CHAPTER

7 Salinity and the reclamation of salinized lands

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7.1 Introduction

Soil salinity results from an excess of salts in the soil, with consequent impacts on plant growth. These salts can include the chlorides, carbonates, and sulfates of sodium, calcium, and magnesium (Rhoades, 1993; Rhoades et al., 1992), with sodium chloride being the most common. The salts affect plant function by imposing an osmotic stress that reduces plant water uptake and through toxic concentrations of sodium and chloride. In some cases irrigation waters contain carbonates and this results in increased soil alkalinity, with effects on the availability of nutrients and the stability of soil organic matter (Eaton, 1950). The effects of salinity often manifest themselves in reduced plant growth and crop productivity, with different plant species exhibiting different degrees of salinity tolerance (Rhoades et al., 1992). Salinity also affects soil biological activity (García and Hernández, 1996).

Salinization not only removes arable land from production but in some cases affects water resources, built infrastructure, and remnant biodiversity. This is particularly important where irrigation waters are compromised by salinity as this directly affects food production. Salinity thus intersects with major global concerns, including food security, desertification, and biodiversity protection. Indeed, the salinization of land is considered a form of desertification, under the United Nations Convention to Combat Desertification. In addition, salinization of rivers is considered a global threat to biodiversity and compromises the ecosystem, goods and services of rivers, wetlands, and lakes (Cañedo-Argüelles et al., 2013; Vengosh, 2003). Notable examples of this include the Aral Sea Basin in Central Asia, the Indo-Gangetic Basin in India, Indus Basin in Pakistan, the Yellow River Basin in China, the Euphrates Basin in Syria and Iraq, the Murray-Darling Basin in Australia, and the San Joaquin Valley in the United States (Qadir et al., 2014). Salinization also contributes to the loss of remnant biodiversity, such as in South Western Australia, which

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is a global biodiversity hot spot (Myers et al., 2000), affecting flora and fauna both on the land and in aquatic systems (Halse et al., 2003).

Lands affected by salinity can be considered in terms of the broad framework of primary and secondary salinity (Ghassemi et al., 1995), which can be further modified to account for additional concerns:

- *Primary salinity* is land that is naturally saline.
- *Secondary salinity* occurs where land has been salinized as a result of:
  - irrigation;
  - dryland salinity that involves changes in landscape- or site-scale water and salt balances;
  - inundation from flooding, storm surges, or tsunamis; and
  - drying of water bodies, with the exposure of saline soils and sediments.

In an alternative framework, Rengasamy (2006) presents three categories based on salinization processes:

- *Irrigation-associated salinity* where leaching is insufficient the salts brought in by irrigation water can accumulate in the root zone, particularly if drainage is poor. Rising saline groundwater can compound the problem.
- *Groundwater-associated salinity* generally occurs in low-lying discharge areas where the water table is close to the surface and salt is brought to the surface by groundwater movement coupled with high evapotranspiration as a driving force.
- *Nongroundwater-associated salinity* usually associated with landscapes where the water table is deep and drainage is poor. Salts accumulate in the soil from rainfall, weathering, and aeolian accession. If the hydraulic properties of the soil are poor, salt can accumulate in the root zone.

The effects of salinization on arable land are of particular concern in terms of future food security (Qadir et al., 2014; FAO and ITPS, 2015). World population continues to increase toward 11.2 billion people by the year 2100 (United Nations, 2017) and per capita demand is also increasing, leading to pressures to expand food production to meet this need. Much of the change in population is projected to occur in Africa with an increase from 2017 to 2100 of 3.2 billion people, compared to an increase of 3.6 billion people globally. There are suggestions that to meet global food demand by 2050 agricultural production will need to increase by 60%–100% from a 2005/07 baseline (Tillman et al., 2011), although recently Hunter et al. (2017) re-examined this target, with consideration of sustainable intensification and suggested that an increase in production of approximately 25%–75% would be sufficient to meet 2050 food demand. Clearly, some of the expansion of agricultural area to meet this increased demand will come through the use of semisaline land and semisaline irrigation waters as nonsaline sources are fully committed (Ladeiro, 2012). In some areas, groundwater used for irrigation is salinizing as overexploitation results in the reversal of groundwater flows and the intrusion of seawater, while an additional concern lies with climate change, through sea-level rise, associated storm surges, and increased inundation with seawater (Church et al., 2013).

Numerous approaches have been developed to manage salinity and reclaim salinized soils, with varying degrees of success, and these are described in this chapter. We first outline the underlying processes that cause salinity and then address various plant-based (e.g., forestry or agronomic), engineering, and policy management approaches, together with emerging approaches using carbon mitigation investment that might provide funding for broadscale reclamation of salinized land.

7.2 Global distribution of salinity

Global estimates of salinity often include both saline and sodic soils (Abrol et al., 1988), with around 1 billion hectares affected (FAO and ITPS, 2015). The FAO uses the definition that salinity occurs when the electrical conductivity in a saturation soil extract is >4 dS m^{-1} at 25°C (e.g., Rhoades and Miyamoto, 1990) with different categories of salinity for values less than this (Table 7.1). Sodicity is defined as where the soil has a small salt content, but the soil contains >6% sodium ions in the exchange complex (FAO and ITPS, 2015). In this chapter we focus on the approximately 412 million hectares of saline soils, which tend to be most prevalent in arid and semiarid regions (Rengasamy, 2006) but do occur in other regions as well (Abrol et al., 1988).

Salinization is a change in the salinity status of a soil with an estimated abandonment of 0.3–1.5 million hectare $year^{-1}$ of salinized soils (FAO and ITPS, 2015). The area of land that is affected by lower concentrations of salinity, which might have less profound effects on plant growth, is unknown. Rengasamy (2006) termed this "transient salinity" and suggested that in Australia two-thirds of the agricultural area was affected. There are no global estimates of this phenomenon.

Table 7.1 Soil salinity classes and crop growth (Abrol et al., 1988).

Soil salinity class	Conductivity of the soil saturation extract (dS m^{-1})	Effect on crop plants
Nonsaline	0–2	Salinity effects negligible
Slightly saline	2–4	Yields of sensitive crops may be restricted
Moderately saline	4–8	Yields of many crops are restricted
Strongly saline	8–16	Only tolerant crops yield satisfactorily
Very strongly saline	>16	Only a few very tolerant crops yield satisfactorily

Globally, a major proportion of the land affected by secondary salinity is associated with irrigation. In 2006, out of a global total of 301 million hectares of irrigated land, around 76 million hectares were salinized (FAO and ITPS, 2015) and this was also the fate of historic irrigation developments such as associated with the Euphrates and Tigris Rivers (Hillel, 1991). Contemporary examples of salinity associated with irrigation include the San Joaquin Valley in California, the Amu Darya and Syr Darya Rivers in Uzbekistan (Egamberdiyeva et al., 2007), and Haryana in India (Datta and Jong, 2002).

Dryland salinity is a particular issue across southern Australia where extensive deforestation of deep-rooted perennial plants for agriculture and replacement with shallow-rooted annuals has changed the water balance at regional or landscape scales. This has mobilized salts stored over millennia in the landscape and compromised agricultural soils and remnant biodiversity throughout much of Australia's 100 million hectare wheat–sheep zone, with an estimated 5.7 million hectares affected by or at risk of dryland salinity (National Land and Water Resources Audit, 2001). Affected areas in catchments drain to waterways and as a result rivers have become saline, thus compromising downstream water supplies (Ruprecht and Dogramaci, 2005).

Salinization can also result from flooding or inundation with saline waters, through breaching of dykes, floods, storm surges, or tsunamis or the drying of large inland bodies of water. In the latter case, changes in water balance through changes in climate or diversion of inflow waters can result in previous lake beds being exposed through evaporation. Such is the case with the Aral Sea, where diversion of contributing rivers resulted in a decline of the Sea's area from 68,000 km^2 in 1960 to 14,280 km^2 in 2010 (Micklin, 2007). The level in what is referred to as the "large Aral Sea" declined by more than 29 m and the salinity concentration increased from 10,000 to 130,000 $mg\,L^{-1}$ (Gaybullaev et al., 2012). Other lakes where the inflows and surface areas have sharply declined, with the consequent exposure of saline soils, include Lake Urmia in Iran, Lake Chad in Africa, and the Salton Sea in California. The problem is also acute in some large river deltas where multiple drivers are contributing to the salinization of freshwater and soils (Rahman et al., 2019).

7.3 Measurement of salinity and impacts on plant growth

Soil salinity is a continuous variable; with the definition of saline soils varying both across countries and with measurement method. Methods of assessment of salinity vary from the laboratory through to the landscape-scale. The saturation soil extract method involves laboratory analysis through the measurement of electrical conductivity (Rhoades, 1993); however, for rapid field-based assessment, electromagnetic (EM) induction instruments have been used, with data either representing points in the landscape or being used to map the distribution of salinity (Lesch et al., 1992; Williams and Baker, 1982). In some cases these data have been combined with other site information (Lesch et al., 1995). Depending on the EM instrument used, salinity can be mapped in the surface layers or to greater depths (Yao and Yang, 2010; Doolittle and Brevik, 2014). Another approach has been to combine satellite imagery with digital elevation information to predict the distribution and temporal change of dryland salinity (e.g., Furby et al., 2010). Because of the wide range of approaches used to measure salinity, the values presented in different studies are not necessarily directly comparable.

Although salinity is a continuous variable, it can be presented for convenience as a series of categories from nonsaline to very strongly saline (Table 7.1), with associated broad effects on plant species. The physiological tolerance to salinity varies, such that some plant species have no tolerance, whereas others can survive and grow in hypersaline environments. Rhoades et al. (1992) summarize the salinity tolerance of a wide range of crop, forage and horticultural and woody species. Mechanisms of salinity tolerance have been reviewed by Cheeseman (1988) and more recently by Volkov and Beilby (2017). This variation in tolerance of different plant species provides one option for management of saline soils and will be discussed later in this chapter, when describing plant-based management approaches.

As described earlier, a major cause of salinization is through the application of salts in irrigation waters. Salinity can be readily measured in water, via the measurement of electrical conductivity (Rhoades, 1993), because conductivity increases with an increase in ionic concentration. Again, this is a continuous variable, but for convenience the quality of water can be presented as a series of categories (Table 7.2). This approach however does not discriminate between ionic species, with apparent salinity being affected by both cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (CO_2^{2-}, SO_4^{2-}, HCO_3^{-}, and Cl^{-}) and these can be analyzed and expressed as a mass or milliequivalents per liter and are often expressed as total dissolved salt (TDS) or total soluble salt.

Table 7.2 Classification of saline waters (Rhoades et al., 1992).

Water class	Electrical conductivity ($dS\ m^{-1}$)	Salt concentration ($mg\ L^{-1}$)	Type of water
Nonsaline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7–2	500–1500	Irrigation water
Moderately saline	2–10	1500–7000	Primary drainage water and groundwater
Highly saline	10–25	7000–15,000	Secondary drainage water and groundwater
Very highly saline	25–45	15,000–35,000	Very saline groundwater
Brine	>45	>45,000	Seawater

7.4 Causes of soil salinity

Soil salinization can be considered in terms of the salt and water balance within a soil profile or of a land system; that is the difference in inputs and outputs. Understanding this broad framework provides indications as to useful management approaches.

For example, if more salt is added to a soil than leaves in drainage, there will be salinization. Salt content on a site can increase through inputs from irrigation water, or from inundation with saline waters. The concentration of salt can also increase through evaporation, as seen when a saline water table is close to the surface and contributes to salinity through capillary rise of water. Here the contributing water table is generally <2 m below the surface, with this depth depending on soil properties such as porosity (Ruprecht and Dogramaci, 2005). Evaporative concentration of salt also occurs during drying of inland water bodies.

Salinity can also be related to landscape hydrology, and the interplay of landscape water balance and groundwater systems, as seen with dryland salinity in South Western Australia. Here, the change in landscape water balance has resulted in the pressurization of groundwater systems and consequent movement of water through the deep regolithic landscapes, resulting in the mobilization of stored salt (Schofield, 1992). Salty groundwater can occur close to or discharge on the surface of the landscape from aquifers under pressure and cause salinization. In these situations, drainage can be problematic, and attempts have been made to manipulate the water balance of the whole landscape (George et al., 2012) and thus reduce recharge and saline discharge.

With adequate drainage salts can be leached and the soil's functions recovered. There are numerous examples of this, such as the recovery of soils inundated by seawater following tsunamis in Indonesia (McLeod et al., 2010), the breaching of dykes in Holland (Gerritsen, 2005), and a storm surge in the Mackenzie Delta of Canada that traveled 30 km inland and flooded 30,000 ha (Lantz et al., 2015). Salt can be removed from soils through leaching with nonsaline waters and this requires movement of both salt and water away from the soil surface. The amount of leaching required will depend on the initial salt content of the soil, the quality of the leaching water, and the characteristics of the soil (Rhoades et al., 1992). Conversely, in locations where the water table remains near the surface, such as in discharge areas, or under irrigation without adequate drainage, the salinity problem will remain.

7.5 Managing salinized landscapes: Stabilization or reclamation?

In some cases, it is possible to reverse the effects of salinization; however, a crucial consideration in the reclamation of salinized soils is the desired end point. That is, are the interventions aimed at stabilizing the soils against further change, or reversing the process and restoring it to another state? Apart from the technical issues, the approach taken will also depend on the economic and sociopolitical context of the land in question; in some cases, abandonment of land may be the rational economic response, as the costs of treatment outweigh the economic or social returns, whereas in others the land may be restored to productive agriculture or revegetated with a biodiverse ecosystem.

There are thus several potential approaches:

- *Prevention*: Here the aim is to stop the development of salinity.
- *Stabilization*: Not all situations allow drainage and a reduction of salt concentrations; however, it may be possible to adapt to salinity. One example would be revegetation with salt-adapted plants. This may also be the case in naturally saline lands that have been damaged by overgrazing.
- *Active management*: Here approaches are taken to reverse salinity, such as through drainage and leaching of soils, or the restoration of catchment water balances through recharge control.
- *Land retirement or abandonment*: In some cases the salinized land is simply too saline for plant-based solutions, it may be technically not possible to treat the land or the costs of treatment, such as installation of drainage is uneconomic. In such circumstances abandonment may be the rational approach.

Ruprecht and Dogramaci (2005) describe three major approaches to managing or reversing salinity: these being (1) engineering, (2) plant-based, and (3) policy and legislative changes. In brief, these approaches either aim to prevent, stabilize, or actively reduce salinity, by manipulating a site's salt and water balances.

7.5.1 Engineering approaches

Engineering approaches can be applied to manage both salt and water balances. Examples in irrigation management include controlling the overall salt input through monitoring both the quality and quantity of water applied, as it is often not possible to use alternative sources of water. Irrigation management involves optimizing the quantity of water applied for particular crops, or the recycling of drainage water on more salt-tolerant crops (Levers and Schwabe, 2017; Rhoades et al., 1992). Although desalination technology exists, this is presently too expensive as a source of irrigation water except for intensive very high-value horticultural crops (Burn et al., 2015).

Leaching of salts from salinized soil requires a source of less saline water to leach the salts, drainage, and management of water tables. Excess water that is applied to the surface and moves beneath the root zone is termed the leaching fraction, and the effectiveness of leaching depends on the salinity and volume of the applied water and the infiltration characteristics of the soils (Ruprecht and Dogramaci, 2005; Rhoades et al., 1992). The recovery from inundation can be relatively rapid under the right circumstances.

Water can be carried away via installed pipes and drains or by pumping, with the resultant saline waters either reapplied to other crops, diverted into evaporation ponds (Rhoades et al., 1992; Levers and Schwabe, 2017), or disposed of downstream. This engineering option requires appropriate management of drainage waters and consideration of the likely off-site impacts from salts and possible pesticide or heavy metal contamination (Rhoades et al., 1992; Degens et al., 2012).

A key issue to consider in any restoration program is the properties of the soils that are being treated, and whether they are indeed amenable to drainage and restoration. Consideration is also needed of the subsequent management of reclaimed soils and resulting issues such as dispersal of clay particles and the associated risk of surface crusting (Rhoades et al., 1992), or managing the residual alkalinity caused by the use of carbonate rich waters.

7.5.2 Plant-based approaches

A range of plant-based approaches has been used in the management of salinized soils. These follow three broad strategies and can involve the use of a wide range of plant species, As discussed earlier there are significant differences in the adaptation of different plant species to differences in salinity.

Approaches include:

- on naturally saline land, managing existing vegetation to reduce the risk of damage or replanting native species to rehabilitate ecosystems;
- treating salinized sites with saline-tolerant plant species; and
- managing the site or landscape water balance by lowering the water table through an increase in evapotranspiration.

Less common is phytoremediation or using plants to remove salt from the soil; as generally the amounts of salt stored in saline soils far exceed the amounts that can be removed in plants (Heuperman et al., 2002). However, there are some promising developments in phytoremediation (Imadi et al., 2016). Here the aim of the technique is to improve the soil by using plants with tolerance to high salt contents in order to enhance soil calcium levels and decrease sodium levels, after which the site can be replanted with less salt-tolerant crops. Nikalje et al. (2018), for example, propose harvesting halophytes for industrial use thereby removing salt; however, these techniques have to consider the total salt stored in a soil compared to what will be removed through biomass removal.

7.5.2.1 Managing vegetation on naturally saline land

Naturally saline land is often covered with halophytic species. In the case of shrubs, these may have been damaged by overgrazing and there is consequent interest in restoring these ecosystems. There is an extensive literature, both in terms of grazing management of halophytic shrublands and also in the restoration of these systems (e.g., Barrett-Lennard, 2002; Squires and Ayoub, 1994).

7.5.2.2 Treating salinized soils

A common treatment for salinized land is to revegetate with salt-tolerant species, with this termed "biodrainage" by Heuperman et al. (2002). The selection of plant species depends on factors such the desired end use, climate and degree of soil salinity. If salinity continues to increase, it is possible to change plant species (Rhoades, 1993); however, there is an upper limit of salinity for which this will work. For grazing systems, there is a range of halophytic grazing shrubs (e.g., *Atriplex* spp.) that can be used (Barrett-Lennard, 2002). There is also a range of product options using trees, these including as a bioenergy feedstock (Sochacki et al., 2012) (Fig. 7.1), for carbon sequestration or timber (Marcar and Crawford, 2004; Lambert and Turner, 2000) or using biodiverse species to restore or enhance wildlife habitat (George et al., 2012).

The evidence that such plantings reduce groundwater levels on salinized sites through increased evapotranspiration is mixed (Morris and Collopy, 1999) and success will depend on the local hydrogeological conditions, such as surface water inflows, the transmissivity of near surface water tables, and the discharge from deeper aquifers. For example, in a study in Victoria, Australia, Heuperman (1999) found that after 10 years trees planted in a salinized area decreased the level of an unconfined aquifer by 2–4 m, reversing the hydraulic gradient such that water flowed toward the trees and site salinity increased. Other studies of revegetation with saltbush indicate substantial use of groundwater (e.g., Barrett-Lennard and Malcolm, 2000). An overriding issue with vegetation-based approaches to lower water tables is that if the onsite salt balance has not been

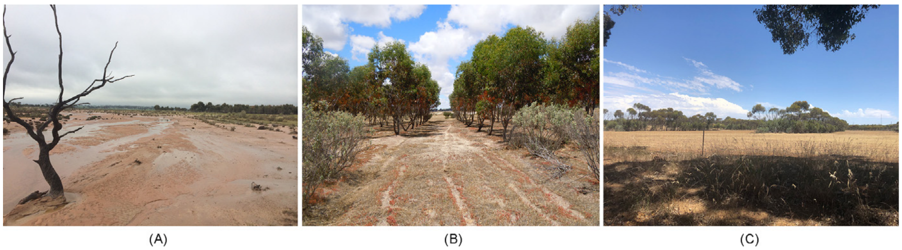

FIGURE 7.1

Salinization is a major issue in South Western Australia affecting around 1 million ha of farmland and nature reserves. Deforestation has pressurized groundwater systems and these have dissolved salt stored in the regolith, with this discharged in lower landscape positions, salinizing both soils and streams. (A) Salinized, formerly productive farmland that has also been affected by water erosion (Wickepin, Western Australia), (B) reforestation of salinized discharge areas with salt-tolerant species *Eucalyptus occidentalis* and *Atriplex nummularia* (Sochacki et al., 2012) (Wickepin, Western Australia), and (C) reforestation of upland recharge areas with belts of mallee *Eucalyptus* (Narrogin, Western Australia) that could be a bioenergy feedstock. Carbon mitigation via bioenergy or sequestration has been investigated as a means of financing the large-scale intervention required to restore the landscape water balance.

managed, then salts will continue to accumulate in the root zone, as the vegetation transpires water (Nosetto et al., 2008; Barrett-Lennard, 2002). This was demonstrated in reforested discharge areas in Western Australia, where although trees decreased the groundwater level, groundwater salinity concentrations increased (Stolte et al., 1997; Archibald et al., 2006).

A range of site management approaches can be used when treating saline land, including the engineering options already described, or soil mounding to overcome localized waterlogging and to encourage leaching of salt. In some cases the lack of plant cover on salinized sites has led to erosion and loss of nutrients, and this requires consideration in site restoration. Wind erosion from salinized areas produces dusts that can represent a human health hazard; Stanturf et al. (2020) review various approaches using vegetation on the salinized, exposed floor of the former Aral Sea. Soil salinity and groundwater levels were critical to successful reestablishment, along with the drought and salinity tolerance of the species used.

A combined engineering and plant-based approach was trialed in the San Joaquin Valley in the United States, where high-value crops are grown on some soils, with drainage induced by pumping. This water was disposed elsewhere in the landscape, in a system termed Integrated Farm Drainage Management, with Levers and Schwabe (2017) demonstrating that the use of a biofuel crop increased the overall profitability of the system and had a lower greenhouse gas footprint than other agricultural crops.

For land that has become alienated from primary production due to salinization, there could be long-term opportunities in introducing engineered salt-tolerant crops. However, despite great effort over recent decades, there has so far been little success in delivering high-yielding, salt-tolerant, and staple food crops to producers. Salt tolerance has been generated in a number of cereal genotypes (e.g., Mujeeb-Kazia et al., 2019; Shahbaz and Ashraf, 2013), but field deployment is limited.

7.5.2.3 Changing landscape-scale water balances

Dryland salinity can increase both stream salinity and the salinity of adjacent soils. As described, this is due to a change in landscape-scale water balance after replacement of deep-rooted perennial species with shallow-rooted species that transpire less. This leads to groundwater rise and mobilization of salts already stored in the landscape. It is thus treated with landscape-scale responses, where the aim is to increase overall evapotranspiration across the landscape, through the protection of existing deep-rooted vegetation or the reintroduction of deep-rooted plants, and thereby reduce groundwater recharge, piezometric pressures, and salt discharge in lower landscape positions.

The landscape approach was successful in controlling saline seeps in the croplands of the United States' Northern Great Plains (Halvorson and Reule, 1980). Here a deep-rooted forage plant (*Medicago sativa*) was planted over 80% of the recharge area and this successfully controlled salinity, whereas 20% coverage didn't. This approach has been recently replicated in the Prairie Provinces of Canada (Wiebe et al., 2010). Here, the area affected by salinity was reduced from 15% in 1981 to 8% by 2011, through changes in the water balance by reducing summer fallows and a 4.8 million hectares increase in the area of permanent cover (FAO and ITPS, 2015).

Both soil and water salinity are major issues in South Western Australia, with around 1 million hectares of soil salinized as a result of deforestation for agriculture (George et al., 1997), and a consequent increase in river salinity in any watershed that has been subjected to land clearing (Halse et al., 2003). Following recognition that disturbing the water balance resulted in the mobilization of salts stored in deep regolith (Peck and Williamson, 1987), subsequent studies indicated that substantial reforestation ($>80\%$ cover) was needed to reverse salinization (George et al., 1999; Bari and Ruprecht, 2003). *Eucalyptus* have been reported to deplete soil water to depths of up to 8 m in 3 years in this region (Harper et al., 2014) with approaches that have resulted in 113,000 ha of reforestation reviewed by Harper et al. (2017). The landscape approach has been successfully demonstrated at scale in the Denmark River watershed in South Western Australia where previous deforestation of 25% of the 56,500 ha watershed resulted in an increase in annual flow-weighted stream salinity from 280 to 1500 mg L^{-1} TDS between 1964 and 1997. Reforestation of 18% of this area with *Eucalyptus globulus* by pulpwood investors resulted in stream salinity reverting to 500 mg L^{-1} TDS by 2017 (Ruprecht et al., 2019).

7.5.3 Policy and legislative approaches

A range of policy and legislative approaches have been used to tackle salinity, these including regulation, research, and education and market mechanisms or economic instruments (Weersink and Wossink, 2005; Ruprecht and Dogramaci, 2005). Examples of regulation include mandating land-use, such as controlling rates of deforestation, the allocation of land for irrigation, managing irrigation schemes through water allocation, or developing rules around the disposal of drainage waters. Education can range from public communications regarding the best practice to formal publications. Economic instruments include procedures such as water pricing and transferable water entitlements, and payment for environmental services.

Successful restoration of salinity at the landscape-scale relies on broadscale land-use change. This is problematic where the most profitable land-use is agriculture, and the replacement by deep-rooted perennials, which have higher evapotranspiration rates, is less attractive. There has therefore been considerable investigation of land-use systems that at least replicate the profitability of the current agricultural system. Thus recent approaches have explored how to make the higher water using farming systems acceptable by making the replacement plants profitable in their own right, such as through the growth of forage plants (Halvorson and Reule, 1980; Wiebe et al., 2010) that can support grazing, the use of plants that can be used to mitigate carbon dioxide through sequestration or bioenergy (Harper et al., 2017; Sochacki et al., 2012; Walden et al., 2017), and timber or payments for environmental services such as water (Townsend et al., 2012).

In some landscapes it may not be possible to achieve the scale of activity needed to manage salinity, either due to the economics of treatment or the nature of the groundwater systems (George et al., 1999; Harper et al., 2017), and here an alternative approach is to follow a containment strategy and only concentrate on the areas that have been salinized (McFarlane et al., 2016). Here plant-based treatments could again be financed through carbon markets (Walden et al., 2017; Harper et al., 2017), in areas where these are in operation.

7.6 Summary and conclusion

Salinity is a major issue in some regions of the world and is predominantly caused by irrigation practice, landscape changes in hydrology, or floods and inundation. It intersects with a range of other issues, including food security, biodiversity protection, and rural livelihoods. The principles of managing salinity can be understood in terms of a soil or site's salt and water balances. There are a range of engineering and plant-based options for reclaiming salinized soils and these have achieved various degrees of success. Combining engineering and plant-based approaches may increase the success of reclamation in some areas. Salinity often occurs over broad areas and a key consideration is financing reclamation efforts that can occur over scale and here markets for carbon mitigation that are developing in response to managing climate change may have a major future role, particularly given the scale of mitigation investment that will be required to contain climate change in coming decades.

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