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The role of plants and plant-based research and development in managing dryland salinity in Australia

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Abstract. The roles of plant-based systems and plant-based research and development for management of dryland salinity in southern Australia vary over a range of biophysical and socio-economic conditions, and differ according to the resources at risk (protection of water resources, biodiversity, infrastructure, dispersed assets such as agricultural land, and salt-affected land). Recommended responses are sensitive to a range of biophysical and socio-economic conditions. Extension and incentives to promote currently available perennials or salt-tolerant plants are only appropriate as the main policy response in a minority of cases. Regulation or permits to limit planting of perennials can be justified in certain areas of high-water-yielding catchments. For the majority of agricultural land that is at risk or is contributing to dryland salinity, the most logical policy response is to invest in development to improve salinity management technologies, including research and development into new plant-based systems. Situations where plant-based R&D for profitable farming systems is the best option include: (i) to reduce salinity impacts on water resources where groundwater systems are responsive and the dependence on fresh runoff for consumptive use is low; (ii) to protect infrastructure and biodiversity where there is relatively high responsiveness of groundwater and the urgency of response is low; (iii) to protect dispersed assets (e.g. agricultural land, most remnant vegetation on farms, flood risk mitigation) where profitable perennial plant options are lacking; and (iv) for land that is already salt affected.

Additional keywords: dryland salinity, plants, policy, research and development.

Introduction

Several factors have contributed to changing attitudes about the roles of perennial-plant-based systems for management of dryland salinity. These include:

(i) new evidence about the effectiveness of plant-based systems in preventing the impacts of salinity. In most regions, prevention of discharge requires much larger areas of perennials to be established than was believed in the 1980s and 1990s;
(ii) increased knowledge about the diversity of groundwater flow systems with their varying responses to plant-based salinity management systems;
(iii) recognition of the potential for plant-based options to have adverse impacts on fresh water flows into rivers in some situations;
(iv) evidence about the disappointing economic performance of most existing plant-based salinity management systems and, related to that, their insufficient current levels of adoption; and
(v) increasing prominence of engineering-responses to manage dryland salinity.

These new understandings have led to calls for a greater investment in research to develop improved plant-based systems for management of dryland salinity ('plant-based R&D') (e.g. Pannell 2001*a*; House of Representatives Standing Committee on Science and Innovation 2004) on the grounds that adequate adoption will require new perennial plants that are more economically attractive than the existing options. In using the term plant-based R&D our meaning encompasses a range of efforts to create improved plant options and systems for salinity management, potentially including plant collection, selection, breeding, testing, agronomic trials, as well as hydrological research and economic research and analysis. In this category we also include investment in infrastructure, market institutions, etc. to support profitable plant-based industries.

Past salinity plant-based R&D produced detailed knowledge of the salinity problem and its causes, but has not produced an adequate range of systems and technologies to manage it. Salinity policy programs take for granted the availability of appropriate salinity management tools, but this optimistic position is often not justified (Pannell 2001*a*).

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Salinity policy makers are subjected to influences from a range of stakeholders with different interests and areas of expertise. Advocates for research are just one interest group among many. These groups include:
(i) private land managers, particularly farmers and their representatives;
(ii) managers of public lands;
(iii) the broader community;
(iv) catchment management organisations;
(v) environmental advocates; and
(vi) other governments.

Groups have differing priorities, which are not always understood and/or respected by other groups. Some have multiple roles and all, to some extent, have vested interests in particular aspects of, or responses to, the salinity problem. Diversity of views within stakeholder groups has further added to the complexity of dealing with community issues.

Given the above background, it is not surprising that policy makers have failed to develop a clear and well-founded position on the roles and limits of plant-based R&D as a response to dryland salinity. This paper is an attempt to develop such a position. Our aims are:
(i) to clarify the role of plant-based systems for salinity management, and
(ii) to determine the appropriate roles for plant-based R&D systems for salinity management in the context of various other possible responses by government.

We recognise that salinity is 1 of a number of degradation issues and that, where possible, governments and catchment management organisations seek multiple benefits in natural resource management. However, we have kept the paper tightly focused on salinity for several reasons (i) to maintain clarity and tractability; (ii) because salinity management has particular policy needs that differ from some other natural resource management issues; and (iii) to provide a first step towards a possible more general framework covering other issues.

The paper was based on our experience of salinity management in southern Australia, where salinity is more common than in the less cleared, summer-dominant rainfall areas of northern Australia. The logic should also apply in northern Australia, although we expect the emphasis will be more on prevention of salinity before it occurs.

Factors influencing the role of plants and plant-based R&D for dryland salinity

The roles of plants and plant-based R&D in addressing dryland salinity depend on a range of factors, including types of assets that salinity affects, hydrogeology, value of the affected assets, and socio-economic considerations. These issues are briefly described in the following sub-sections as background to discussing the role and scope for plant-based management and associated policy responses, including plant-based R&D.

Types of impact

The main impacts of dryland salinity are on:
(i) agriculture through land salinisation. Two million ha of agricultural land is affected by shallow water tables (Anon. 2002). The most serious problems are currently in Western Australia (WA) and to a lesser extent South Australia (SA) and Victoria, but increases are predicted in New South Wales (NSW) and Queensland (National Land and Water Resources Audit 2001);
(ii) water resources. Dryland salinity will contribute to the future salinisation of currently fresh rivers, affecting the supply of irrigation and drinking water (National Land and Water Resources Audit 2001);
(iii) infrastructure. Roads, communication infrastructure, pipelines and buildings are amongst the infrastructure assets affected. Rising water tables threaten a number of towns in WA, NSW and Victoria (National Land and Water Resources Audit 2001);
(iv) vegetation and biodiversity. Large areas of remnant vegetation and plantation forests are affected, with increases predicted in all states. In WA it has been estimated that 450 plant species are endemic to low-lying areas in salinity prone regions and are at risk of extinction (Keighery 2000). Aquatic biota are also affected by rising salinity (Kefford *et al*. 2003);
(v) flood risk. Shallow water tables result in increased flood damage to roads, fences, dams, agricultural land and wetlands. Increased flood risks have been studied for only a small number of case studies (e.g. Bowman and Ruprecht 2000). With the predicted 2 to 4-fold increase in area of wheatbelt land in WA with shallow water tables, there will be at least a 2-fold increase in peak flood flows (R. George pers. comm. 2000); and
(vi) Aesthetics. Aesthetic changes occur as a result of all of the above impacts, affecting the sentiment of the broader community and raising political support for policy action.

Hydrogeology

In this section we focus on the variety of groundwater flow systems (GFSs) present across Australia and consider their implications for plant-based R&D. The groundwater response to perennial vegetation establishment depends on the gradient and permeability or conductivity of the material through which water flows (gravel, sand, clay). These vary among different GFSs.

Three categories of GFSs (local, intermediate and regional) have been classified (Coram *et al*. 2000) to indicate the broad spatial scale over which groundwaters flow. The different flow systems indicate the distances over which changes in agricultural land use may have off-site impacts. These have been used to suggest the scales over which such changes would need to occur to achieve long-term equilibrium in groundwater levels. We acknowledge that there are some limitations to the current GFS classifications (e.g. they are not spatially explicit and the conceptualisations are over-simplified). However, as they have been widely promoted and used to help make decisions about prioritisation of salinity-related investments, they are the current 'benchmark' on which to base our analysis.

Time lags in downstream discharge response to clearing or revegetation are very different between 3 broad GFS categories (100 years or more in regional GFSs compared with 20–50 years in local GFSs, Coram *et al*. 2000). The response time has a major influence on the economic value of any off-site benefits. Other things being equal, the economic benefits of off-site salinity prevention resulting from establishment of perennials will be higher (because they are more rapid) in local than in regional GFSs.

The 3 major GFS classifications have been broken down into a number of major types, which are thought to have similar behaviours. In Tables 1 and 2 we present simplified summaries of the attributes of each GFS type and give some example geographic locations and indicative levels of conductivity. This information is a compilation of previous information (Coram *et al*. 2000; and http://www.ndsp.gov.au/catchclass/ accessed May 2004 with significant input from Phil Dyson, pers. comm.). We have developed these tables as background to later discussion in which the GFS is relevant to the choice of policy response, and also to update the very general comments about the role of plants and farming systems given on the above website.

In the final column of Tables 1 and 2, we make comments about the issues and R&D needs and the likely on-site and off-site responses. These 'responses' refer to the time taken for groundwater tables to reach equilibrium following a land-use change or engineering intervention. For the purposes of this paper, the term 'on-site' is taken to mean the land on which perennials or engineering options are established, plus immediately neighbouring land up to a distance of say 100 m or less. 'Off-site' refers to all distant land greater than 100 m away from 'on-site' or water.

For local GFSs the estimated on-site responses are commonly 10–30 years. Off-site response times are 50 years (Table 1). Note that the impact of low conductivity is different for on-site effects because it enhances the ability of land-use changes to be effective locally, while reducing their capacity to be effective at a distance. There is considerable potential for runoff reduction with planting of perennials on duplex soils and in steep areas within GFS types 3, 4 and to a lesser extent 5, so careful targeting of plant-based solutions is required in these regions. These situations are likely to occur more in high rainfall regions of eastern Australia than in WA or SA. In locations with high rainfall and a local GFS, only very deep rooted perennials can sufficiently use winter rainfall excess.

For intermediate and regional GFS responses (Table 2), on-site responses can be rapid (10–20 years) where conductivity is low (e.g. GFS 12). Off-site responses take considerably longer (e.g. 100 years or more). Intermediate and regional systems generally occur in medium to low rainfall areas, so the requirement for extra water use is less severe than for GFS 3 and 4. On the other hand, because of low gradients, the scale of perennials needed to control salinity would be very great.

Value of assets

In considering whether intervention to avert salinity impacts is justified, a key factor is the value of the assets at risk. Putting values on some salinity impacts is difficult because they include both market values (e.g. financial value of water resources to be used for irrigation and town water) and non-market values (e.g. non-financial value of irreversible loss of biodiversity, sometimes referred to as passive or non-use values).

For impacts on terrestrial assets, the values per hectare of land affected vary widely among the asset classes. Financial losses per hectare are greatest for impacts on infrastructure, due to the high cost of their repair or replacement. Non-financial losses per hectare are greatest for some environmental assets of outstanding significance. By comparison the potential loss (either financial or non-financial) per hectare of non-irrigated agricultural land are much smaller. The areas of land are very large, so the total value is high, but in considering investment in protection of particular pieces of land, the analysis needs to consider the values threatened on that land. For protection of water resources, each case has a particular mixture of financial and non-financial values at stake.

Economic and social factors

The factors involved in adoption behaviour in response to natural resource management problems have been discussed by Guerin and Guerin (1994), Cary *et al*. (2002) and Ridley (2004). Pannell (2001*b*) reviewed the issues in the context of dryland salinity. At the farm level there are 2 main considerations:

(i) the perception by farmers of likely net-benefits in adopting perennial plant-based systems relative to annual systems, including any on-site salinity-related benefits; and
(ii) the capacity of farmers to incorporate new practices into the farming system. Factors affecting capacity include financial resources, labour resources and managerial resources.

The key factor affecting adoption by commercially-oriented farmers is their perceptions about on-site benefits (profitability of harvested products and the value of any local salinity benefits), which should outweigh the on-site costs (direct input costs as well as opportunity costs of activities displaced by perennials). Policy makers who make decisions about salinity intervention must additionally consider the off-site benefits (e.g. reduction in salinity) and costs

Table 1. On-site and off-site probable responsiveness of plant-based options in local groundwater flow systems

Adapted from Coram *et al*. 2000 with review from Phil Dyson (pers. comm.)

Groundwater flow system type	Example regions	On-site response	Off-site responses	Comments regarding: Conductivity (m/day)	Comments regarding: Issues and R&D needs
Local flow in deeply weathered Precambrian rocks (GFS type 1)	Much of south-west WA, the upper Eyre (Wanilla), SA, Dundas Tablelands, Vic.	Poorly responsive 20–30 years	About 50 years	<0.5	Most of the area is not suited to lucerne except where it is of overlying aeolian sediments with high enough pH, or where valley floors comprise alluvial floodplains. Alternative very deep-rooted herbaceous or woody species are needed as the current C_3 perennial grasses are insufficient. Some C_4 species may have potential. The R&D need is to look at deep-rooted perennials tolerant of high salt stores and low pH pallid zone kaolinite rich clays in the upper regolith.
Local flow systems in fractured rocks (GFS type 3)	Central highlands of Vic. and tablelands of Great Dividing Range of NSW (e.g. Boorowa)	10–20 years	About 30 years	0.5–2	Groundwater recharge is typically much greater in areas with shallow soils where the fractured rock outcrops. This is most common on the mid to upper slopes. The thin skeletal soils often have soil fertility, acidity and water holding capacity limitations, posing challenges for introduced perennial pastures. The terrain calls for low risk, low input perennials, with native grasses often being the best current option because of their capacity to persist. However, the water balance of native grasses is still being verified. R&D into deep-rooted plants (woody species) is the priority where commercial agriculture will remain and where salt stores are high. Where salt stores are high but commercial agriculture is unlikely to remain, regeneration of native woody species is the priority. Where soils are duplex and salt stores are low, enhancement of native perennial grasses can be a priority to maintain runoff.
Local flow systems in deeply weathered, fractured rocks (GFS type 4)	Most common and significant GFS in the foothills of Great Dividing Range, Vic., NSW, Qld, Mount Lofty Ranges (SA), Kamarooka, Vic.	20–30 years	Within 20–50 years	<0.2–2	This GFS typically occurs in the lower foothills along the fringes of the Dividing Ranges of eastern Australia. Salt stores can be very high in some areas. It is possible to grow good stands of lucerne where there are red sodic soils rich in carbonate and annual rainfall is less than 500 mm. In many other areas, higher rainfall and subsoil acidity issues require the use of other perennials. The R&D requirement in these circumstances is to develop deep-rooted farming systems tolerant of such challenging conditions, with R&D being similar to GFS type 1. There are no preferential recharge zones in this environment, hence recharge management must be practiced over the entire landscape.
Local flow systems in weathered granitic rocks (GFS type 5)	Shallow terrain, footslopes of Dividing Range, Vic. (Warrenbayne, northern Strathbogie Ranges), NSW (upper Liverpool Plains), Qld	> 10 years	Within 20–50 years	<0.5–2	As for GFSs 3 and 4. The potential for fresh water runoff is lower due to lower slopes, but the discharge is often fresh and therefore break of slope agroforestry has considerable potential for water interception and high timber yields. The main R&D requirement relates to performance monitoring to ascertain the effectiveness of plantations as phreatophytes, and the extent that summer access to groundwater improves their growth characteristics.
Local flow systems in fine grained, unconsolidated sediments (GFS type 7)	South-west Vic. and Barwon Downs and Heytesbury, laterites in south-west Qld	Discharge sites and local benefits: very responsive due to low conductivity 10–30 years	50 years, poorly responsive aquifers	<0.5	High winter rainfall excess suggests that existing perennial grasses are unlikely to control recharge. These are wet and/or saline areas requiring plant-based R&D to develop salt tolerant systems for waterlogged saline areas. The use of woody species or herbaceous perennials should be emphasised to markedly increase water usage. The invasive nature of species traditionally introduced for salinity such as tall wheat grass is becoming an issue.
Local flow systems in sand dunes (GFS type 10)	Sand dunes of the south-eastern wheatbelt sandplains in WA (e.g. Lake Warden) and the Mallee in Vic.	Often <5–10 years	10–20 years	<0.5–2	Lucerne and agroforestry are likely to control recharge but unlikely to be economic compared with cropping. R&D issues are salt tolerance, drought tolerance, management of perennials for persistence, integration of perennials into cropping systems and development of new farming systems based on short-cycle woody species. There is likely to be large private benefit from treating. Clay spreading is proving very successful in some of the more silicious dunes but is of largely private benefit and not high priority for R&D.

Table 2. On-site and off-site probable responsiveness of plant-based options in intermediate and regional groundwater flow systems

Adapted from Coram *et al*. 2000 with review from Phil Dyson (pers. comm.)

Groundwater flow system type	Example regions	Comments regarding: On-site response	Off-site responses	Conductivity (m/day)	Issues and R&D needs
Intermediate, local flow systems — fractured basaltic and sedimentary rocks (GFS type 12)	Layered sedimentary rocks of NSW, Qld and SA	Low conductivity. Local benefits in 10–20 years	20–50 years	<0.5–2	Herbaceous perennial options have potential in lower rainfall areas in SA and WA. In summer dominant rainfall zones, large episodic events occur and recharge control will be extremely difficult, perhaps even with woody species.
Intermediate flow systems within alluvial sediments infilling palaeo-channels present within deeply weathered granitic rock terrain (GFS type 2)	About 60% of WA wheatbelt, lower Eyre Peninsula, Kangaroo Island, SA	>30–50 years for catchment-based recharge management	About 100 years	<2–100	Potential for deep-rooted perennials, but high groundwater salinities, low rainfall and subsoil constraints will limit persistence of perennials. R&D needs are for highly salt tolerant species, persistent perennials, preferably compatible with cropping and new farming systems based on short-cycle woody species.
Intermediate flow systems in fractured rock Palaeozoic aquifers (GFS type 6)	Lower relief rock terrain comprising fractured rock that is not deeply weathered and typically found between the headwaters and the foothills of the uplands of the Great Dividing Ranges (e.g., Axe Creek, Vic.), Kyeamba Creek, NSW	30–50 years	About 75 years	1–2	Groundwater systems are highly buffered against watertable change by the large volume of aquifers. These groundwater systems are typically driven by large groundwater recharge areas coincident with fractured rock aquifer outcropping in the rocky headwaters of large sub-catchments. Groundwater recharge occurs in the headwaters and groundwater discharge and salinity occurs in the immediate mid-catchment regions. Recharge areas comprise a mix of fractured rock and shallow skeletal and highly permeable soils that have major soil acidity limitations. The R&D need is to develop lower recharge sustainable land management systems in these challenging low productivity environments. Native perennial grasses in conjunction with native woody vegetation appear to offer the greatest opportunities.
Regional and intermediate flow systems with fractured basaltic Cainozoic/ Mesozoic rocks (GFS type 11)	Basalt plains of western Vic.	30 years or more	>100 years (moderate–high conductivity in regional system)	1–2	Woody perennials are options but large-scale plantings are needed. Current perennial herbaceous options are not sufficient. Water tables are already high in many areas. Salt tolerance is a priority for R&D. Note that there remains some discussion regarding the extent to which the water balance has changed in the basalt plains of the Western District in Victoria. Given the regional or sub-regional nature of the groundwater system and the high rainfall environment, farm scale recharge mitigation is inappropriate. Non-invasive salt tolerant vegetation appropriate to wet/waterlogged landscapes should be utilised.
Regional flow systems in alluvial aquifers (GFS type 8)	Riverine plains of Vic. (e.g. Loddon) and NSW (lower Billabong Creek), northern NSW rivers (e.g. Liverpool Plains) and Qld, Perth, Bremer Basin WA	>>50 years	>>100 years	50–1000	Groundwater discharge is driven by very large-scale processes that operate over distances of >50–1000 km. Regional groundwater recharge in mid-catchments results in discharge in the lower catchments. Salinity is also often exacerbated by groundwater mounds associated with irrigation regions. The time scales and effort required to achieve a new surface water balance through changed farming practices, together with the excessive time required to realise a salinity response dictate that catchment-based recharge mitigation is not appropriate. Where water tables are shallow there is potential for the use of phreatophytic vegetation that has a high level of salt tolerance. There are excellent opportunities for lucerne and low rainfall farm forestry in this context. The R&D needs should focus on less conventional phreatophytic and halophytic farming systems in areas at greatest risk of developing salinity problems.
Regional flow systems within unconfined aquifers comprising unconsolidated marine sediments (GFS type 9)	Mallee plains, Vic. and SA	>100 years	>80–100 years	2–10	Salinity benefits cannot be realised within a timeframe considered reasonable by contemporary stakeholders. The extent of hydrologic change required to even initiate a change in the water balance is extreme given the super-regional nature of the groundwater regime. Salinity-affected assets can only be managed by local engineering responses or responses that seek to gain production from saline landscapes. Plant-based R&D should focus on halophytic vegetation and boutique opportunities that seek production from saline groundwater. The high iron content of groundwater is proving a mitigating factor for the latter.

(e.g. reductions in water volumes in rivers). The crucial importance of farm-level economics in adoption behaviour is underscored by studies showing that existing perennial plant-based options in most regions of southern Australia are either unprofitable or lack profitability on a scale that would generate more than localised benefits (Bathgate and Pannell 2002; Lefroy 2002; O'Connell and Young 2002; Abadi *et al*. 2003; Kingwell *et al*. 2003).

Social issues also affect adoption of perennial plant-based management options. Over 16 million hectares of Australian land is managed by farmers with an estimated value of agricultural operations of less than $22,500 (Hooper *et al*. 2002). These small and 'lifestyle' landowners manage a significant quantity of relatively high value, potentially highly productive land, usually in areas that are close to (perhaps within one hour's drive of) cities or larger towns that provide opportunities for employment. The states with the greatest numbers of small farms are Victoria and NSW (Barr *et al*. 2000), with more than a quarter of the agricultural land in Victoria being on small farms (Neil Barr, pers. comm. 2004). Many are in high rainfall areas (and therefore have the potential to influence significant amounts of freshwater runoff) in the Goulburn-Broken region and parts of the Upper Murray region in Victoria. There are also some significant areas close to regional centres within the NSW and ACT catchment areas of Murray and Murrumbidgee that have many non-commercial land managers (east of Albury and Wagga Wagga, and surrounding Canberra).

There are likely to be a number of differences in policy approach needed to effectively influence land managers whose main income is not from agriculture. As well as having different priorities and objectives, some have limited time and resources available for making major land-use changes. Others have limited interest and management capacity to do so. One implication is that plant-based options would need to be low cost, low risk and low effort. There may need to be attention to providing incentives for land retirement, rather than only emphasising profitability. Beyond this, it seems possible that a different mix of incentives and penalties may be appropriate and in some cases no action may be most appropriate. Extension activities should also be targeted differently for this group of farmers (Hollier *et al*. 2003). Further investigation is needed to assess the components of this mix, particularly research on the likely responses of these land managers to the various policy instruments available to governments. Barr and Wilkinson (2005) discuss these issues further.

Plant-based management of dryland salinity in a policy context

In this section and the next, plant-based systems and plant-based research are considered from the perspective of an idealised policy maker choosing among a suite of policy options and attempting to maximise community-wide net benefits. We realise that the concept of an idealised policy maker is an over-simplification, and that the process of policy formation is more complex than considered here, in part because a range of policy objectives can be sought. These issues are covered in more depth by Pannell (2005).

Circumstances are identified where it would or would not be logical for policies to promote uptake of existing plant-based options, and situations where the best response would or would not include R&D to develop improved plant-based options. This perspective involves consideration of on-farm and off-farm issues, both positive and negative.

Policy makers have a number of choices on the policy 'menu' for investment that aims to manage salinity, either by influencing how landholders respond or by directly funding works. The full menu (Table 3), includes extension, incentives, regulation, engineering, technology such as plant-based R&D, other R&D, and no action. Plant-based management of one form or another is relevant to each of these policy options. Extension or incentives can be used to encourage uptake of existing perennial and/or salt-tolerant plant-based systems, regulation can discourage their uptake in particular situations, plant-based systems would compete with (or perhaps complement) engineering responses, and R&D can develop new plant species and farming systems. A combination of options is also warranted in some situations (e.g. extension and incentives). Further details of these options are discussed below.

Extension. This is usually the appropriate response where perennials are already economically competitive, although in some cases where they are competitive, penalties may be warranted to discourage adoption. Extension may also be appropriate in cases where farmers generally lack information or have mis-perceptions about the salinity problem or its management. This second type of extension is not specific to particular hydrological or economic circumstances.

Incentives and regulation. The choice between incentives and regulation is somewhat arbitrary. We have assumed that, where a policy instrument is used to change current land use or common farming practice, the instrument used would provide a positive economic incentive (e.g. a form of subsidy or compensation). This is the main mechanism by which policy would promote adoption of existing plant-based options that have non-agricultural benefits but which are not sufficiently attractive to farmers to be adopted spontaneously. In contrast, a policy instrument used to prevent a change away from existing land use or common farming practice (e.g. to prevent the planting of trees where their off-site costs exceed their benefits, or to prevent the installation of deep open drains where this would generate excessive downstream environmental costs), would be based on a penalty (e.g. a regulation backed with fines, or a requirement to purchase a tradeable water right, a land-use zoning constraint).

The use of incentives or regulation, as opposed to 1 of the other policy approaches, is considered to be appropriate where there is 'market failure' due to externalities (e.g. off-site impacts on other types of assets). The criteria for market failure require not just that there are externalities, but also that the overall benefits from changing the off-site impact would outweigh the costs (the net-benefit test). (i.e. the mere existence of a negative externality is not sufficient to ensure that there is market failure, if the costs of abating the externality are too great.) This is important for dryland salinity because analyses have found that the net-benefit test fails in many locations, often because the off-site (public) benefits are outweighed by the on-site (private) costs (e.g. Pannell *et al*. 2001; Dawes *et al*. 2002; Heaney *et al*. 2000) or because preservation of fresh-water flows, where they occur at high levels, tends to be more important than prevention of additions to groundwater (Heaney *et al*. 2000; Bathgate *et al*. 2004). The chances of failing the net-benefit test are greater where groundwater flow systems are regional or intermediate-scale (since hydrological response times are slow and required changes in land use would be large) and where the cost to land managers of changing their land use in the desired way would be high. A particular use of incentives that may be appropriate in some cases is to promote land retirement, where the costs of doing so are less than the alternatives, including do nothing. Where incentives are deemed appropriate, they are commonly used in combination with extension. The extension is targeted towards increasing the chances of establishment and persistence of the new plant-based system. Extension in such cases would be directed towards known management issues, such as fertiliser application and grazing management.

Acquisition of land can be justified where the administrative costs of providing incentives and/or enforcing regulation exceeds the costs of land acquisition and administration. These circumstances may arise in potable water supply catchments, or where the values of downstream biodiversity or irrigation water supply assets, (including the threat to dams from sedimentation, as was the case in the Snowy Mountains) are high.

We note that non-targeted incentives (e.g. taxation concessions) have influenced the adoption of woody perennials and led to resource-management benefits in some cases (e.g. lower salinity in the Kent River in Western Australia due to widespread commercial planting of *Eucalyptus globulus*). However our focus is on achieving cost-effective natural resource management improvements, so we do not consider such non-targeted approaches.

Engineering. Capital-intensive works such as groundwater pumping are only justified where a high value asset is under threat and plant-based management options are judged not to be cost-effective or to act quickly enough to protect the asset. Two different versions of this response are included in our analysis: salt interception schemes to protect waterways (i.e. pumping of saline groundwaters that would have discharged into rivers, with disposal of effluent into evaporation basins) and localised engineering works (usually pumping) to protect terrestrial assets. We have narrowed down the circumstances where these approaches are most likely to be relevant (as explained in detail below), but have further qualified our recommendation with the phrase 'if economic', since their economic performance is variable and case specific.

Table 3. Major policy response options for management of salinity

Policy response	Explanation
Extension	Technology transfer, education, capacity building. This is relevant to promotion of existing plant-based options where they are attractive to land managers. It can include education of town residents where appropriate.
Incentives	Positive financial incentives to encourage a change of management. Examples include subsidies, market-based instruments and cost-sharing. This is relevant to promotion of existing plant-based systems for agriculture in some circumstances. It can also be used to encourage land retirement where appropriate.
Regulation	Negative incentives to discourage a practice or land use. For example, to require purchase of water rights, impose regulation on land use or on drainage installation. This is relevant to the discouragement of existing plant-based systems in some circumstances. It can include land use zoning for particular purposes, or government acquisition of land.
Engineering	Salt interception through pumping saline water to avoid discharge into rivers. This is an alternative or a supplement to plant-based systems. Local engineering works on-site to protect public assets where part or all of the salinity problem is generated locally, not from farm land (e.g. in many salt-affected towns). This category represents direct investment in public engineering works. Engineering for agricultural land is represented in other categories (extension, incentives, penalties or other R&D)
Technology	Invest in development or improvement of technological options for salinity management, particularly plant-based R&D systems. The category may also include investment in infrastructure, market institutions, etc. to support profitable plant-based industries.
Other R&D	Research to provide information to support planning and decision making, such as remote sensing to pinpoint salt stores and research to measure the performance of existing management technologies (as distinct from developing new ones). Research into land retirement (e.g. into the speed and type of perennial revegetation that would occur naturally if land was removed from agriculture). Research into the performance and design of engineering options.
No action	No response is justified because the costs of intervention outweigh the benefits.

At the farm level, engineering is relevant to management of salinised land in some regions (deep open drains in the Upper South-East of SA and parts of the wheatbelt of WA). In cases where engineering has primarily on-site costs and benefits, it is arguably not a subject for government intervention, although government funds have been used in SA, and some farmer groups in WA are increasingly pushing for government to provide and fund infrastructure (large arterial drainage systems) to facilitate disposal of effluent from farm drains. Complicating this issue are concerns about possible downstream impacts. There is still considerable uncertainty about the extent and significance of these. Given the impetus behind some proposals for large drainage schemes, research to quantify likely downstream impacts appears a high priority.

Technology. We suggest technology such as plant-based R&D for profitable farming systems to be the best option when market failure from externalities is unlikely, and perennials are likely to generate worthwhile salinity benefits (without unduly compromising water yields) if the production economics could be turned around. Implicit in this recommendation is there are worthwhile and untapped opportunities for technology development (Pannell and Ewing 2006), or there is a need to investment in infrastructure or market development to support new industries based on perennial plants. Plant-based R&D can be a valuable strategy to supplement incentives in some cases. Even if it is not successful in producing economically competitive perennial land use, such R&D has the potential to reduce the public cost of providing incentives in the medium term, by reducing the farm-level cost of converting to perennials.

Other R&D. This category includes all other relevant research.

No action. In situations where no other responses can be justified, for example due to expense, low effectiveness or a low salinity threat, 'no action' becomes the best response.

Recommended policy responses for specific circumstances

The recommendations that follow are based on a mixture of research results, theory, rules of thumb, assumptions, judgments and logic. The recommendations are not 'hard-and-fast', but provide transparent arguments as a broad guide, a basis for further debate, and for reconsidering salinity policy on a more sophisticated and realistic basis.

Recommended policy responses are shown for 4 sets of cases: recharge areas with salinity impacts on waterways (Table 4), recharge areas with salinity impacts on relatively small scale terrestrial assets (Table 5), recharge areas with salinity impacts on dispersed assets such as agricultural land (Table 6), and salt-affected agricultural land (Table 7). The suggested responses are different for different categories of assets at risk. Research to assist with planning of policy interventions (within 'Other R&D') has an overarching role and is relevant to all scenarios in all 4 tables.

Responses for recharge areas with salinity impacts on waterways

There are 4 main factors driving the choice of policy approach for protection of water resources (Table 4):

(i) the potential input of salt from groundwaters into the waterway. This depends on recharge rates (dependent on soil texture and slope), salt stores in soil and salt concentration in groundwaters, all of which can be highly variable, even within a sub-catchment;

(ii) the responsiveness of groundwaters in potential discharge areas to establishment of new perennial vegetation in recharge areas. 'Low' responsiveness equates broadly to intermediate and regional GFSs and 'High' responsiveness represents the more rapidly responding local flow systems or perhaps on-site effects in the cases of intermediate and regional GFSs;

(iii) issues surrounding the importance of fresh runoff water. This includes both the level of dependence on the waterway for consumptive use and the volume of surface or near-surface flows of fresh water entering the waterway (dependent on soil texture, slope, vegetation type and rainfall); and

(iv) farm-level economics, particularly whether existing perennial plant-based options for reducing recharge on farm-land in the sub-catchment are more or less profitable than agriculture based on annual plants.

The most common recommended policy response in Table 4 is regulation or permits (e.g. tradable water rights) to limit loss of fresh runoff that would provide both dilution of salinity and a volume of flow. [The Council of Australian Governments (COAG) has endorsed this approach through the National Water Initiative. States that have signed the Initiative (i.e. all except WA) will be required to address all forms of development that 'intercept' water, including forestry, groundwater use, and on-farm dams. The policy options are regulation of land and water management (backed with penalties for non-compliance) or a requirement to purchase tradeable rights for the water that is intercepted.] This response is mainly applicable to local GFS types 3, 4 and to a lesser extent 5 (Table 1). Historically, this has tended to take the form of government acquisition of land, especially in catchments for city water supplies.

The high frequency of this response in Table 4 is not an indication that it applies to most land in water-resource catchments. It only applies to high rainfall, upper parts where the majority of fresh water runoff is generated. Regulation is predominantly relevant to the upper catchments of North-East Victoria, Goulburn-Broken, Murray, and Murrumbidgee, which supply 70% of the divertable water resources of the Murray-Darling River system (Crabb 1997). This includes the small river valleys of the Ovens, Kiewa and

Murray, which comprise 2% of the Murray–Darling Basin area but produce 38% of the total river flows (available at http://www.necma.vic.gov.au/region; accessed 4 November 2005).

Detailed work at the paddock level has shown that soil type has a major influence on whether water is lost as deep drainage or as runoff (Ridley *et al*. 2003) and so would influence the categorisation of land into areas of high or low fresh runoff. Many high rainfall areas (greater than 700 mm per year) are currently being targeted for forestry development.

Where the potential input of salt from groundwaters is low and fresh runoff is low, no action is usually the most appropriate response from a waterways salinity management perspective. Where perennial plant-based options are more profitable than traditional agriculture, we suggest extension to promote the existing options, although this situation is not applicable to large areas. Salt interception schemes (where economic) are suggested where the salinity threat is high but groundwater responsiveness to revegetation is low.

Five categories have plant-based R&D options as part of the recommended approach (cases 3, 5, 6, 11 and 12) to protect water resources. The strongest case for development of profitable plant-based options can be mounted for cases 5 and 6, where groundwater systems are responsive and runoff generation is low. This response would apply mainly to GFS types 5, 7 and 10 in Table 1. Where runoff generation potential is high, and current options are unprofitable (case 3 in Table 4), case by case analysis is needed to assess whether applying regulation to discourage land use change or development of plant-based options to encourage it is the

Table 4. Suggested policy responses for recharge areas with salinity impacts on water resources (i.e. salinity in streams/rivers), including consideration of potential loss of flows

Case no.	Potential input of salt from groundwaters	Groundwater response to vegetation[A]	Supply of fresh runoff	Farm-level economics of perennial plant-based options relative to existing land use	Policy response
1	High	High[A]	High	More profitable	Regulation[B, C] or extension[D]
2	High	High	High	Slightly less profitable	Regulation or incentives[D, E]
3	High	High	High	Much less profitable	Regulation, plant-based R&D[F] or incentives for retirement [D, G]
4	High	High	Low	More profitable	Extension
5	High	High	Low	Slightly less profitable	Profitable plant-based R&D or incentives[E]
6	High	High	Low	Much less profitable	Profitable plant-based R&D or incentives for land retirement[G]
7	High	Low[A]	High	More profitable	Not applicable[H]
8	High	Low	High	Slightly less profitable	Not applicable
9	High	Low	High	Much less profitable	Not applicable
10	High	Low	Low	More profitable	Extension + engineering if economic
11	High	Low	Low	Slightly less profitable	Profitable plant-based R&D + engineering if economic
12	High	Low	Low	Much less profitable	Profitable plant-based R&D + engineering if economic
13	Low	High	High	More profitable	Regulation
14	Low	High	High	Slightly less profitable	Regulation
15	Low	High	High	Much less profitable	Regulation
16	Low	High	Low	More profitable	Extension
17	Low	High	Low	Slightly less profitable	No action
18	Low	High	Low	Much less profitable	No action
19	Low	Low	High	More profitable	Not applicable
20	Low	Low	High	Slightly less profitable	Not applicable
21	Low	Low	High	Much less profitable	Not applicable
22	Low	Low	Low	More profitable	No action
23	Low	Low	Low	Slightly less profitable	No action
24	Low	Low	Low	Much less profitable	No action

[A]High responsiveness equates to local groundwater flow systems (GFSs), low responsiveness equates to intermediate and regional GFSs.
[B]Penalties would be applied to discourage conversion of annual or, in some cases, herbaceous perennial-based agriculture to higher water using systems (e.g. forestry). The penalty would reflect the loss of water values for downstream users.
[C]Preliminary analysis (Heaney *et al*. 2000; Bathgate *et al*. 2004) shows that preservation of fresh-water flows is more important than prevention of additions to groundwater.
[D]Whether penalties or extension applies requires analysis to determine net off-site effect of perennials.
[E]Incentives paid to establish/manage existing perennials if the net effect is positive.
[F]Plant-based R&D could be for profitability or land retirement, depending on the demographics.
[G]Analysis required to determine whether it is in society's interests to retire land from agriculture.
[H]Low responsiveness to groundwater and high fresh runoff are unlikely at the same location.

better option. Incentives for land retirement are likely to be more appropriate than development of profitable plant-based options in areas at risk of salinity where demographic trends suggest commercial agriculture is unlikely to remain a major economic activity. R&D into land retirement responses is also appropriate in a minority of such cases where the outcome of removing agriculture is unknown (e.g. the speed and perenniality of natural regrowth).

Cases 11 and 12 (low responsiveness to groundwater and low runoff potential) occupy the largest areas in cropping regions, for example the Riverine Plains in Victoria and NSW, much of the Mallee and the WA wheatbelt (e.g. GFSs 2, 8 and 9 in Table 2). The case for development of profitable plant-based options for these cases is less straightforward. The argument is that there are simply no responses other than plant-based R&D that could conceivably lead to perennial plant-based systems being established over wide areas in these regions. Plant-based R&D offers the prospect of generating salinity benefits in the long term (up to 100 years) at a cost that is low enough to justify the investment. The value of salinity-related benefits per hectare of perennials will certainly be low, due to the large areas required and the long time lags, but the only realistic alternative is 'no action', inevitably resulting in major additions of saline groundwater to rivers in the long term. The case for plant-based R&D in these (and other) categories is bolstered by the likelihood of generating additional benefits not related to salinity, including increases in farm profitability from the improved farming systems. Where plant-based R&D is judged to be infeasible or unwarranted, an alternative for some downstream water users may be desalination.

Incentives to grow existing plant-based options are only an appropriate response in cases 2 and 5 (high groundwater response, perennials slightly less profitable than annuals). This response would be appropriate for areas within the Great Dividing Range with local GFSs, in those parts of the landscape where the profit shortfall comparing perennials with annuals is less than the off-site benefits from perennials. In case 5, site-specific analysis would be needed to assess whether incentives, development of plant-based options or a mixture provides the greatest net benefit.

Responses on recharge areas with salinity impacts on terrestrial assets

Table 5 shows recommended policy responses for non-agricultural terrestrial assets threatened by salinity where impacts occur in relatively small, concentrated areas. The key drivers of the policy response are the value of the asset,

Table 5. Suggested policy responses for recharge areas with salinity impacts on terrestrial assets (infrastructure and biodiversity)

Case no.	Value of asset under threat	Response of ground-water under asset to vegetation on farms	Urgency	Farm-level economics of perennial plant-based options relative to annuals	Policy response
1	High	High	High	More profitable	Engineering (on site responses) if economic + extension
2	High	High	High	Slightly less profitable	Engineering (on site responses) if economic + incentives
3	High	High	High	Much less profitable	Engineering (on site responses) if economic + plant-based R&D or incentives for land retirement
4	High	High	Low	More profitable	Extension
5	High	High	Low	Slightly less profitable	Incentives + plant-based R&D
6	High	High	Low	Much less profitable	Plant-based R&D
7	High	Low	High	More profitable	Engineering (on site responses) if economic
8	High	Low	High	Slightly less profitable	Engineering (on site responses) if economic
9	High	Low	High	Much less profitable	Engineering (on site responses) if economic
10	High	Low	Low	More profitable	Extension
11	High	Low	Low	Slightly less profitable	Plant-based R&D or no action
12	High	Low	Low	Much less profitable	Plant-based R&D or no action
13	Low	High	High	More profitable	Extension
14	Low	High	High	Slightly less profitable	Plant-based R&D
15	Low	High	High	Much less profitable	Plant-based R&D
16	Low	High	Low	More profitable	Extension
17	Low	High	Low	Slightly less profitable	Plant-based R&D or no action
18	Low	High	Low	Much less profitable	Plant-based R&D or no action
19	Low	Low	High	More profitable	Extension
20	Low	Low	High	Slightly less profitable	No action
21	Low	Low	High	Much less profitable	No action
22	Low	Low	Low	More profitable	Extension
23	Low	Low	Low	Slightly less profitable	No action
24	Low	Low	Low	Much less profitable	No action

Table 6. Suggested policy responses for recharge areas on agricultural land that is contributing significantly to salinity on dispersed assets, including agricultural land, flood risk, and remnant native vegetation on farms

Case no.	Response of groundwater to vegetation[A]	Farm level economics of perennial-based options relative to annuals	Policy response
1	High[A]	Profitable	Extension
2	High	Slightly less profitable	Plant-based R&D
3	High	Much less profitable	Plant-based R&D
4	Low[A]	Profitable	Extension
5	Low	Slightly less profitable	Plant-based R&D
6	Low	Much less profitable	No action or plant-based R&D

[A]High responsiveness to groundwater equates to local groundwater flow systems whereas low responsiveness equates to intermediate and regional systems.

the groundwater responsiveness, the urgency of the problem, and the farm-level economics of adopting perennial plants.

The main examples of non-agricultural terrestrial assets are physical infrastructure such as roads and buildings, and environmental assets, including important areas of native vegetation, probably in reserves. Rural towns contain some of the most threatened infrastructure. One of the features of many threatened rural towns is that their salinity problems are largely generated locally within the towns, through release of scheme water (e.g. from watering gardens) and poor management of storm water. These problems, which are among the most economically important impacts of salinity, are not amenable to the sort of policy responses that have traditionally been applied to dryland salinity (e.g. encouragement of revegetation on farms). Rather, their prevention would require on-site actions, particularly engineering works. Some actions may be relatively cheap (improved storm-water management) while others may be very expensive (groundwater pumping). In some cases better management of urban vegetation (less lawns, more trees) can provide partial solutions, or a means of extending the time to the need for other interventions. Analyses (Anon. 2001) have demonstrated that the benefits and costs of these measures vary widely between cases, so careful economic analysis is required.

Engineering for on-site responses are suggested when the value of the threatened asset is high and the urgency of action is high. The more expensive engineering responses will only be economically justified in such cases, and even then only in a sub-set of them. Extension is recommended in all the scenarios where perennials are more profitable than annuals.

Incentives to grow existing plant-based options are only appropriate in two of the scenarios (cases 2 and 5) where the asset value is high, groundwater responsiveness is high and perennials are only slightly less profitable than annuals. In case 2, the problem is urgent, meaning that plant-based systems alone would not protect the asset in time, requiring on-site engineering works (if economically justified), potentially supplemented by incentives. If modest incentives are sufficient to achieve substantial land-use change in these sub-catchments, they may be justifiable, provided that the problem is caused by water from agricultural land rather than sources local to the threatened assets. In case 2, incentives to grow plant-based systems may allow cost-savings due to reductions in running costs of on-site engineering works in the long run. In case 5 where the situation is not urgent, analysis would be required to assess whether development of plant-based options, incentives or a mixture provided the most benefit.

Table 7. Suggested policy responses for salt-affected agricultural land

Case no.	Downstream impact from management of salt-land or water	Economic performance of existing management options for salt-land or salt water	Policy response
1	Positive	Positive	Extension
2	Positive	Slightly negative	Incentives + plant-based or engineering R&D
3	Positive	Negative	Plant-based or engineering R&D or incentives for land retirement
4	Neutral	Positive	Extension
5	Neutral	Slightly negative	Plant-based or engineering R&D
6	Neutral	Negative	Plant-based or engineering R&D
7	Negative	Positive	Regulation
8	Negative	Slightly negative	Regulation (or no action if no adoption)
9	Negative	Negative	Regulation (or no action if no adoption)

R&D for development of new plant-based options is suggested for all remaining cases, apart from where the asset value is low and groundwaters are unresponsive when no specific action is suggested. The low value, unresponsive categories are relevant to much of the agricultural areas, and thus for most land, no specific action will be justified to protect terrestrial assets.

Where the value of the asset is high, the response to groundwater under the asset is low and urgency is low (cases 11 and 12), the rationale for recommending development of plant-based solutions is similar to cases 11 and 12 in Table 4. We recognise that the economic value of off-site benefits from revegetation will be low in many cases, due to the scale of perennial vegetation needed to be effective and the time lags involved. However, the cost of successful plant-based R&D per hectare of perennials established is also low. It can be adopted and have impacts over very large areas, eventually resulting in worthwhile public benefits in cases where farms are contributing to off-site salinity. Although the salinity-related benefits from technology development for assets in this category are likely to be modest, they are benefits that are not efficiently attainable by any other means. Further, 'successful' R&D in this context means that the development results in solutions that are more profitable than current farming practices, resulting in economic benefits to farmers. There would also be a range of other economic, environmental and social benefits (e.g. diversification of income, provision of habitat for native fauna, carbon sequestration, provision of jobs in harvesting, processing and transport of products from woody perennials). If salinity-related benefits are not sufficient to justify plant-based R&D, the combination of benefits is likely to be. Of course, in cases where perennials on farms would have no impact on the assets, or where opportunities for development of plant-based solutions do not exist or are too expensive, the recommendations would revert to 'no action', at least with regard to salinity.

It is possible that land may not remain in one category, as groundwaters rise or technological progress occurs. For example, in the longer term, the situation for an asset may become urgent, potentially justifying on-site engineering responses that were not previously appropriate.

Responses for agricultural land and other dispersed assets threatened by salinity

In contrast to the salinity impacts in relatively small, concentrated areas as shown in Table 5, Table 6 refers to more dispersed effects of salinity and shallow water tables, including impacts on agricultural land, remnant areas of native vegetation on farms, and on flood risk. The common feature of these impacts is that, relative to some of the scenarios in Tables 4 and 5, there are low benefits per hectare from establishing perennials to prevent salinity. For agricultural land, this is partly because even highly productive agricultural land is not comparable in value per hectare to expensive public infrastructure; all agricultural land would be rated 'low' using the value scale in Table 5. For flood risk, the reason is that the establishment of perennials on any given hectare of agricultural land makes only a tiny contribution to flood prevention. For protection of remnant native vegetation the reason is that many small remnants would be of lower conservation value than larger reserves, either due to small size or to environmental deterioration. When that is not the case, the remnant would be considered within Table 5 rather than Table 6.

In aggregate, the impacts represented in Table 6 would be very large indeed, but the key point is that the contribution *per hectare of perennial plants established* to reduce those impacts would be small (Bathgate and Pannell 2002). This rules out incentives or regulation as defensible methods of promoting land use change. They may be successful in promoting change, but to do so they would need to be so large that they would cost more than the modest benefits generated. A similarly adverse assessment would apply to the option of government directly funding engineering works to protect dispersed assets such as farmland, because the cost would be excessive. In addition, in the case of farmland such an approach creates concerns about the appropriateness of government funding works on private land for private gain.

Given these conclusions, the policy response in Table 6 is simple. For protection of this category of assets, where commercial farms have perennial plant options that are economically competitive with annuals but have not yet been adopted, the main policy tool should be extension. Where current plant-based solutions are not profitable, plant-based R&D should be undertaken to attempt to develop better options. 'No action' may be relevant if the expected outcomes from plant-based R&D are not sufficiently positive.

The prescription applies regardless of the GFS responsiveness and so regardless of whether the benefits of planting perennials are highly localised or broader reaching. It is relevant to any farm land that is at risk of becoming salt-affected but has not become saline by the time profitable perennials for recharge areas become available. If recharge areas are converted to discharge areas too soon for appropriate development of new options, the response should be no action in the short term, and one of the responses in Table 7 once the land becomes saline.

Responses for salt-affected land

Table 7 refers to land that is currently salt-affected. The 2 factors driving the recommended policies are the downstream impacts and the on-site economics. It is believed that revegetation of saltland can generate downstream benefits from improved water quality (salinity, sediment and nutrients), reduced flood risk and potentially provision of habitat for biodiversity but quantitative evidence is currently lacking. Deep open drains that are popular among some farmers in WA and SA may have negative downstream impacts due to the disposal of sediment and saline effluent in waterways, potentially contaminated with acidity and heavy metals in some cases. They may also worsen downstream flood risk by concentrating flows into a shorter period of time, although there are also suggestions that they may reduce flood risk. Again, quantitative evidence is lacking, either way. Surface water control (shallow drainage) is also relevant in many salt-affected areas where salinity and water-logging interact.

We suggest that where downstream impacts of drains are positive or neutral, the policy approach should be broadly similar to that in Table 6. That is, extension where the management options are profitable, and development of new options (plant-based or engineering) where they are not. In this case, the plant-based options would be based on productive salt-tolerant species. There may be cases where treatment of saltland would have downstream impacts that are sufficiently positive and on-site costs that are sufficiently low to justify payment of incentives, but this needs further analysis. Where a practice has sufficiently negative downstream impacts, penalties (e.g. a regulatory approach) may be justified.

Discussion of the role of plant-based systems and plant-based R&D

The role for existing plant-based options in managing dryland salinity is represented in Tables 4 to 7 by 3 policy options: *extension* in cases where profitable plant-based systems already exist, *incentives* in cases where off-site benefits from perennials exceed the on-site costs (including opportunity costs from foregoing production of annuals) and *regulation* where plant-based systems have adverse impacts on non-agricultural values, particularly reduced water yields in waterways.

Overall, it is rarely possible to justify intervening to force or provide incentives for adoption of perennials for salinity benefits alone. The time lags are so long and the required scales of planting are so high that the present value of salinity benefits per hectare of new perennials is generally small. This is true for all regional and intermediate GFSs and some of the local systems. If we want to do something about salinity in these catchments, the most realistic policy option is to invest in technology, especially plant-based R&D, meaning the development of new and improved types of plants, plant-based systems and industries that are more economically attractive to landholders. This approach applies to the largest area of land, by far. There are a number of elements for recommending this option in so many of the cases considered in Tables 4 to 7, as:

(i) the existing suite of plant-based options is limited. Plant-based R&D can extend the reach of salinity management beyond the minority of cases where extension and incentives are appropriate;
(ii) salinity budgets are limited. The available policy budget for salinity is sufficient to influence management of only a minority of the land contributing to salinity problems. Plant-based R&D offers the only prospect for effectively managing salinity on a larger scale;
(iii) plant-based R&D will generate additional benefits beyond salinity mitigation, including diversification of farm income, provision of habitat for native fauna, carbon sequestration, and social benefits from provision of jobs in harvesting, processing and transport of products from woody perennials;
(iv) partial success in plant-based R&D will still be of benefit, particularly through reducing the incentives required for adoption of perennial plants;
(v) There are unrealised R&D opportunities. We believe that the current shortage of profitable options reflects the absence of past investment in this type of plant-based R&D, rather than the absence of opportunities to develop profitable systems. It is early days in the systematic search for new improved systems, but the opportunities are exciting. A range of current research directions and prospects are summarised by Pannell and Ewing (2006);
(vi) plant-based R&D reduces the problem of justifying investments to prevent very long-term impacts of dryland salinity. The standard economic technique of discounting is used to convert future benefits into present values so that they can be compared with current costs of mitigating actions. However, for very long-term outcomes, even low discount rates mean that current costs dominate the decision. Plant-based R&D partly sidesteps this problem by using commercial levers to promote plant-based systems, with salinity mitigation as an ancillary benefit. Of course an evaluation of the research itself would require the use of discounting, but once new profitable options had been developed, the impact of discounting on their attractiveness would be much less than for current options. The primary benefits of new options would be commercial benefits in the relative short term; and
(vii) the downside is low. Compared with the cost of existing salinity programs, the cost of appropriate plant-based R&D is very small, with the possible exception of managing the risks associated with the introduction of new plants. The ability of widely adapted plants to become weeds is a clear possibility, as raised by Semple *et al*. (2004).

Plant-based R&D is not a direct instrument as other policy options. It is unrealistic to expect that ideal plant-based options will be created for all of the categories where plant-based R&D has been recommended. The plant-based R&D that delivers benefits may not have been targeted at the particular category it ends up addressing. Plant-based R&D attempts to create opportunities for the community to gain environmental, economic and social benefits. Salinity-related benefits would come as part of a package of outcomes, and benefits that result may not be substantial. Indeed, they probably will not be. Nevertheless, plant-based R&D remains the approach that is most likely to generate broad-scale benefits from salinity management.

Conclusions

Choices about the most appropriate government response to salinity should be sensitive to hydrological and socio-economic conditions and the types of assets under threat. Where the main aim of salinity management is to reduce impacts on water resources, the logical approach in some upper catchment areas is for regulation or permits to prevent loss of fresh water runoff entering waterways. There are few cases where providing incentives to grow existing plant-based options is the most appropriate response. Investment into plant-based R&D is justified in several cases, particularly where groundwater systems are responsive and the potential for runoff generation is low. In a minority of locations, salt interception schemes are technically and economically feasible.

For protection of high value, non-agricultural terrestrial assets (infrastructure and biodiversity), each of the policy approaches is relevant in some circumstances, although the role for incentives is very limited. Engineering (subject to economic analysis) may be appropriate when the value of the asset is high and the urgency for action is high. Plant-based R&D is relevant in a number of situations, particularly where the asset value is high but the urgency is low. It is justified on the basis of reducing the public cost per hectare of treatment.

Compared with infrastructure and biodiversity, agricultural land is generally of low relative value. Where profitable perennial options exist, extension is the main tool. More commonly, where current plant-based options are not sufficiently profitable, plant based R&D to improved options should be undertaken.

Where land is already salt-affected, development of plant-based or engineering options is justified where the downstream impacts are positive or neutral and where profitable options are lacking. Development of new options could potentially also be justified even if downstream costs were expected, provided that on-site benefits were expected to be sufficiently large. A choice between regulation and no action applies where the downstream impact of managing salt-land is sufficiently negative.

Investment in profitable plant-based options remains an important management option to maintain water quality in rivers in the long term. It still has an important contribution to make to land protection and other assets. There are 3 main plant-based management strategies that remain important in particular situations: (i) to reduce or delay saline discharge with existing plant-based options; (ii) to make productive use of salt-affected land; and (iii) to develop new perennial and/or salt-tolerant species and systems (using plant-based R&D) that are economically competitive with annual agricultural options. The third strategy, in particular, has a crucial role in achieving salinity management over much larger areas than will be possible with current perennial plant options.

The study has a number of implications for government, agricultural R&D corporations, and catchment management organisations. It provides a pathway to more cost-effective and scientifically defensible investments in management of dryland salinity by providing guidance on the broad categories of policy measures that are appropriate in different circumstances. It highlights the need to policy investments to be highly sensitive to case-specific circumstances, and well informed by science. It implies that there should be a number of shifts in emphasis in the funding directions of the existing policy program, most notably less emphasis on incentives and extension, and more on plant-based R&D. It confirms the appropriateness of the attention that has recently been given to engineering and permit-based approaches. Given that 2 of the more prominent policy responses in our recommendations are plant-based R&D and regulation, and that these are likely to be best considered, managed and implemented at scales greater than existing regional bodies, the degree of emphasis on regional decision making in the existing program should also be reconsidered.

The authors have instigated collaborative work with regionally based catchment management bodies in order to attempt to validate and further develop the framework. This will involve testing the logic and practicality of the current version of the framework, developing recommendations for more specifically defined policy measures, estimating the cost of applying the framework, integrating the framework with other existing decision frameworks, and communicating results to stakeholders, including policy makers and policy advisors.

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