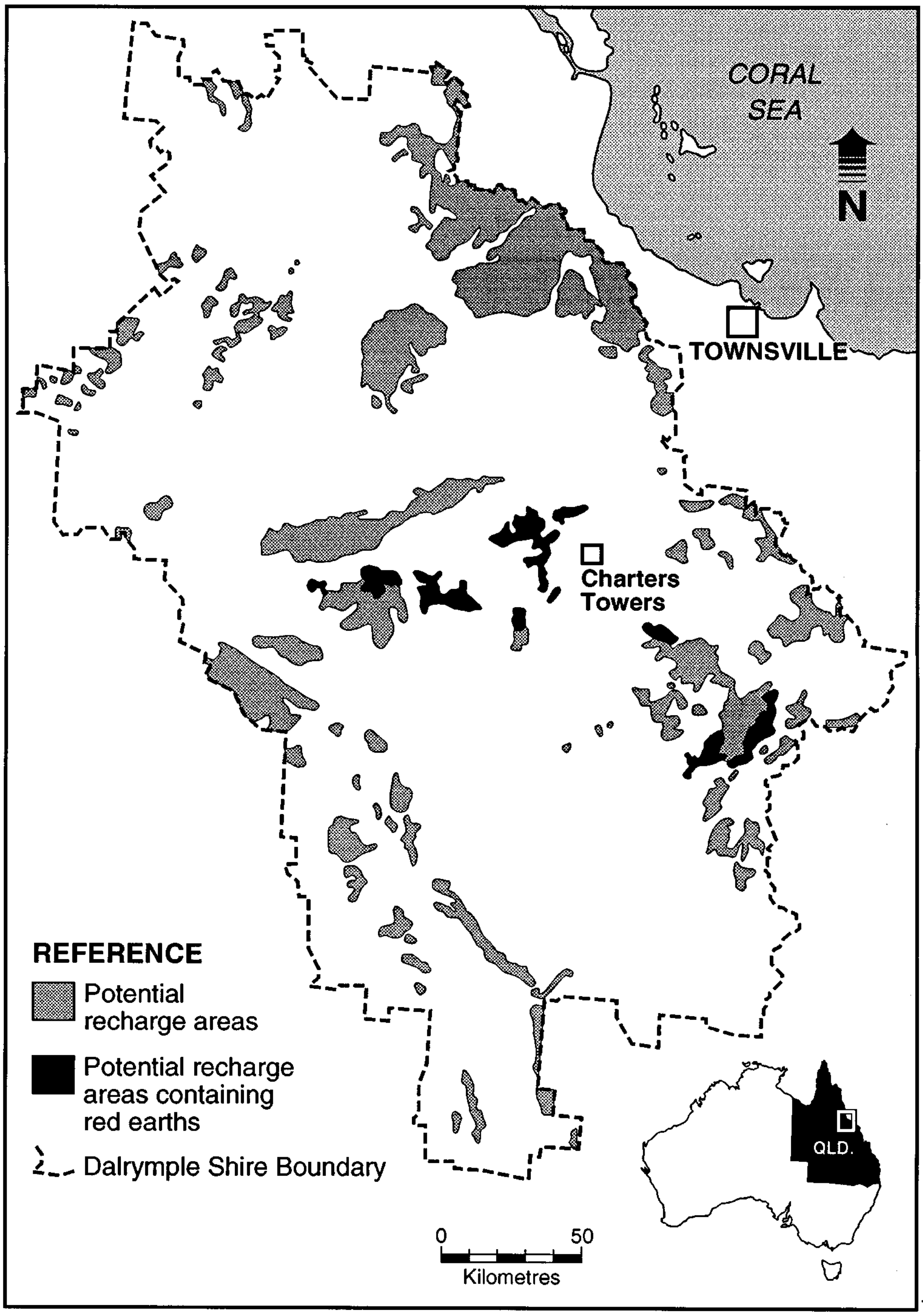

Fig. 7. Estimated recharge areas using Atlas of Australian Soils map units with high permeability and good drainage as the selection criteria.

An examination of salinisation hazard using soils, geological, and groundwater data in a GIS framework

As a preliminary assessment of the risk of salinisation after tree clearing, potential intake areas for recharge to groundwater have been estimated from the digital Atlas of Australian Soils. Map units have been assigned codes for the attributes 'permeability' (high, medium, low) and 'drainage' (good, moderate, poor) on the basis of the dominant Principal Profile Form described for the map units. Soil map units with permeability code of 'high' and drainage code of 'good' have been assumed to correspond to potential areas for recharge to groundwater (Fig. 7). These areas should not be cleared in order to maintain evapotranspiration levels and to avoid increased deep drainage contributing to a rise in watertables within the landscape. These areas have been overlaid on the AUSLIG Digital Elevation Model (DEM) to check whether they are found in upland positions and the correspondence has been good.

Overlaying point EC measurements with the geology of Australia polygons suggests that the Tertiary Campaspe Beds unit has a high proportion of soils with high ECs (Fig. 8). The Campaspe Beds are poorly sorted, weakly cemented, argillaceous sandstone with some minor conglomerate, siltstone, and claystone. A large area of this formation is capped by nodular ferricrete (Clarke and Paine 1970). Salts are found in yellow and grey earths, duplex soils, and deep grey cracking clays derived from these sediments.

The EC criterion of 0·4 (mS/cm) is an EC 1 : 5 value that indicates moderate levels of salt for soils with clay contents of 20–40% (Shaw 1988). The presence of salt stores in the landscape suggests that a salinity hazard exists from salt that could be remobilised by rising groundwater tables. The salinity level for the underlying aquifer is 1500–5000 mg/L (Groundwater Resources of Queensland, QDPI/Water Resources) and the distribution of groundwater salinity is shown in Fig. 9.

Discussion

The comparative water balance measurements, coupled with the analysis using simulation models, provide good evidence that a conversion of woodland to native grassland will produce a substantial increase in deep drainage in the seasonally wet/dry tropics. Through the use of simulation models, the increase in deep drainage was predicted to occur across sandy red earths, red earths, neutral red duplex, and yellow podzolic soil profiles. The analysis showed that the deep drainage under woodland can be expected to be strongly episodic. Long-term water balance simulation suggests that under woodland deep drainage can be expected once every 25 years on a duplex soil with a heavy-textured B horizon and, on clearing, this frequency of deep drainage can be expected to increase to once every 2 years. On the more permeable red earths, the frequency of deep drainage can be expected to increase following clearing from once every 5 years to twice every 3 years. The estimated deep drainage for a red earth under native grass and woodland was 50 and 18 mm, respectively, for a rainfall year that was shown to be about average for the Charters Towers region of the Upper Burdekin Catchment.

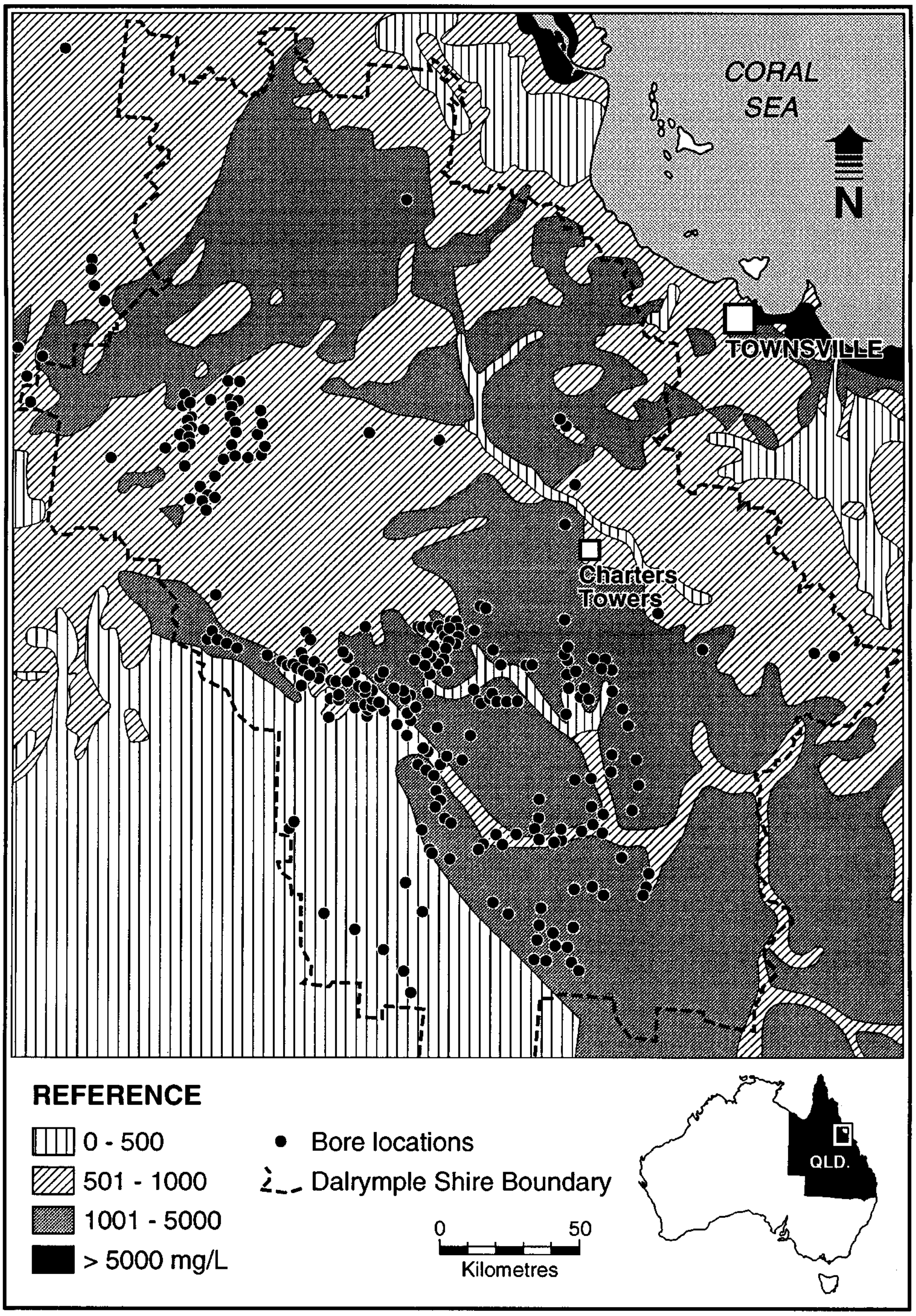

Fig. 8. Salinity of groundwater over the Upper Burdekin Catchment in North Queensland.

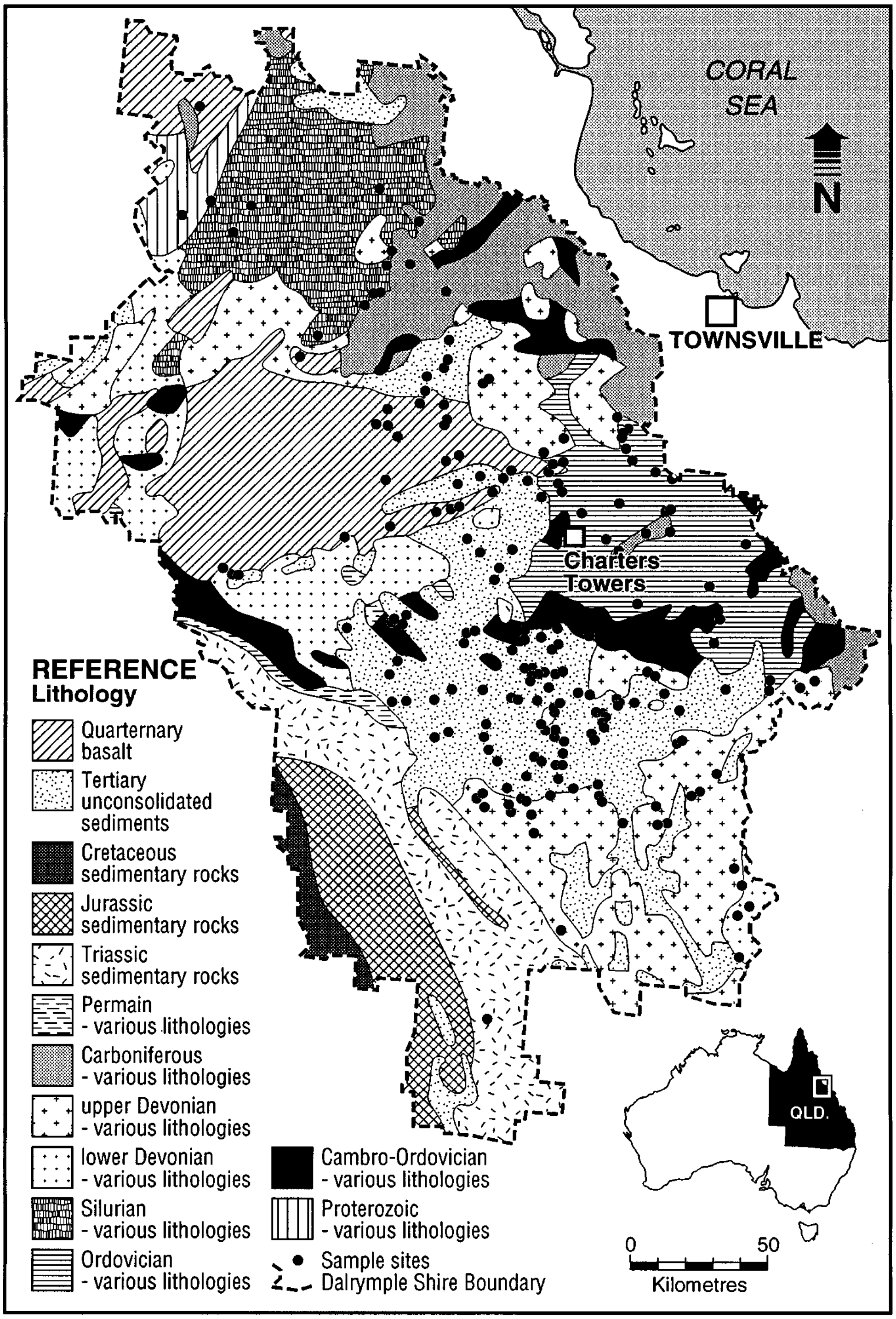

Fig. 9. Geological units and sample sites with high salt content in overlying soil profiles.

These findings are fundamental to recognising that the conversion of eucalypt woodlands to grassland in the wet/dry tropics on most soils can be expected to produce a substantial increase in deep drainage. The data show that by introducing a perennial legume to replace the native grass, deep drainage may be reduced, but the effectiveness of the replacement vegetation is strongly dependent on nutrient status. Tree killing or clearing may make more water available to the plant community, but generally it cannot be used effectively and converted into dry matter whilst the nutrient or other edaphic constraints remain. Failure to utilise this extra water results in an increase in the drainage term of the overall water balance.

The fact that deep drainage will be increased under clearing provides the first prerequisite for a salinity hazard. This can be expected to be so for the lands of the Upper Burdekin Catchment. The second prerequisite is the presence of salt stores in the landscape that can be remobilised with changes to the regolith and groundwater hydrology. The data presented in Figs 8 and 9 illustrate that in the Upper Burdekin there are significant salt storages in the soil, regolith, and groundwater that underlie much of the catchment. Therefore, in the Upper Burdekin the first 2 prerequisites for salinity hazard are clearly present. Increased deep drainage and groundwater recharge can be expected following clearing and there are significant salt stores in the landscape.

Although it is possible to establish that there is a salinity hazard both from potential salt storage in the landscape and from saline groundwater tables, it is not possible to estimate whether this hazard will be translated into a problem unless existing watertable movement is known. We have been able to estimate deep drainage from field observation and from simulations, but our lack of knowledge about groundwater depth, movement, and landscape stratigraphy are critical limiting factors in concluding the risk assessment. It must be recognised that we do not have routine tools that can evaluate the risk of salinity at any site where clearing is anticipated. There is an urgent need to research and develop tools that link estimates of increases in deep drainage to landscape and regolith processes in ways which can predict groundwater response and hillslope watertable developments that are able to mobilise salt in the landscape. The translation of any given increase in deep drainage to a watertable rise is dependent on catchment shape, regolith stratigraphy, aquifer properties, and slope of soil surface. The linkage and inferencing of 1-dimensional water-balance simulation models to appropriate groundwater models will be required, along with geomorphic and stratigraphic information, before it is possible to translate salinity hazard to salinity risk for particular locations in the Upper Burdekin.

Short-term experimental measurements have a limited ability to capture changes to water balance and deep drainage following woodland replacement, because the generation of deep drainage is strongly episodic in the wet/dry tropics. However, this paper illustrates the power of appropriate simulation models, coupled with experimental measurement, to transcend the tyranny of site and season variability that continues to plague so many hydrological studies.

Conclusions

In the Upper Burdekin Catchment, 2 prerequisites for salinity hazard are present. Increased deep drainage and groundwater recharge can be expected following tree clearing and there are significant salt stores in the landscape. There are landscapes in the Upper Burdekin where salinisation processes are clearly evident (De Corte *et al*. 1991), and this paper has identified the regions of the catchment where recharge can be expected to be very substantial should trees be killed or cleared. In these recharge areas, trees and the woodland must be retained. With the evidence presented in this paper on salinity hazard, and the earlier work of Gillard *et al*. (1989), it is apparent that indiscriminate clearing of the eucalypt woodlands is a risky land management option in terms of both property economics and potential salinisation. Consequently, tree retention will provide the best means of salinity control in the Upper Burdekin. Tree killing or clearing should only proceed once the risks of dryland salinity have been evaluated and shown to be negligible.

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References

Burrows, W. H. (1991). Tree clearing in perspective—a question of balance. *Search* **22**, 46–8.

Clarke, D. E., and Paine, A. G. L. (1970). Explanatory notes on the Charters Towers geological sheet, Queensland. (Sheet SF/55–2). BMR, Canberra.

Coventry, R. J. (1982). The distribution of red, yellow and grey earths in the Torrens Creek area, central north Queensland. *Australian Journal of Soil Research* **20**, 1–14.

Coventry, R. J., and Williams, J. (1984). Quantitative relationships between morphology and current soil hydrology in some Alfisols in semiarid tropical Australia. *Geoderma* **33**, 191–218.

Dalrymple Landcare Committee (1989). The Management of eucalypt country in North Queensland. Dalrymple Landcare Committee, August 1989.

De Corte, M., Cannon, M., Parry, E., Bright, M., and Scanlon, J. (1991). Land degradation in the Dalrymple Shire: a preliminary assessment. CSIRO/QDPI/NSCP, Davies Laboratory, Townsville.

Gillard, P., Williams, J., and Monypenny, R. (1989). Tree clearing in the semi-arid tropics. *Agricultural Science* **2**, 34–9.

Littleboy, M., Silburn, D., Freebairn, D., Woodruff, D., and Hammer, G. L. (1989). PERFECT: a computer simulation model of productivity erosion runoff functions to evaluate conservation techniques. QDPI, Brisbane.

McIvor, J. (1989). Positive improvement on eucalypt country in North Queensland. *In* 'The Management of Eucalypt Country in North Queensland'. Dalrymple Landcare Committee, August 1989.

Probert, M. E., and Williams J. (1985). The residual effectiveness of phosphorus for *Stylosanthes* pastures on red and yellow earths in the semi-arid tropics. *Australian Journal of Soil Research* **23**, 211–22.

Probert, M. E., and Williams, J. (1986). The nitrogen status of red and yellow earth soil in the semi-arid and tropics as influenced by Caribbean stylo (*Stylosanthes hamata*) grown at various rates of applied phosphorus. *Australian Journal of Soil Research* **24**, 405–21.

Ross, P. (1990). SWIM—A simulation model for soil water infiltration and measurement. Reference Manual, CSIRO Division of Soils, Davies Laboratory, Townsville.

Shaw, R. J. (1988). Soil salinity and sodicity. *In* 'Understanding Soils and Soil Data'. (Ed. I. F. Fergus.) pp. 109–34. (Australian Society of Soil Science, Queensland Branch: Brisbane.)

Talsma, T. (1969). *In situ* measurement of sorptivity. *Australian Journal of Soil Research* **7**, 269–76.

Talsma, T., and Hallem, P. M. (1978). Hydraulic conductivity measurement of forest catchments. *Australian Journal of Soil Research* **18**, 139–48.

Williams, J., and Bonell, M. (1988). The influence of scale of measurement on the spatial and temporal variability of the Philip infiltration parameters—an experimental study in an Australian savannah woodland. *Journal of Hydrology* **104**, 33–51.

Williams, J., and Chartres, C. J. (1991). Sustaining productive pastures in the tropics: managing the soil resource. *Tropical Grasslands* **25**, 73–84.

Williams, J., Ross, P., and Bristow, K. L. (1992). Prediction of the Campbell water retention function from texture, structure, and organic matter. *In* 'Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils'. (Eds M. Th. van Genuchten, F. J. Leij, and L. J. Lund.) pp. 427–41. (University of California: Riverside, CA.)

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