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An assessment of the efficacy of deep drains constructed in the wheatbelt of Western Australia Part 1 A discussion on drainage implmentation in the wheatbelt : a case study review, summary, conclusions and recommendations

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A DISCUSSION PAPER ON DRAINAGE IMPLEMENTATION IN THE WHEATBELT: A CASE STUDY REVIEW SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.

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PART 1

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AN ASSESSMENT OF THE EFFICACY OF DEEP DRAINS CONSTRUCTED IN THE WHEATBELT OF WESTERN AUSTRALIA.

Executive summary

As one of its commitments to the State Salinity Action Plan, Agriculture Western Australia has undertaken a strategic review of current and historical deep drainage projects. A 'rapid appraisal' methodology was utilised, based principally on existing hydrological investigations and interpretation and anecdotal evidence provided by landholders to clarify the role of drainage in managing water in dryland rural landscapes.

The objectives of this discussion paper are to:

1. Review the current status of groundwater drainage practice
2. Provide an assessment of deep drains in the landscape and
3. Propose recommendations on the development of drainage policy to enable the application of best management practice in groundwater drainage.

Engineering systems are routinely used in agricultural areas to manage surface water (drains, banks, waterways, floodways etc) and subsurface water (deep drains, groundwater pumping systems etc) and associated salinity. The use of shallow and deep drainage can improve plant growth and water use on waterlogged sites. However, deep drainage does not provide the sole solution to water management problems and should be part of an integrated approach to water management at farm and catchment levels.

Apart from a small number of case studies, little research has been conducted and summarised in recent years. Limited hydrological analysis has been undertaken in the past and therefore no criteria have been established to explain the varied results achieved due to the construction of deep drains in the wheatbelt landscape. The major reason given for installation of drains is to manage or control salinity and waterlogging at sites in the lower landscape, and to halt or restrict the spread of salinity within the catchment.

Salt affected areas within the wheatbelt are normally associated with broad, relatively flat, poorly drained valley systems. Soil water transmissivity and catchment flow within these environments are complicated by low hydraulic gradients for upward flow, preferential flow paths, inundation, sandy surface soils, flooding and seasonal waterlogging resulting in poor crop yields. The spatial and temporal variability of water movement within the saturated and unsaturated zones of the soil profile creates a highly complex and variable soil solute transfer system.

The wheatbelt catchments are characterised by low permeability, low gradients which may intermittently yield large quantities of saline water. The ramifications of applying

simplistic, universal engineering solutions to large areas over which hydraulic conditions are highly variable, are often hidden, dramatic or inconsequential. Consequently opinions on the effectiveness and success of drains or drainage options is highly variable and often counterintuitive.

Observational and anecdotal evidence suggest that the answer to this particular drainage dilemma may lie in processes that take place in the unsaturated zone. Deep drains may reduce waterlogging, improve leaching, lessen inundation and increase plant survival (and therefore yield) at distances greater than groundwater drainage theory may predict, with relatively little change to the groundwater status of saline sites. Groundwater monitoring alone will not be able to detect these changes. Crop yield, soil water and solute measurements are required. A standardised scientific method needs to be applied to the drainage issue.

The assessment of some drainage sites suggest that the improvements in production recounted by the farmers were often achieved through ameliorating waterlogging caused by surface water runoff. In areas where surface water management is the major issue, less expensive options are available. The economics of effective grade banks versus deep drains has been illustrated in the economic analysis. The results suggests that the area required to break-even is generally 50 percent less for grade banks owing to the lower costs of construction and maintenance.

Given the obvious improved economic potential of using the appropriate engineering solution (ie. banks versus drains) problem definition becomes paramount and that the best-designed solution should be implemented to achieve the highest return on the capital investment. The physical characteristics of the site require investigation and drain performance should be assessed within the context of the catchment response, soil profiles, farming practices and landscape water management strategies.

The greatest impact of drains has been observed from those installed at the break of slope either because their location was at a point of stronger upward flow; the discharge areas were small; and/or as a result of interaction with dykes (or other geological constraints). Drains installed in low flat valley floors appeared to be less successful. A flood risk assessment prior to drain construction is recommended to ensure that the contribution to peak flow discharge downstream is not detrimental to the capacity of the system to accept the flow.

Based on this review it is evident that site definition, engineering design standards, appropriate layout and construction techniques, impact assessments of downstream consequences and wider community consultation is required before any large engineering system is adopted. Careful site evaluation is required to assess the feasibility of drainage, with each proposal for drainage treated on its merits. Furthermore, it is clear from the State Salinity Action Plan that implementation of drainage works must be consistent with achieving each of the stated Plan goals through integrated water management in the landscape at the farm and catchment scales.

1.Introduction

There is a wide range of earthworks that can be grouped together as 'drainage'. These include small earthworks (e.g., spinner drains, W-drains, grade banks, etc.) to large earthworks (e.g. floodways, deep channels and aquifer pumping systems). Drainage can be simply defined as *"the act of transferring water and solutes from one area to another"*. It is achieved by initiating or increasing the flow of water.

In Western Australia, drains are usually installed to reduce the impacts of waterlogging, flooding, inundation and salinity caused by shallow groundwaters on plants (native and exotic) and infrastructure (towns, houses, roads, etc).

This review examines the effectiveness of deep drains in improving plant production in the wheatbelt of Western Australia. Deep drains are generally >60 cm deep and installed with the objective of removing shallow, saline groundwater. A 'rapid appraisal' methodology has been used, based principally on existing hydrological investigations and interpretation to clarify the role of drainage in managing water in rural landscapes that receive less than 600 mm annual rainfall.

Wheatbelt drainage systems monitored to date have been constructed to act directly on the water table, e.g., deep drains, tube drains and groundwater pumping systems. Drain designs and monitoring should consider other issues such as the salt, nutrient and sediment loads transported within the system to the drain outlet.

The very low gradients of the saline valley floors of the wheatbelt necessitate drains to be several kilometres long to allow sufficient fall to enable outflow. For example, in a landscape with a 0.1 percent gradient, it is necessary to construct more than two kilometres of drain to bring a two metre deep drain to the surface. Many areas in the wheatbelt have gradients less than 0.1 percent.

Benefits from drains can occur by improving the flow of water out of both the saturated and unsaturated zones and /or by alleviating intermittent or seasonally inundated areas. Soil conditioning and soil amendments can enhance the movement of water through soils and thus improve the effectiveness of drains.

2.Drainage and the State Salinity Action Plan

The aims, strategies and actions for drainage must be consistent with the broad goals of the Salinity Action Plan, which are:

- reduce the rate of degradation of agricultural land, and where practical recover, rehabilitate or manage salt-affected agricultural land;
- protect and restore key water resources to ensure salinity levels are kept to a level that permits safe, potable water supplies in perpetuity;
- protect and restore high value wetlands and natural vegetation , and maintain natural (biological and physical) diversity within the agricultural areas of Western Australia; and;
- protect designated infrastructure affected by salinity.

Drainage is recognised as a salinity management tool in the Salinity Action Plan and to clarify the issues surrounding drainage and the disposal of drained waters the government has committed agencies to:

- define more clearly the category of drainage schemes most likely to cause downstream impacts and environmental damage;
- establish an authorisation process for each category of drainage;
- provide authorising bodies with powers to assess drainage on broad environmental criteria;
- ensure the protection of downstream land; and
- ensure that other essential water management practices are implemented with drainage proposals to reduce accessions to groundwater;
- develop a new drainage assessment and regulatory process that establishes a more efficient and integrated authorisation process.

To achieve the drainage related outcomes of the Salinity Action Plan three elements are necessary:

1. An agreed set of goals and a time frame.
2. A common understanding of the water management problems that give rise to: a perceived the need for drainage; the cause of the problems, and a set of available technical and cultural solutions or management options.
3. A clear understanding of the options available for improving drainage practice.

The discussion of drainage in the Salinity Action Plan explicitly recognises that current activities could, and should, be made more consistent with the goals of sustainable development, production and conservation (Wallace 1999).

3.Background

Surface and subsurface engineering systems are one group of seven fundamental water and salinity management practices (Salinity Action Plan, Version 2, in prep). Engineering systems are routinely used in agricultural areas to manage surface water (drains, banks, waterways, floodways etc) and subsurface water (deep drains, groundwater pumping systems) and associated salinity. The use of shallow and deep drainage can improve plant growth and water use on waterlogged sites. However, deep drainage does not provide the sole solution to water management problems and should be incorporated into an integrated approach at both the farm and catchment level to improve water management in the landscape.

There have been reviews of the role of surface and subsurface drains by George and McFarlane 1993, McFarlane and Cox 1992 and George and Nulsen 1985, and reports on specific drainage case studies (eg Ferdowsian *et al.* 1997, Speed and Simons 1993, Green 1990, Silberstien 1989).

Drains are generally installed to control salinity and waterlogging at sites in the lower landscape, and to halt or restrict the spread of salinity within the catchment. In deciding to construct earthworks, it is important to clearly differentiate the benefits achieved from the alleviation of waterlogging and inundation, and those achieved by the lowering of the groundwater table. Plants can tolerate higher levels of salinity in non-waterlogged conditions than they can when waterlogged. Thus draining surface water to reduce waterlogging on marginally saline land can result in a dramatic improvement in plant productivity.

The design of earthworks or engineered drainage solutions to ameliorate salinity and/or waterlogging will be subtly different depending on whether areas are suffering from saline encroachment resulting from rising watertables (or capillary action); affected by waterlogging; or affected by both (Nulsen 1982).

In areas where soils are affected by saline groundwater, drainage is principally designed to manage the depth of the watertable. In the wheatbelt, critical depth to the watertable to avoid salinisation of the soil profile is considered to be around 1.5 to 2.0 metres (Talsma 1963, Peck 1978, Nulsen 1982, George 1985). The critical depth varies with soil type; watertable salinity; and plant cover. For example, in coarse to medium sands and some heavy clays the critical depth may be < 1.0 to 1.2 metres but for some silty or loamy soils it can be 3.0 to 4.0 metres (George 1985).

In an effort to solve the problems associated with waterlogging and salinity farmers are increasingly looking to various forms of drainage. Contributing to this "single-solution" approach is the perceived lack of evidence of the effectiveness of alternative management systems and uncertainties associated with long-term options such as:

1. Re-vegetation systems;
    - local effects on groundwater,
    - few successful examples, tree death;
    - have low cost-benefit ratios;
    - long lead times;
2. High water use cropping systems
    - Preliminary analysis suggests that it is highly improbable that annuals alone can significantly change the catchment water balance in the short term, without the use of other management strategies.

In addition there is an apparent lack of any 'rigorous', yet simple analytical tools available to assess how combinations of various systems will impact on hydrology and farm economics. By contrast, drainage is an obvious, apparently simple and executable option that is viewed as having an immediate and effective impact on the "problem". In essence there is significant visual evidence of an excavated trench and flowing water showing a return on the investment in drains.

3.1 Drainage Processes

International drainage designs have been developed, largely in irrigation areas, to manage the saturated zone and their effectiveness judged by the degree of watertables control. In the Western Australian landscape the soil, groundwater hydrology and environment is markedly different from the areas overseas where drainage has generally been successful. Major difference include:

- variability in the extent of soil saturation, where the soil profile can either be intermittently, seasonally, or permanently saturated;
- brackish to extremely saline groundwater is often present;
- the soil profiles are highly variable (ie. texture, cementation, biology), often with contrasting (or duplex) profiles consisting of shallow, sandy, permeable A horizons overlying clayey, semi-permeable B horizons;

- the climate is strongly influenced by seasonal patterns and periodic extremes in rainfall coupled with high evaporation rates;
- native vegetation has varying levels of adaptation to salt and waterlogging, and
- areas targeted for costly drainage projects nominally support broadacre agriculture rather than high value, intensive agriculture thereby reducing the probability of cost recovery.

Salt affected areas within the wheatbelt are normally associated with broad, relatively flat, poorly drained valley systems. Soil water transmissivity and catchment flow processes within these environments are complicated by low hydraulic gradients for upward flow, preferential flow paths (Henschke 1983), inundation, sandy surface soils, flooding and seasonal waterlogging resulting in poor crop yields (Belford *et al.* 1990). The spatial and temporal variability of water movement within the saturated and unsaturated zones of the soil profile is complex. Seasonal rainfall patterns and episodic events exert strong influences on soil water and soil solute regimes and recharge (Lewis 1998; Lewis and McConnell 1998). Salt-waterlogging interactions have a synergistic effect on plant growth and this response is often not acknowledged (Barrett-Lennard 1986).

Deep drains may reduce waterlogging, improve leaching, lessen inundation and increase plant survival (and therefore yield) at distances greater than groundwater drainage theory would predict, with relatively little change to the groundwater status of saline sites. Groundwater monitoring alone will not be able to detect these changes. Crop yield, soil water and solute measurements are required to examine the full impact of the drains. The scientific method hypothesis testing needs to be applied to the drainage issue, to resolve many of the uncertainties in the process of impact of deep drains

Agricultural drains may perform better than predicted as a result of one or combination of the following factors:

- improved drainage of surface runoff;
- reduced inundation;
- minor leaching of surface soils;
- control of saline run-on;
- improved lateral flow reducing or eliminating the effect of perched watertables in duplex soils;
- greater permeability in profiles than texture-lithology suggests (e.g. influence of preferred pathways is often understated).

This would infer that the construction of deep drains reduces waterlogging and enhances solute leaching rather than just significantly lowering the water table. If the overriding problem is one of surface water management (ie waterlogging and inundation) then shallow surface drains may be a more appropriate option to achieve similar results to deep drainage but at a reduced cost. Grade banks or interceptor drains placed upslope from the problem area may assist in intercepting runoff and subsurface seepage and minimise the occurrence and duration of waterlogging. Drain performance should be assessed within the context of the catchment response, soil profiles, farming practices and landscape water management strategies.

4.Drainage Case Studies

In recent discussions with landholders, community groups, and other agencies, it has become apparent that the issue of agricultural drainage has become narrowly focused on the engineering structures and not the fundamental soil-water and catchment hydrologic transfer processes involved in salinity and waterlogging management.

The principle aim of groundwater drainage is to lower the watertable enabling the landholder to reclaim salt affected areas. Drains achieve this by preventing additional accumulation of salts through capillary rise and evaporation of groundwater and by allowing rainfall to leach accumulated salts out of the upper soil profile into the drains for removal. As a general practice the landholders have confined their drainage activities to the drainage lines within the catchments. This results in an unconventional drainage system overlying the natural system of lateral drains flowing into a main drainage line that has an outlet into a lake or river system.

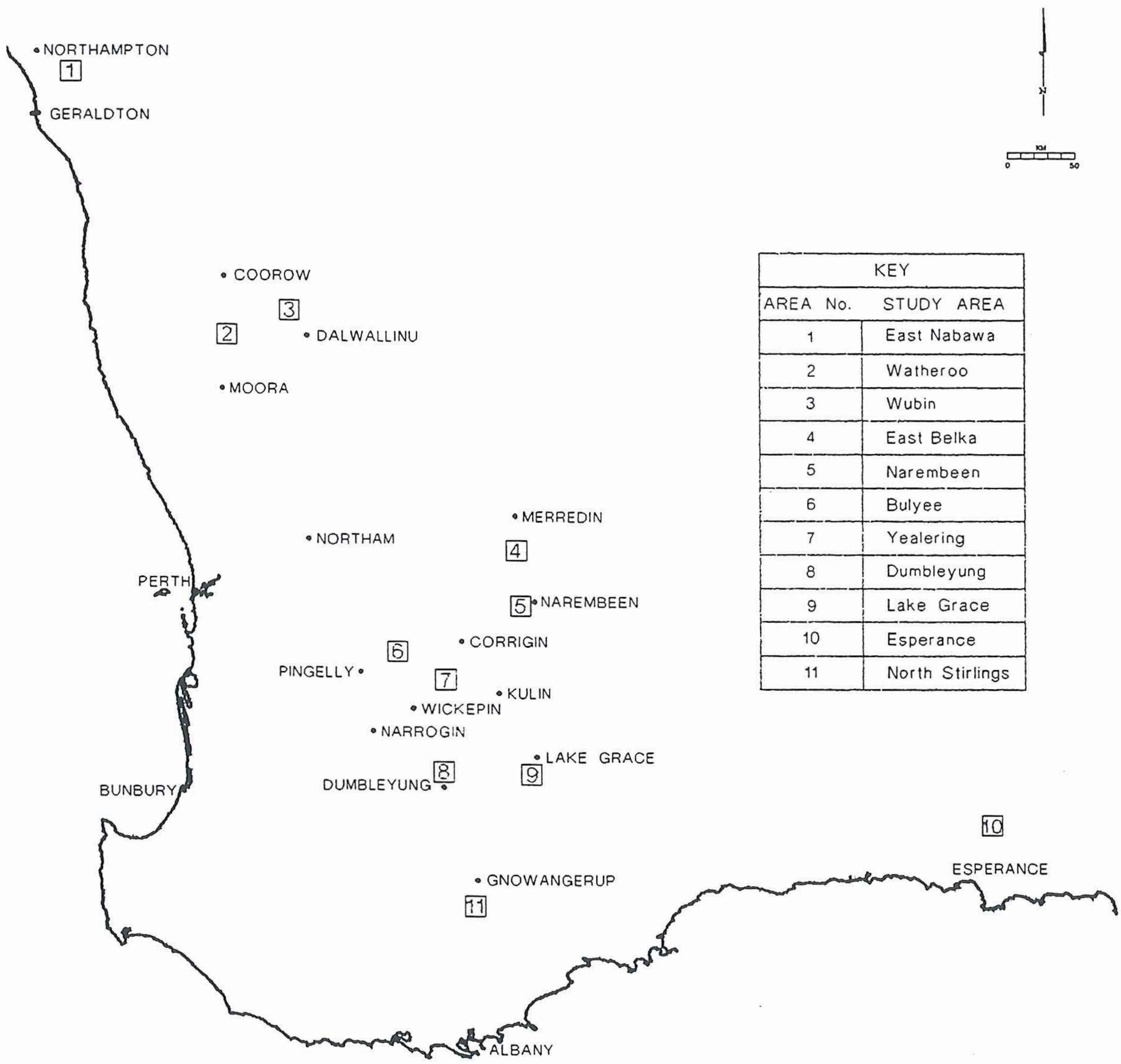
During the late seventies and early eighties interest in saltland drainage increased in the northern wheatbelt covered by the Moora District Office (Shires of Moora and Dalwallinu), due in large part to some local farmers promoting deep drainage following successes on their own farms. Mr Sutherland (in 1978) and Mr Scott (in 1979) near Watheroo were the original initiators of large-scale deep drainage in the Moora district. The interest generated was mainly in open drains, though there was some interest in tube drains and mole drains.

Case studies reviewed were restricted to deep drains (>1.0 metre) that have been constructed in non-irrigated agricultural land within the agricultural region of south-west Western Australia that receives less than 600 mm of rainfall per annum (Figure 1).Eleven study areas were visited and 25 drainage sites (Table 1) were reviewed to assess the effectiveness of (open or closed) deep drains in the wheatbelt agricultural areas. A summary of the data is presented in Table 1, with a detail report on each site given in Part II of this review.

The Department of Agriculture was involved in implementing a series of trials in the Moora and Narrogin districts in the early eighties. The contention at the time was that by monitoring these projects and assessing groundwater levels, soil salinity and ground cover objective measures of the effectiveness of drains in different landscapes would be obtained thus providing a measure of cost-effectiveness and transferability of the techniques to other areas. Four sites near Watheroo and two near Wubin were chosen for the initial drainage studies and five sites near Yealering were developed. The Department of Agriculture considered that deep drains would not be effective in the Yealering district owing to the clayey nature of the subsoils.

The trials were designed to evaluate two methods of drainage; deep open drains and tube drains (although some pumping test evaluations were carried out on Charles Hyde's property). Subsurface (deep) drainage using buried tube drain laterals emptying into an open main drain were constructed on the Hyde, Hudson, Crombie and Elsegood properties to monitor the success of saltland reclamation during the period between 1981-1986. The layout of the tube drains followed the accepted pattern that is tubes placed perpendicular to the main drain 40 to 60 metres apart emptying into a main "trunk" drain.

Deep open drains were constructed on the Scott, Sutherland, Barnes, Corke, Manton and Packer properties. Both the open and tube drains were aimed at lowering the watertable and removing salt from the upper soil profile to reverse the effects of soil salinity and improve productivity. The main aim of the trials were to determine the ability and efficiency of the two methods at reclaiming severely salt affected valley sites (George, *et*



KEY	
AREA No.	STUDY AREA
1	East Nabawa
2	Watheroo
3	Wubin
4	East Belka
5	Narembeen
6	Bulyee
7	Yealering
8	Dumbleyung
9	Lake Grace
10	Esperance
11	North Stirlings

Fig 1 LOCATION OF DEEP DRAIN CASE STUDY SITES

Table 1. Summary of drainage case studies

Region	Landscape Position	Soil Type	Effect	Cost-effective	Other treatments	Off site impacts	Comment
1-East Nabawa							
Site 1.1 (1990)	Valley floor; positioned above lowest point to 'cut off' water movement into the lower landscape.	Heavy red clays;	Limited-negligible on water able. Restricted water-logging and salinity. Improved surface drainage.	Moderate Rye grass and saltbush supply substantial fodder	Trees and saltbush have been planted to the east of the drain.	Discharge clay pan site is now virtually perennial lake. 4000 trees established on perimeter of clay pan have perished due to inundation in 1996.	Initial water levels dropped by 1 metre. No further progress. Reduced the incidence and duration of localised waterlogging. Extremely low hydraulic conductivity of clayey profile. Water levels fluctuate seasonally within 1 metre of the surface. Area was bare an salt affected prior to drainage; At least 20 ha of land now cropped, productivity increased. After initial high discharge drain now only flows in winter. Est. 0.70 m of drain sediment in drain.
2-Watheroo							
Site 2.1 (1978)	Lower landscape-valley floor.	Grey medium to fine soil and sand. overlie calcrete underlain by inter-bedded clay and coarse sand.	Original levels 0.5-1.0 m and rising. Effective in reducing water levels to 1.7-2.2 m bgl up 50 m from drain. Some leaching of soils.	No data.	No data.	81 hectares considered salt-affected using ariel photographs for 1996 up from zero in 1969. Water quality 1024mS/m (1998).	Problems began after clearing light land in 1968/9. More water in creek. Salt lakes acting as detention basin Deepened outlet near National Park in 1978. 240 ha classed as salt-affected 1979. Desilted twice. Attempted to isolate drains from surface runoff. Linked chain of salt lakes drain to National Park. 2 m drains installed in 1980. Deepened to 3m in 1983. Flow est. 1.2L/s
Site 2.2 (1980)	Lower landscape-valley floor.	Alluvial soils. Yellow earth sand. Mottled heavier inter-bedded soils	Decreased watertable depth from 0.6-1.1m bgl. Lower levels could be achieved with deeper drains.	$2.06 per metre (1981)..	Pine trees planted. Area fenced.	No data. Salinity levels in monitoring bores decrease approximately 50% in 4 bores and remained relatively constant in other bores. Drains to creek.	Deep drain used to connect tube drains laid in 30 and 15 m grid pattern. Needs desilting. Still discharging. Effective in lowering watertables in this soil type. Performance limited by depth of lateral tubes (drains). Unstable soil types cause batter slump. Lateral tube drains promote undercutting and slumping.
Site 2.3 (1983)	Lower land scape.	Deep duplex, loamy sand overlying sandy clay. Compacted clay soils at top of subsoil horizon.	Original water table depth at 0.8 m bgl. Yield increased on 7 ha site from 0 to 1.2 t/ha Aroona wheat. Water logging reduced.	Calculations required.	No data.	Est. export of salt 8-9 t/ha/yr. Drains to creek and salt lakes.	Needs de-silting. Seasonal flow response. High incidence of batter slump. Sand layer occurs within 1.6-1.8 m in drain-Ks 1-2m/day. Tube drains installed in March 1984. Tube drains effective at lowering watertable depth from 0.8 to between 1.31 to 1.62. Collector drain constructed in unstable materials. Surface soil salinity lowered due to leaching (EM38 survey).
Site 2.4 (1978)	Valley floor	Alluvial-colluvial soils. Yellow earthy sands.	Depth to watertable increased from 0.50 to 1.2 (north) and 0.65 (south) to 60m distance. Improved crop to north, limited impact south.	No data	No data	Suspect sediment is discharged from drain due to rapid erosion of batters. Water quality 18,000 mg/L (TSS).	A 2m deep drain sunk in March 1981. Bores installed prior to drain construction.-data 1980-1985. Desilted. Flowing but is silted up-seasonal flows. Sandy soils major batter slump. Sediment filled drain to within 0.5 m of surface (in some sections) during Moora flood (March 1999). Poor location of drain.
3-West Wubin							
Site 3.1 (1983)	Valley floor		Reclaimed 20 ha of marginal country. Reduced salinity;	Improved crop growth;	Grade banks, trees, increased cropping, working contours.	Drains to salt lakes	Desilted Silted, seasonal flow. Gypsum and trace elements added to soils to improve productivity.

Table 1. Summary of drainage case studies (cont)

Region	Landscape Position	Soil Type	Effect	Cost-effective	Other treatments	Off site impacts	Comment
Site 3.2 (1983)	Saline valley floor-break of slope	Gravelly clay loam (0.5m) grading to mottled asndy clay overlying laterite or silicrete hard pan; Mottled clay to 2.5-3 metres;	Limited impact in heavy clays (lower valley). Appears effective for drains on break of slope (duplex).	Improved crop growth; reduced salinity;	Grade banks and increased storage capacity upslope. Tree planting; decrease in sheep numbers..	Drains to salt lakes impacts not assessed or monitored.	New drains; Desilting required old drains Successful in some areas. Tube drains blocked. Integrated approach required Silted, but flowing. 0.5 L/s in new drains. Limited leaching of salts from upper profile. Est. Ks 0.01 to 0.08 m/day. Area affected by salinity increased from 122 ha (pre-drain) to 153 hectares (post-drain) Reduced rate of salinity expansion- 3 hectare increase in 7 years.
Site 3.3 (1981)	Saline valley floor-Lower landscape	Red/brown calcareous earth to 1.7m; Underlain by mottled clay. "Coffee rock" indurated layer at 0.90 m.	Limited impact although some revegetation is evident..	No data-reduced or halted salinity expansion.	Continuous grade banks constructed 400m upslope from drain. Level banks installed above grade banks to manage surface runoff.	Drains to salt lakes impacts not assessed or monitored	2m deep open drain, 10 km in length. Part of extensive network in the Buntine-West Wubin area. Effective close to drain (<10m). Crop failure occurred in areas of high soil salinity. Water tables 1.0-1.2 m bgl after drain constructed. Limited leaching of salts (except near drain). Later sections closed deep drain (1986). Volunteer bluebush and grasses cover area, once bare salt scald.
4- East Belka-Kelliberrin							
Site 4.1 (1997)	Valley floor	Duplex soils. Heavy clay soils, underlain by hardpan and weathered granite.	Reduced waterlogging. Draining of perched aquifers and surface runoff. Limited impact on watertable depth.	Not known	No data	No data. Est. average salt yields from two sites 1.3-2.0 t/ha and 0.4-1.5 t/ha.	New drains. 3-5 km of 1.5 m deep drains. Soil permeability ranged from 0.01 to 0.2 m/day and were highly variable. EM 38 survey indicated some leaching at semi-permeable sites. Nil at others. Flow varied from 0.03 to 0.1 L/s. Shallow surface drains could have achieved similar outcome. To improve drainage spacing at 8-15m for heavy soils. Increased costs.
Site 4.2 (1984)	Break of slope/seep	Sandplain	Significant. Reduced watertable by 2m. reclaimed seepage area.	Yes (no data)	none	None Water recovered stored in dam for livestock.	Cost of drains installed to prevent discharge at saline seep detailed in George 1991. Other sites trialed at Holleton and Berbudin
5- Narembeen							
Site 5.1 (1996-7)	Deep drains (2m) placed in existing creek system in bottom of valley floor.	Medium to heavy soils (eg. Mallee sand and loam duplex; morrell; salmon gum clay)	Drain collects surface runoff. Limited impact at this stage. May drain perched water tables. Batter slump and siltation evident.	Opinion varies. No data available.	Trees and shallow drains examined but not considered effective for magnitude of problem.	No Data. CALM refused permission for drains to be constructed in the reserve down stream.	Salinity and waterlogging major problem in broad flat valley system. New drains Lateral drains. Seasonal flows. Drainage designed by contactor. Not all landholders convinced drains were best option. Percentage of healthy vegetation <10%. Occasional sand lens evident in drain batters. Zone of impermeable mottled clay grading to laterite coffee rock at between 0.3 and 1.0 metres
6- Bulyee							
Site 6.1 (1996)	Closed deep drains in valley floor near existing creek line.	Medium to heavy soils (eg. Sandy duplex; morrell; salmon gum clay)	Little change in watertables.	Improved productivity suggested. No data	Not investigated.	No data.	New drains Limited success. Positive feedback. Lateral drains. Seasonal flows. Zone of impermeable mottled clay grading to laterite coffee rock at between 0.3 and 1.0 metres. Drains perched watertable. Drains designed for lower landscapes. Flow not measured. Car tyres in lateral drains as experiment.

Table 1. Summary of drainage case studies (cont)

Region	Landscape Position	Soil Type	Effect	Cost-effective	Other treatments	Off site impacts	Comment
7-Yealering							
Site 7.1 (1982)	Mid to lower slope. Break of slope at the base of sandplain-salmon gum/ti-tree clay flats.	Sandplain soils. Salmon gum clays.	Limited or no impact.	No. Not going to install more.	95% of drains fenced and area near drain re-vegetated (trees, shrubs and grasses).	None	Closed deep drains. Seasonal variation in water table depth. Water levels remained above 150 cm and within capillary range of soil surface. Discharge from the drain decreased. None noted in January 1999.
Site 7.2 (1982)	Valley floor	Salmon gum clays.	Silted-tube drains blocked. Drain acts as interceptor for water moving downstream.	Crop improvement downslope from drain.	W-drains;	No data	Initially, but tubes blocked Tubes blocked. Some secondary surface erosion evident. Minor improvement in crop production. Watertable at 0.9m (Jan. 1999)
Site 7.3 (1982)	Valley floor-drainage line	Sandplain soils. Salmon gum clays	Reduced water-logging. Improved productivity and access. No impact on water tables on salt flat.	Improved productivity ($1000/km)	W-drains and grade banks. WISALTS	No data	Alleviated waterlogging. Saline areas evident. Piped inlets for surface drainage undercutting batters causing slump. Pooling of water behind spoil causing salinity. Maintenance 7-10 years (1996). Long term evaluation required due to low-transmissivity of clays. Poor placement of drains may contribute to there performance. Flood run-on experienced from upper valley.
Site 7.4 (1982)	Valley floor	Salmon gum clays.	Reduced water-logging. No impact on water tables	Improved productivity. ($1000/km)	Tree planting. WISALTS	No data	Alleviated waterlogging. No measurable fall in water levels. Not effective drain-seasonal factors more important.
Site 7.5 (1982)	Valley floor-break of slope	Sandplain soils. Salmon gum clays	Improved drainage from sandplain. Area below drain remained waterlogged.	No data	Lateral drains.	No data	Improved drainage from sandplain. Lower flats remained waterlogged. Preferred pathways influential. Maintenance 7-10 years. Reduced salinity expansion.
8-Dumbleyung							
Site 8.1 (1998)	Saline valley floor	Grey clays. Sand seams present.	Too early to judge effect.	Unknown. Depends on the final result.	Scraper drains and W-drains tried initially.	Initial water quality 5000 mS/m now 5600 mS/m.	New drains Spoil heaps eroded. Flow rate est. 2.3 L/s. Some controlled inflow of surface water. Will not be installing further drains unless current project is successful.
Site 8.2 (1998)	Dissected Salmon Gum valleys.	Salmon Gum valley soils	Too early to judge effect	Unknown. No data as yet.	Trees; revegetation.	Downstream impacts not evident (as yet).	New drains Country drier. Trees healthier. Flooding along side drain. Seasonal variation in drainage flow. Flow rate est. 2.3L/s (>2000 mS/m).
Site 8.3 (1985)	Seepage area: Valley floor; Break of slope to the west; Creekline to the east; Large recharge area upslope.	Avoided sandy areas during construction. Sandy Clay duplex soils. Heavy clay subsoils	Mixed response:- effective in some areas, but drain has had no effect in areas near seep on valley floor, approx. 300 m from break-of-slope. Improved marginal country	Farmer considers cost effective in places, where saline expansion has been contained. Not in others. Would construct more drains.	Installed contour banks and has re-vegetated sections of the farm. Fenced remnant vegetation..	No monitoring of offsite impacts. Discharge into Doradine Creek was already occurring via the seepage area at base of slope on valley floor.	Drains worked in some areas, useless in others. Halted spread of salinity in marginal land in section 500 m long, for 10-12 years, but has become in-effective due to siltation.. Needs cleaning, clogged with silt and vegetation. No batter slump, surface inflow in seepage areas on valley floor but not upstream. Drainage was considered by landholders as most appropriate treatment of the site. Discharge measured @ 0.16 L/s (1370 mS/m). Water discharged from drain is less than amount discharge at surface by seep.

Table 1. Summary of drainage case studies (cont)

Region	Landscape Position	Soil Type	Effect	Cost-effective	Other treatments	Off site impacts	Comment
Site 8.4 (1990)	Broad valley floor. Modified creekline. Drain follow contour of low points in valley.	Sandy loams, sandy clay loams and shallow sand-clay duplex soils. Coffee rock clay layer of variable thickness evident at 0.30 m	Improved productivity of marginal land near drain. Improved growth of native vegetation. Reduced hydro-period and waterlogging.	Drain not considered as cost effective by landholder, but drains have improved productivity, reduced waterlogging and restricted salinity expansion.	Minimum tillage improved surface drainage; Surface water management and Landcare works installed upslope to assist drains. Deep ripping; Piped inlets for surface ponding; per-ennial pastures trialled.	Drain discharges near main road. No immediate impacts evident. Landholder responsible for damage to road in agreement with Shire. Water quality not to exceed 5000 mS/m.	Minimal silting. Surface water excluded Localised depressed water levels. No obvious offsite degradation hazards. Closed drain. EPA and CALM involved through NOI assessment process. Flows recorded (02/99) 0.05 L/s (3300 mS/m) start of drain; 0.11 L/s (19710 mS/m) mid-drain, 0.16 L/s outlet (4850 mS/m). Sand seams evident in sections of the drain. Relatively fresh water discharged into drain. Flow increases during winter discharge (est. @ 0.34 L/s). Will not be installing further drains until convinced current drains are working.
9- Lake Grace							
Site 9.1 (1989)	Drains follow contour approx. 1m above break of slope near valley floor.	Coarse sandy loams.	Landholder considers drains have controlled surface water and groundwater. Area saline affected decreased; vegetation growth improved.	Implied cost effective through improved wheat yields; Paddocks back into production in 5-10 years.	W-drains tried.	Drains discharge into creek that flows into Lake Grace. Saline environment. Impacts not monitored.	Installed to control waterlogging and salinity. Difficult soils to construct drains extensive erosion and batter slump. Possible leaching of salts as area affected has decreased. Improved crop yields. Regular maintenance required (7-10 years). Landholder may construct more as they have been effective. Estimated hydraulic head of 2.5-3.0 m above lower valley floor.
Site 9.2 (1972)	Valley floor near break of slope.	?	Improved productivity on about 300 hectares	Improved crop yields; 1972 -$5,000 on 3-4km drains. Spent further $30,000 on 10 km of drains since 1980..	?	Drains flow to Mears Lake on to Avon River. No data on off-site impacts.	10-15 kilometres of drain with a maximum of 1.5 m. Began drainage network in 1972. Redirects runoff from the Kunjin and Wogerlin catchment that caused waterlogging. Farmer happy with performance and considers them to be a good investment.
10-Esperance							
Site 10.1 (1986-7)	Drainage depression surrounded by flat plain with less than 3% slope.	Grey shallow alkaline sandy duplex soils. Scaddan Series	Minor impact on watertable. Used for management of perched watertables and surface water.	Managed as saline land. Farmer considered it to be cost effective as it halted spread of salinity (cost $8,000)	W-drains and trees (Euc) trialled prior to drain construct. Gully fill and grassed waterways added to reduce erosion	Disposal into natural saline salt lake system, part of the upper Neridup creek. Water evaporate before reaching creek system. No impacts evident at this stage. Minor sediment deposits (VISUALY ASSESSED).	Flows most of year (0.2 L/s) Area of saline land unaffected. Improved surface and sub-surface drainage to allow establishment of trees, saltbush and barley grass. Watertables not affected. Most siltation occurred in years 3-4 slight batter slump. Surface water allowed to enter drain via gaps in spoil heaps and shallow spur drains.
11-Nth Stirling							
Site 11.1 (1983-4)	Lower valley.	Duplex soils. Red brown loam to pale sands over silty clay; Fine to medium sand lens..	Watertable lowered near drains. Salt affected area near drain reduced by 27 ha. 8 ha cropped.	Not cost effective. Area required to be recovered is 40 ha. Total cost $30,000.	No data.	Increase sediment and salt discharge to six-mile creek system.	!0 km of drains constructed. Overall effect of drainage system could not be measured and its long-term impact not predicted. Some visible improvements in crop production near drain. Reduced incidence of waterlogging. Considerable erosion on either side of drain. Batters relatively stable. 1300 ha in catchment salt affected. Low gradients. Variable flow 0.2-2L/s. 8300 mS/m

al. 1990a). Observation bores and piezometers were installed to monitor the effect of the drainage systems on the groundwater.

During the eighties a series of drainage trials were established (at Dixons) within the eastern wheatbelt to study the impact of tile and open drains to manage sandplain seeps. Results reported by George (1991), indicated that deep drains could reclaim sandplain seeps and that livestock could use the water recovered. Complementary revegetation and drainage systems were also trialed and developed with some success.

Additional deep drainage sites were examined at the Green (East Nabawa) and Syme (West Buntine) properties and in the Bulyee and Belka Valley. Most sites had been active or constructed for a minimum of ten years, with the exception of five sites including the Wakeman and Bulyee Catchments (1996); Belka Valley (1997); and the Cook and Bairstow (Dumbleyung) properties (1998). The sites represent a range of soil types and conditions, but are almost all placed within the lower landscape or saline valley floors. The exception is those drains constructed on the break of slope, or change of landform from sandplain to clay soils. Hard pans were identified in most drains in the Moora district and were comprised of laterite, silcrete or carbonaceous "coffee rock". Heavy clay subsoils were a general feature at most drainage sites and the degree of connectedness of preferred pathways, sand lenses and other permeable materials influenced the transmissive properties of the soils feeding the drains.

Salt crystallisation and induration characterised drains constructed in the heavier clay soils, which reduced the "seepage" capability of the drain walls limiting baseflow. Siltation of the drains was a major problem in areas constructed in more permeable or less stable sites (ie Sutherlands) or where surface runoff was able to access the drain causing batter slump. A number of alternative treatments were tried at most sites either prior to or after drain construction (eg. grade banks, level banks, w-drains, working to contour, direct drilling and tree planting) with varying degrees of success. A summary of the perceived advantages and disadvantages of drains is given in Table 2.

Table 2 Summary of the outcomes of drainage case studies from the landholders point of view

Advantages	**Disadvantages**
➢ Reduced soil salinity through leaching (mainly lateral tube drains); ➢ Reduced waterlogging and inundation period; ➢ Increased discharge; ➢ Increased productivity; ➢ Effective at break of slope and in combination with other treatments; ➢ Reclaimed marginal land ➢ Reduced the rate of salinity expansion;	➢ Not cost effective; ➢ Limited watertable drawdown; ➢ Poor construction and design; ➢ Increased saline and sediment discharge; ➢ High maintenance cost (with few drains maintained); ➢ Downstream flooding and inundation; ➢ Other solutions may have been just as effective at a reduced cost. ➢ Spoil and drains restrict access to areas of the property ➢ Low gradients and hydraulic heads

The general opinion of the landholders surveyed in this review is that the 'drains work', but that the degree of their effectiveness varies widely. Of the 25 sites reviewed, 18 landholders indicated that the drains had alleviated waterlogging and salinity problems to some extent, although the cost-effectiveness of the drainage projects has not been assessed in detail.

Four landholders suggested that the drains had no, or limited success, with three undecided. In general, most landholders were looking or had looked at alternatives to drainage, such as trees, land conservation earthworks and changing cropping systems to complement their drainage programs. There was a general feeling that more could be achieved by integrating options for farming systems and water/salinity management, and that length of time required to obtain a positive result was an important factor in assessing the success of drains.

5. Economic Analysis

5.1 A comparative economic analysis of drains

The drainage studies have had a hydrological focus and in the main have concentrated on measuring the impact of deep drainage on the groundwater table. As such, changes in crop production resulting from drainage were not formally assessed. However, anecdotal crop yield information was gathered for a range of sites where farmers have constructed deep drains. This information has been complied and presented as a series of case studies on drainage in the wheatbelt of Western Australia (Part II of this review). The nature of the data presents verification difficulties and the evidence for crop improvements does not conform to standard methods normally applied. The improvements claimed through the use of deep drains were, in some cases, not consistent with the measured impact of drainage on the local groundwater table. However, the drains may have had other effects on soil water relations, which were not measured.

Determining the profitability of drains is complicated by the relatively large number of factors that can influence the impact of drainage on crop production and net returns. The inherent variability of these factors between sites is also of concern in determining any statistically significant differences between sites. The variability and the uncertainty within the data gathered in each of the case studies suggests that it is perhaps more appropriate to determine the minimum values of the important parameters that will ensure that the costs of drain construction and maintenance are covered by increased returns. In other words, conduct break-even analyses.

The aim of the following discussion is identify the most important factors from the point of view of profitability, and assess whether the minimum values of the parameters required to break-even, compare favourably to the known range of these values.

5.2 Factors affecting the profitability of banks and drains

The economic problem is addressed by comparing the discounted cashflows that occur prior to, and after construction of the drains. There are a large number of factors that affect the cashflow and hence profitability of drains. However only seven factors directly affect the profitability of earthworks and include:

1. Cost of construction;

2. Cost of maintenance;
3. Frequency of maintenance;
4. Number of years after construction that land is reclaimed;
5. Area reclaimed;
6. Increase in average returns per hectare after reclamation, and;
7. Interest rate.

5.2.1. Cost of construction.

The cost of construction varies between regions but appears to be independent of the soil characteristics. However the major factor affecting construction costs is the type of drain (ie. deep, shallow, mole or tile drains). Deep drainage (as opposed to banks) is one of the most expensive options used to reduce the incidence and duration of waterlogging, and in the majority of cases this appears to be the primary cause of decreased yields.

5.2.2. Cost of maintenance.

Maintenance costs tends to be a fixed proportion of construction costs and appears to be independent of soil characteristics. The type of earthworks employed affect the apportioned costs with deep drains costing around 65% of construction costs, while grade banks cost around 40% of construction costs.

5.2.3. Frequency of maintenance.

Frequency of maintenance depends largely on soil type. Drains constructed in heavier soils are less erodable and therefore are less prone to silting as opposed to drains constructed in lighter sandier soils. The frequency of maintenance can vary from 3-5 years for lighter soil types, to 7-10 years on heavier soils.

5.2.4. Number of years after construction that land is reclaimed.

The number of years required for the land to be reclaimed depends on the annual rainfall pattern, how quickly the soil profile is drained of excess water, and where salinity is a problem, for the salt to leach below the root zone. The gradient and the hydraulic conductivity of the site being drained are the two major factors that influence the rate of reclamation. Heavier clay soils (without preferred pathways) conduct water less quickly and therefore take longer to drain and than lighter sandy soils. The drains are often influential in duplex soils where the presence of the drain enables a more rapid removal of perched watertables. A delay of only 2-3 years may reduce the cashflow of the drains sufficiently to make construction unprofitable.

The delay to reclamation is important to consider because it affects the increase in average returns per hectare over time due to drainage. For example, if income is increased because of reclamation only after a period of time (say 3 years) the average return over the planning horizon (30 years in this case) will be lower compared to the average increase where yields are increased in the first year. The longer the delay in reclamation the lower the average return over time.

5.2.5. Area reclaimed.

The area that is reclaimed after construction of the drains is the most uncertain parameter. This is due in part to the difficultly in measuring or estimating the area reclaimed, especially where the primary factor affecting yield is seasonal waterlogging. The area of waterlogging varies between seasons, as does the impact on yield. In some cases the long term trend is influenced by a rising watertable that affects the extent and duration of water logging. The total area affected is difficult to measure unless seasonal estimates have been made over successive annual periods. Accurate estimates are expensive and therefore are unlikely to be made for many sites.

The uncertainty regarding the area reclaimed has implications for the economic analysis because it is critical to determining profitability. Small errors in the estimates of area reclaimed could have a large influence on the estimated financial benefits or losses attributed to drain construction.

5.2.6. Increase in average returns per hectare after reclamation.

The increase in average return per hectare depends largely on the increase in yield and the optimal rotation of the reclaimed area. On the face of it the increase in average returns is easy to estimate, but in reality it is more difficult. Increasing the arable area of a farm will usually result in higher average net returns but invariably there are costs associated with a higher productive area. Resources of farms are limited and an increase in area will mean that the limited resources are spread more thinly across the farm. This will often mean that the measured yield increase in the reclaimed paddock is more than the actual increase in yield.

An example of this is where there is an increase in the area of crop sown. In many regions of WA there are yield penalties associated with delayed sowing, so that the later sown paddocks tend to yield less than they would have had they been sown earlier. If a reclaimed area is sown to crop then seeding is likely to be delayed in other paddocks. This will reduce the yields in these paddocks compared to yields occurring prior to reclamation of waterlogged or saline areas using drains. The decrease in returns from delayed sowing needs to be subtracted from the increase in returns of the reclaimed areas. However, it may be assumed that the reclaimed land may be sown last.

5.2.7. Interest rate.

The interest rate at which money can otherwise be invested is the opportunity cost of constructing drains and banks. It could have a large impact on the viability of the expenditure on earthworks. However it does not tend to change much over the medium term and therefore cannot be changed in the scenario analysis. It is assumed to be constant for all expenditure on earthworks at 5%.

To determine the relative importance of the parameters described above a spreadsheet model was developed. Given the uncertainty in the area reclaimed the main focus of the model was to determine the increase in productive area per kilometre of drain required to recover costs associated with drainage.

5.3 Scenario Analysis

Ten scenarios based on varied costs of construction, frequency of maintenance, maintenance costs and change in gross margin per hectare were run to assess the sensitivity or influence of each factor on the minimum affected area to be reclaimed required to break even (Table 1). Annualised costs and returns and the increase in productive area required to break even were calculated are illustrated in Tables 2(a-c).

The results indicate that deep drains, which cost around $5000/km to construct, need to reclaim a minimum of 5 ha/km and depending on frequency of maintenance and gross margins may be required to reclaim up to 18 hectares per kilometre of drain to break even. This equates to a drainage zone that extends between 25 and 90 metres from either side of the drain. While this may be considered to be a relatively small distance the extent of the influence of the drain on the watertable varies markedly according to soil type.

In heavy soils, the drawdown on the water table may only extend to a distance of 10 metres either side of the drain. This is equivalent to a total area of 2 hectares/kilometre of drain. In sandier profiles the influence of the drain may extend (in exceptional circumstances) up 80 metres either side of the drain (or 16 ha/km). However, in most cases reviewed the areal extent of the impact of the drain on localised groundwater tables was generally less than 20 metres (or 4 ha/km) and rarely exceeded 40 metres (or 8 ha/km).

The area required to be reclaimed increases with lighter soil types as the frequency of maintenance drops from 7-10 years to 3-5 years as the batters are less stable and prone to erosion. Scenario five (D5) illustrates the impact of increased maintenance costs on the area required to break even (up from 5 ha. to 11ha) and the increase in annualised cost of the drains (up from $594 to $968).

The increase in returns per hectare has a marked affect on the profitability of using drains to ameliorate waterlogging or salinity. Scenarios D1 to D3 and B1-B3 assume that the higher levels of production lead to an increase in the gross margin of $140/ha. This is only likely to be achieved where production prior to the construction of the drains is close to zero. An increase in the rotational gross margin of $140/ha can be achieved with pulse yields of around 0.8t/ha ($250/t) and wheat yields of around 1.7 t/ha for 2 years following the pulse crop. The gross margin could be higher if Canola was to be introduced into the rotation, however it is likely that the increase in net returns would be lower for much of the wheatbelt than the suggested $140. Gross margins reduced for three scenarios (D4, D6 and B4) to demonstrate the influence of net returns on the area required to be reclaimed (Table1). An increase of only $70/ha results in a significant increase in the productive area required to break-even. An increase of between 1 to 2 hectares is equivalent to an increase in the distance from the drain of between 10 and 20 m/km. Low returns could be expected for a number of years after reclamation, particularly for soils that are structurally degraded and nutrient deficient as a result of salinisation.

Measurements on some sites where drains have been installed suggest that drains often lead to improved production through ameliorating waterlogging caused by surface water runoff. In areas where this is the root cause of the waterlogging problem less expensive solutions are available. For example a series of well-planned grade banks can prevent water pooling in low-lying areas, by redirecting runoff in the upper catchment into preferred grassed waterways or storages. The economic potential of effective grade banks is illustrated in Scenarios B1-B4. The results show that less than 1 hectare per kilometre of bank needs to be reclaimed to break-even, owing to the lower costs of construction and maintenance.

Table 1. Sensitivity analysis for 10 scenarios based on varied costs of construction, Gross Margins, and maintenance schedules for Drains (D) And Banks (B)

Scenario	D1	D2	D3	D4	D5	D6	B1	B2	B3	B4
Years to reclamation	3	3	3	3	3	3	3	3	3	3
Increase in GM/ha	140	140	140	70	140	70	140	140	140	70
Construction costs	6000	5000	4000	5000	5000	5000	3500	2500	1500	1500
Frequency of maintenance	8	8	8	8	4	4	7	7	7	7
Maintenance costs	0.6	0.67	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3
Annualised increase in GM	$110	$110	$110	$ 55	$110	$ 55	$110	$110	$110	$ 55
Annualised costs of drains	$713	$594	$475	$594	$968	$968	$347	$248	$149	$ 149
Area required to break even	6	5	4	11	9	18	3	2	1	3

Table 2(a) Annualised increase on profit relative to scaled Gross margins and years to land reclamation.

Increase in GM ($)	Increase in profit – annualised ($)									
	Years to reclamation									
	1	2	3	4	5	6	7	8	9	10
20	19	18	16	15	14	13	12	12	11	10
40	38	35	33	31	29	27	25	23	22	20
60	56	53	49	46	43	40	37	35	32	30
80	75	70	66	62	57	54	50	46	43	40
100	94	88	82	77	72	67	62	58	54	50
120	113	105	99	92	86	80	75	70	65	60
140	131	123	115	108	101	94	87	81	75	70
160	150	141	132	123	115	107	100	93	86	80
180	169	158	148	138	129	121	112	104	97	90
200	188	176	165	154	144	134	125	116	108	100

***Costs of drains have NOT been deducted**

Table 2(b) The annualised cost of drainage construction per kilometre based on maintenance costs and original cost of construction

Cost/km ($)	Annualised cost of drains ($)									
	Frequency of maintenance (years)									
	3	4	5	6	7	8	9	10	11	12
1000	238	194	160	140	133	119	114	102	99	97
2000	475	387	320	281	266	238	229	204	199	195
3000	713	581	480	421	399	356	343	306	298	292
4000	951	774	639	562	532	475	458	408	398	389
5000	1189	968	799	702	665	594	572	509	497	486
6000	1426	1161	959	843	798	713	686	611	597	584
7000	1664	1355	1119	983	931	831	801	713	696	681
8000	1902	1548	1279	1124	1065	950	915	815	796	778

Table 2(c) Estimated area required to break even based on an increased GM of $140, 3 years to reclamation and maintenance cost set at 60% of construction costs.

Cost/km ($)	Area reclaimed - break even									
	Frequency of maintenance									
	3	4	5	6	7	8	9	10	11	12
1000	2	2	1	1	1	1	1	1	1	1
2000	4	3	3	2	2	2	2	2	2	2
3000	6	5	4	4	3	3	3	3	3	3
4000	8	7	6	5	5	4	4	4	3	3
5000	10	8	7	6	6	5	5	4	4	4
6000	12	10	8	7	7	6	6	5	5	5
7000	14	12	10	9	8	7	7	6	6	6
8000	17	13	11	10	9	8	8	7	7	7

Years to reclamation	**3**
Increase in GM/ha	**140**
Maintenance costs	**0.6**

Given the obvious improved economic potential of using the appropriate engineering solution (ie. banks versus drains) it is recommended that the root cause of the problem be established (ie. problem definition is paramount) and the best-designed solution be implemented to achieve the highest return on the capital investment. The physical characteristic of the site require investigation and should include an examination of the soil profile, slope, hydraulic gradient and depth to groundwater; in combination with an investigation of the catchment hydrological processes that are the root cause of the problem.

6. Drainage Review

The survey has identified that one of, or a combination of, the following influences the effectiveness of drains:

- groundwater gradient;
- permeability of soils;
- poor design;
- batter collapse;
- iron oxide precipitation and pore blockage of drain walls;
- sedimentation (poor grade control);
- at risk of mass failure in floods;
- recharge of discharged flow sources upslope;
- machinery and livestock access, and;
- offsite problems associated with downstream discharge.

The factors may not be significant at every site, but for the sites that were surveyed at least one of these factors influenced the effectiveness of the drains.

Drains placed at the 'break of slope' appear to provide significant improvements in the occurrence of salinity and waterlogging. For example, a significant change in the incidence of waterlogging and improvements in crop growth were noted by several farmers. However, drains installed on flat, low lying areas had a highly variable impact on waterlogging and salinity levels, with most farmers reporting only a limited impact on crop production and almost no effect on groundwater levels.

The drains surveyed had rarely altered the groundwater conditions (saturated zone) beyond 80 metres from the drain in extremely permeable sites (eg. sandplain sites) and only had a demonstrable impact on watertables less than 10 metres from the drain in low permeability typical valley soils. The two major factors restricting the effectiveness of deep drains are the low permeability of the sub soils and the low hydraulic gradients of the wheatbelt landscape. Some of the factors that affect the efficiency of drains are listed in Table 3.

The assessment of some drainage sites suggest that the improvements in production recounted by the farmers were often achieved through ameliorating waterlogging caused by surface water runoff. In areas where surface water management is the major issue, less expensive options are available. For example a series of well-planned grade banks can reduce waterlogging and the frequency of inundation by redirecting runoff in the upper catchment into preferred grassed waterways or storages. The economics of effective grade banks versus deep drains has been illustrated in the economic analysis that suggests that the regardless of gross margins the area required to break-even is generally 50 percent less for grade banks owing to the lower costs of construction and maintenance.

Given the obvious improved economic potential of using the appropriate engineering solution (ie. banks versus drains) it is recommended problem definition is paramount and that the best designed solution be implemented to achieve the highest return on the capital investment. The physical characteristics of the site require investigation and should include an examination of the soil profile, slope, hydraulic gradient and depth to groundwater; in combination with an investigation of the catchment hydrological processes that operate within the farm environment.

The physics of drainage is not well understood by most landholders and drainage contractors. Therefore conclusions about the impacts of drains are often incorrectly assigned and the belief that only deep drains are effective is promulgated. Equally agency personnel do not have a clear understanding of the motives of farmers installing drains. There is an assumption that farmers' management decisions should only be driven by profit. Thus there is a communication breakdown which can polarise the community and agency people. These communication issues are outlined in Table 3.

Options

Shallow drains, properly combined with other water management practices (agronomic manipulation and strategic tree planting) may be an alternative on some properties to manage excess water. Anecdotal evidence from farmers visited during this survey indicated that shallow drains have reduced the expansion of salinity and the incidence and duration of waterlogging on some areas.

Table 3. Factors affecting the efficiency of drains and impediments to effective communication on drainage between Agriculture WA and farmer groups.

Ineffective drainage systems	**Communication problems**
• poor site conditions; • inadequate site investigations (site hydrology); • lack of science in 'design and monitoring' stages; • lack of quality in engineering design; • the 'one design' (or machine) suits all sites philosophy; • inappropriate design and installation (private industry); • lack of maintenance reducing efficacy; • impacts of large floods events ignored; • failure to account for off site effects of water disposal.	• lack of knowledge of hydrological processes involved and their application; • lack of preliminary site investigation; • large drainage system failure to deliver the expected outcomes; • no or minimal resolution of off site consequences (salt loads, stream flows, flood risk, sediment loads); • illegal drainage construction; • unsightly nature of drains; • uninformed debate and poor institutional arrangements; • ineffective, indecisive, ill informed legislative / regulatory environment; • limited experience or training of extension officers involved in catchment planning; • limited communication on drainage between agencies and clients (farmers).

From the review of existing drains it is clear that the commonly used forms of drainage (especially open trench systems) may not be the most, cost effective method of managing groundwater and controlling dryland salinity. Closed drains offer some alternative in areas with unstable soils or where flooding is likely.

There is also some confusion and differences of opinion as to what constitutes a successful drainage system. The advantages and disadvantages from the landholders point of view are given in Table 2.. Measures of success differ between individual landholders. Some indicate that if the drain is seen to alleviate problems associated with waterlogging and salinity then it is successful irrespective of whether the water tables were lowered or the crops produced recovered investment costs. Success is often substantiated if the landholder is able to work on land that was previously difficult to farm.

In many cases the outcomes achieved may have been accomplished through alternative engineering and biophysical options. Indeed in some case studies it is considered that a combination of factors such as: grade banks and storages (dams) constructed upslope, reduced annual rainfall; reduction in sheep numbers, a return to total cropping systems and changes in farm management practices have contributed to the success observed over the 10 to 15 year period.

The difficulty in determining the *measures of success* adopted by farmers, the agency and the farming community are pivotal to understanding the decision processes employed by the two groups in assessing drainage projects. However, once common ground is found and information traded in a cooperative and beneficial environment, then the possibility exists to implement reforms on drainage and, more importantly, develop integrated water/recharge management in agricultural landscapes. The wheatbelt catchments are characterised by low permeability, low gradients which may intermittently yield large quantities of saline water. The ramifications of applying simplistic, universal engineering solutions to large areas over which hydraulic conditions are highly variable, are often hidden, dramatic or inconsequential. Consequently opinions on the effectiveness and success of drains or drainage options is highly variable and often counterintuitive.

Drainage systems should therefore be viewed as part of a package of water management options (Appendix B). Farmers can adopt low recharge farming systems that have elements from the proposed five categories listed below. To be effective an integrated approach is required where the impact of alternative management strategies and possible synergies between systems are examined

Lack of knowledge, limited planning and inappropriate design for specific site conditions are the main cause of past failures of treatments. Therefore, the suggested direction of the development of new integrated farming systems that are focussed on landscape water management are:

1. Increasing the water use of annual crops and pastures;
2. Increasing the area of perennial vegetation;
3. Employing surface water management systems to reduce the incidence and duration of inundation and waterlogging;
4. Using deep groundwater pumping and enhancing discharge (ie. beneficial use of discharge in evaporation ponds or via aquaculture);
5. Protect, maintain and expand areas of native vegetation.

7. Conclusions

Drains having the greatest impact were those installed at the break of slope. This was because either their location was at a point of stronger upward flow, the discharge areas were small and/or as a result of interaction with dykes (or other geological constraints). Drains installed in low, flat valley floors appeared to be less successful. Drains constructed in 'thin valley' depressions with 'thin' parallel salt (< 20 m) may be effective, but the use of surface drains should be investigated prior to the construction of deep drains.

A flood risk assessment should be conducted before the drains are installed to ensure that the contribution to peak flow discharge downstream is not detrimental to the capacity of the system to accept the flow. In addition complementary design criteria need to be made available and the high risk of failure due to flooding (ie valley) should be highlighted. The costs associated with regular drain maintenance vary with drain design, soil type, stability, and the risk of erosion and sedimentation.

Based on this review it is evident that site definition, engineering design standards, appropriate layout and construction techniques, impact assessments for downstream neighbours and wider community consultation is required before any large drainage system is adopted. Careful site evaluation is required to assess the feasibility of drainage, with each proposal for drainage treated on its merits. Furthermore, it is clear from the Salinity Action Plan that implementation of drainage works must be consistent with achieving the goals through integrated water management at landscape and catchment scales. Therefore, drainage must meet the integrated goals of sustainable land and water use and conservation of natural diversity.

8 Recommendations

These recommendations are made to assist in the formulation of policy and to guide research, development and communication related to land drainage.

Research / Investigations

1. Completion of the current review of case studies.
2. Continuation of monitoring of existing 'base-line' projects (eg. Bulyee, Belka and Nabawa).
3. Identification and monitoring of the downstream impacts of deep drains (ie. salinity, sediment and nutrient exports).
4. An intensive and long-term site investigation of selected areas proposed for drainage. Investigation to include monitoring prior to drain construction. Inclusion of a site within each SRD region or major landscape system.
5. Agriculture WA (SRD) to support the GRDC proposal jointly submitted with CSIRO / UWA to investigate the hydrology and impact on drains at Narembeen
6. Agriculture WA (SRD) to support (if required) the involvement of the CHG in a proposed NDSP2 Concept Project review of the effectiveness of engineering systems.
7. Follow-up monitoring of previous sites where significant data are available. To include completion and publication of drainage project review (15 years on).
8. Assessment of the implementation of the drainage options and actions as described in Appendix B (Table B2).

Development / Communication

1 Development of a decision support system to enable landholders to make informed and rational decisions concerning drainage and water management options.

2 Provision of documented guidelines for drainage best practice in design.

3 Publication of drainage information (ie. case studies, monitoring projects) and provision of a framework to adopt an integrated approach to drainage for different regions within the agricultural areas of the South-west (ie, break-up of regions based on rainfall, soils salinity problems etc).

4 Promote 'best practice' (eg closed drains; on-farm storage and beneficial use, alternatives) through field days, publications and the proposed multi-disciplinary advisory group.

Policy

1 Formation of an earthworks (drainage) contractors association.

2 Accreditation and training of earthworks contractors to improve standards and regulation within the industry.

3 Development of multi-disciplinary technical advisory teams (ie. "Flying Squads") based at Moora, Merredin and Katanning to provide information on best practice, assist with "water problem" assessment and planning solutions/options to landholders and community groups.

4 Development of a Memorandum of Understanding between the relevant agencies (CALM, DEP, WRC, AGWEST) to provide for a 'one stop' approach to drainage planning and regulation.

5 Promote and foster the concept of independent farm water management strategies in variable landscapes as part of coordinated drainage within catchments.

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Appendix A.

Table A.1. Design Criteria for deep drains

Engineering Design and Site suitability Criteria (Deep drains):

High permeability	for lateral impact and leaching
Adequate gradient	to drive water movement, without damage
Stability	to prevent wall collapse and sedimentation
Surface water management	to prevent erosion and sedimentation
Periodic saturation	for solute flushing
Capacity	ability to cope with extreme rainfall events (volume, freeboard)

Construction systems and designs (require):

An accredited contractor	for security of job specifications
Appropriate machinery	to design specifications/for maintenance
With a maintenance plan	for long term effectiveness

Monitoring Program (require):

A system to be installed on site	to measure effects on water tables changes in soils, solutes and water quality variations in crop productivity
A system installed offsite	to measure the impacts of drain outflow saline discharge, sediment yield, flood runoff

Table A.2(a) Drainage Options for agricultural drainage systems and comments on best practice use.

Type	Construction	Options	Use	Problems
Deep drains	excavator, other specialised machinery	Open, with or without banks, (closed), +/- connected on a catchment basis	extensive agric., valley floors	clays, low permeability, unstable soils, runoff, velocity (erosion, deposition, silting), poor lateral connectivity, cost, disposal, storm damage
tile drains	trench diggers, excavators, other	With gravel, with moles	protecting high value assets, lowering water tables	clays, low permeability, poor lateral effect, cost, construction expertise.
Pumping wells	drilling rig, excavator	Relief wells, syphons, single or multiple wells	protecting high value assets, lowering water tables	low permeability, cost, disposal, energy, radial impact
v, w, spoon, beds,	grader, spinner, scraper	many	surface water control	low volumes, storm damage, poor water table control
waterways	scraper, grader, dozer	with/without walls, (not) connected on a catchment basis	valley floor	storm damage, poor water table control, relative cost
banks	dozer, grader eg WISALTS, Watkins-McNabb	level, grade, interceptor, reverse, sills, gap spreaders	hillsides	design and layout, workability of farm

Table A2(b) Requirements for improved effectiveness and life of drainage system

Type	Hydraulics *permeability**	Soils *stability rating*	Water Management *catchment effects*
Deep drains	high	highly stable	input from valley areas, closed to runoff from catchment, closed system
Tube drains	high	stable	only sub-surface flow
Pumping wells	high	n/a	only sub-surface flow
v, w, spoon	mod, low	stable to low stability	majority = surface flow
Waterways	mod, low	stable	majority = surface flow
Banks	moderate, high	stable	mixed sub- and surface flow

* high - > 0.5 m/day, moderate > 0.1, low < 0.01

Appendix B.

Management of water in the landscape problems, causes and options

Table B.1(a) Perceived water management problems and associated effects (Adapted from Wallace 1999).

Surface Water	Groundwater	Water-borne
• waterlogging; • erosion (soil, drainage line, stream banks); • enhanced recharge; • flooding, inundation and associated destruction of fences and other structures.	• groundwater rise, and all associated salinity problems; • increased surface flows from waterlogged or saline soils;	• siltation; • nutrient loading • eutrophication; • spread of weeds; • pesticides; • water quality decline.

Table B.1(b) Landscape water management option and factors contributing to management problems and associated effects

Biophysical Changes non-structural	Cultural Structures	Natural Structures	Episodic Events	Interaction between of causal factors
• replacement of natural veg. with annual crops and pastures; • changes in soil properties as a result of agriculture; • loss of storage and discharge function of natural wetlands; • degradation of nutrient sink function of wetlands.	• roads, tracks; • railway lines; • drainage works; • cultivation of drainage lines; • paving and other enhanced drainage in towns and urban areas.	• Topography, landform, soils, geology, and salts stored in soil profile will all have a range of impacts such as: • dykes impeding groundwater flow; • natural surface barriers; • sand bars; • extensive flats and areas of low relief.	• high volume, high intensity rainfall events, particularly summer cyclones; • high volume, long duration events, high volume and prolonged wet seasons; • wildfires and associated loss of cover; • extended periods with little or no rainfall.	• All the preceding factors interact. How they interact at a particular site, or within a particular sub-catchment or basin, will vary.

Earthworks	Revegetation and High Water-use Plants	Agronomic Change	Enhanced Storage	Other
• diversion structures (eg, grade banks, levees); • drainage structures (eg, seepage interceptors, deep drains, w-drains, pumps); • storage structures (see enhanced storage).	• perennial woody vegetation; • perennial grasses and legumes; • stabilisation of stream banks; • nutrient stripping.	• contour farming; • continuous cropping; • phase cropping; • salt land agronomy.	• increase dams up-slope and use keyline farming; • increase valley storage; • evaporation basins; • regulation of flow to wetlands.	• complete change of land use in prone areas, eg, adopt productive saline systems and aquaculture; • protection of remnant native vegetation; • do nothing.

Table B2. Options for modifying drainage practices and attitudes towards implementing drainage projects (Adapted from Wallace 1999)

Agent for Change	Strategy Options	Actions and Comments
Economics	Provide means for increasing water use across all soil types through high water use, profitable production systems.	• Includes commercial woody revegetation and perennial grazing systems, aquaculture and salt harvesting, and so on.
	Pay landholders to implement high water use systems.	• Some State and NHT funds are going into this, but their impact at landscape and regional scales is small. • WRC implementation of cost-sharing arrangements in recovery catchments for water resources
	Adjust Farm Water Grants Scheme to enable earthworks for surface water management to be funded with water harvesting works.	• Ministerial initiative required to refocus scheme to included conservation earthworks and discharge control sites (ie. dams, evaporation basins) in conjunction with water harvesting proposals. • Provide a mechanism to allow Focus Catchment groups to apply for funds for conservation earthworks under the FWGS to enable an integrated approach to catchment planning
	Restructure landholdings and assist non-viable properties to leave or improve economic viability.	• Under a government rural adjustment scheme, buy non-viable properties, re-survey and sell pieces than can be farmed and re-vegetate salt-affected areas.
	In rural areas, increase local water harvesting and productive urban use of annual rainfall.	• Encourage through the Rural Towns Rescue program. • Encourage by increasing the charges for scheme water. • Encourage rural communities to develop community water supplies to reduce the dependence on piped scheme water supplies
	Remove structural disincentives for adopting high water use options.	
	Develop taxation and other incentives systems that encourage landholders, or other private enterprise groups (eg through benefits of corporate citizenship, carbon credits, and so on), to implement high water use systems on agricultural lands.	• Use of drought taxation investment allowance to encourage better water harvesting using Landcare structures.
	Develop a system of tradeable quotas in effluent (saline water) disposal based on EIS	
Legislation and Regulation	Develop a statutory framework that allows drainage to be judged by State agencies on the basis of environmental impacts.	Criteria for the assessment of environmental impacts might be based on: 1. technical competence (ie, we should stop people doing things that are very obviously high risk to themselves and others); 2. threats to productive land use values; 3. threats to infrastructure values (eg, flooding and towns); 4. threats to water conservation, particularly potable water; and 5. threats to natural diversity conservation.

Legislation and Regulation cont	Encourage local government to develop appropriate powers and regulations.	
.	Explore and outline actions available to individuals under common law. Clarify legal status, opportunities, and obligations of organisations and groups involved in catchment scale drainage works and proposals. Explore use of current Drainage Act as a means for State Government to manage drainage activities. Explore output based means of judging drainage proposals, and ability to implement using cross-compliance regulations.	• Legislation review is the first step in this process. For example, quantify outputs of water, salt, silt and nutrients per hectare of farmland. Those who wish to increase these outputs by, for example, > 10%, would be required to implement a minimum level of revegetation, contour farming, etc.
Communication, education, training and extension	Capture, evaluate and share anecdotal information concerning drainage and land use changes, and document concepts and ideas of land managers concerning water management and drainage. Identify information required by landholders, government agencies and other stakeholders to implement integrated water management. Develop and communicate/extend a framework for understanding and integrating landscape water management. Extend knowledge critical to landscape scale management of water. Provide appropriate training for agency personnel, CLCs, contractors, etc. For all community members, connect effective, integrated water management to quality of life issues and land use values.	• Developing better requirements of proponents is one action that will establish a much better flow of information from land managers to agencies.
Knowledge and technology	Develop an explanation of water movement in the landscape, and the options for better managing water, based on current knowledge. Develop, and implement with managers, research that tests current hypotheses concerning solutions at a landscape scale. Implement research that develops the technologies missing from current array of solutions.	• Identify the barriers to action that exist due to gaps in knowledge and understanding. • As part of this process identify critical knowledge/technology gaps. • Develop appropriate models for planning and decision-making at paddock, farming, catchment and basin scales. • It is critical that we test our knowledge by implementing solutions at a landscape scale. These will be demonstrations of what does or does not work. • Development of new industries will be important in this arena (eg. Outback Oceans project)
Direct, large scale operational action by State Government	Government takes direct action to establish trunk drains and groundwater pumping systems. Government resumes land and revegetates it.	