# chapter 2

## Three Approaches for Managing Saline, Sodic and Waterlogged Soils

## Overview

There have been four major approaches to dealing with salinity and sodicity in Pakistan.

### Engineering approach

The engineering approach assumes that salinity in irrigated areas can be reversed using drainage schemes that lower watertables. Over 7.8 million hectares have now been treated using salinity control and reclamation projects (SCARPs). However, the projects are extremely expensive, many salt-affected soils are not treatable, and the sustainability of the approach is questionable.

### Reclamation approach

The basis of the reclamation approach is the use of small-scale interventions to improve soil condition. This is particularly appropriate where soils are saline because of their high sodicity (lack of soluble calcium) and low rates of water infiltration. Interventions include the leaching of salt with higher levels of irrigation, the use of chemical amendments (such as gypsum and acids), the use of organic wastes, and the use of plants to improve soil condition. Best results may be obtained using combinations of methods.

### Saline agricultural approach

Under the saline agricultural approach, useful production can be achieved from salt-affected wasteland (without reclamation). In these instances, the main focus is on the economic utilisation of the land while still in the saline or sodic condition. There may be improvements in soil condition but this is a spin-off benefit.

### No intervention

This chapter focuses on the first three of these approaches. There are few situations in which doing nothing is the best response.

## 2.1 The Engineering Approach

The *engineering approach* has been used to develop large-scale drainage projects on land where soils are saline because of shallow watertables. Salinity is controlled by draining the soil using networks of tubewells, surface drains and subsurface tile drains. The drained groundwater is then made available for irrigation, or it is returned to the rivers.

### 2.1.1 The problem of canal seepage

Irrigation canals seep at a rate of about 0.21 cubic metres of water per day per square metre of wetted soil area (recalculated from Ahmad and Chaudhry 1988, p. 7.8). The link between the proximity of irrigation canals and shallow watertables was first observed as early as 1851.[1] Although a variety of potential solutions for decreasing waterlogging were tested (Ahmad and Chaudhry 1988, pp. 7.5–7.10), only three techniques were really useful.

*Surface drainage.* Surface drains were first constructed to deal with the problems arising from the Western Jumna and Sirhind canals (now in India), but also proved effective in tackling waterlogging following the opening of the Lower Chenab Canal. In 1933 a comprehensive plan was prepared to construct large numbers of surface drains; by 1947 about 5380 kilometres of drains had been constructed in Pakistan.

*Lining of canals.* Experiments on the lining of canals began in 1895 with unsuccessful attempts to stop seepage by lining canal beds with oil-impregnated paper, sprayed bitumen or clay puddle. By 1938–39, the lining of canals with tiles and cement was found to reduce seepage by about 75%.

*Pumping of groundwater.* Up to 1920, a number of small-scale experiments were conducted with tubewell pumping to decrease waterlogging. However, larger-scale experiments did not occur until the mid-1930s. In 1945, a project was started to install 1800 tubewells along the main lines and branches of the Rechna and Chaj Doab canals. These were to be powered with hydroelectricity from the Upper Jhelum Canal at Rasul; the project was therefore called the 'Rasul Tubewell Project'. By 1951, about 1500 tubewells had been constructed.

### 2.1.2 Development of the SCARP program

In 1954, there were renewed investigations of the control of waterlogging and salinity under a technical assistance program with the United States. These led to the first Salinity Control and Reclamation Project (SCARP). A formal agreement for SCARP-I was signed in 1957, and the project was completed in 1963. The key strategy of SCARP-I was to install large-capacity tubewells for the pumping of aquifers. These tubewells also provided extra irrigation water to leach salts and increase cropping intensity.

Investigations of groundwater pumping expanded in the late 1950s and early 1960s with the founding of the Water and Power Development Authority (WAPDA) in 1958, and the publication of four reports all suggesting that the problems of salt/waterlogging could be solved by expanding the SCARP program.[2]

Initially, the SCARP program placed emphasis on the installation of large-capacity publicly owned tubewells capable of pumping at rates of 60 to 110 litres per second (Ahmad and Chaudhry 1988, p. 6.36). However, in the revised action plan there was increased emphasis on the installation of smaller-capacity, privately owned tubewells capable of pumping at rates of about 15–30 litres per second (Ahmad and Chaudhry 1988, pp. 6.38–6.39). It is estimated that by December 1996, there were more than 19 000 publicly owned (Water and Power Development Authority 1997) and 243 000 privately owned tubewells.[3] In addition, about 11 000 kilometres of drains had been constructed (Water and Power Development Authority 1997).

### 2.1.3 Left Bank Outfall Drain

One of the biggest projects to dispose of saline effluent is the Left Bank Outfall Drain located in the Lower Indus. This region includes 5.7 million hectares of cultivable

1 Attention was drawn to the problems of seepage in the area of the original Western Jumna Canal in 1851 when malaria became severe because all depressions and low lands close to the canal were filled with water. Waterlogging was also reported along the Sirhind Canal in 1880 and in the area of the lower Chenab Canal in 1892 (Ahmad and Chaudhry 1988, p. 7.2).

2 These were: the so-called 'Revelle Report'—a report commissioned by President Kennedy of the United States (White House, Department of Interior Panel on Waterlogging and Salinity in West Pakistan, 1964); two reports commissioned by WAPDA, one from Harza Engineering Company International (Hansen et al. 1963), the other from Hunting Technical Services Limited and Sir M. MacDonald and Partners (1966); and a World Bank commissioned study published by Sir Alexander Gibb and Partners et al. (1966).

3 The number of privately owned tubewells is a conservative estimate; in 1981 there were 183 000 tubewells in Pakistan, and during the period 1976–81, this figure was growing at about 6300 per year (Ahmad and Chaudhry 1988, p. 6.23). We have assumed a growth rate of 4000 per year after 1981 (see comment of Ahmad and Chaudhry 1988, p. 6.22).

land, of which 85% is underlain by saline groundwater. Stage 1 of the Left Bank Outfall Drain is to alleviate waterlogging and salinity on 577 000 hectares in the Nawabshah, Sanghar and Tharparker districts. The project will control waterlogging by installing 2000 tubewells over an area of 395 000 hectares. Watertables in this area were previously about 1.5 metres from the soil surface. A further 22 000 hectares, also with shallow watertables, will be provided with tile drains. Both tubewells and drains will be pumped into a disposal system providing surface drainage for the whole area. The disposal system will then discharge into a spinal drain, which will extend 290 kilometres to the sea. This project will cost around 26 billion Pakistan rupees (PKR)[4] and is expected to export 25 to 30 million tonnes of salt into the sea each year.

### 2.1.4 Does the engineering approach work?

In 1968, WAPDA created the SCARP Monitoring Organisation to evaluate the performance and effectiveness of SCARPs in terms of their design characteristics and planned objectives. The International Commission on Irrigation and Drainage (1991, Tables 10, 11, 14, 15) monitored the average outcomes of the early SCARP projects, covering 2.3 million hectares (SCARP-I, SCARP-II, SCARP-III, SCARP-IV), and suggested that these drainage schemes:

- increased cropping intensities from 84 to 117%;
- decreased areas with severe waterlogging from 16 to 6%;
- increased areas of salt-free (surface salinity) land from 49 to 74%; and
- increased gross value of production by 94%.

At present 57 SCARPs and drainage projects have been completed (covering an area of 7.8 million hectares at an estimated cost of 26.4 billion PKR); a further five drainage projects are planned (Water and Power Development Authority 1997).[5]

In spite of these successes, the present strategy suffers from a number of critical deficiencies.

- *Many salt-affected soils are not treatable.* The approach has little chance of success in 1.03 million hectares of land that have soils which are impermeable to water (Photo 2.1) (Rafiq 1975). Also the approach is confined to the Canal Command Area. About 2.64 million hectares of salt-affected land lies outside the Canal Command Area and this will not be tackled.
- *The costs of the approach are very high.* At the present time, the annual cost associated with maintaining the current engineering approach on 7.8 million hectares is about 11 billion PKR per year (see Table 2.1) or about 1300 PKR (US$30) per hectare per year. About 80% of these funds come from the private sector.
- *The sustainability of the approach is questionable.* About 60% of Pakistan's salt-affected land is saline–sodic; these soils are further deteriorated by leaching with extra irrigation water. Between 70 and 75% of tubewells are pumping water of marginal or hazardous quality in the Punjab; the situation is worse in Sind.[6] About 2 to 3 million hectares have already been adversely affected by the use of water of high sodicity hazard (Rafiq 1990). Although WAPDA accepts the need to measure the salinity and sodicity hazard of pumped groundwater, it is largely unable to divert hazardous water away from the irrigation system.[7]
- *The projects are of large scale.* In general, they cannot be reduced in size to tackle problems at levels of individual farms or isolated areas.
- *The criteria for determining the success of projects are inadequate.* A SCARP should assess its success by comparing the salinity and sodicity values in local soils before it starts with values measured after implementation. Salt and water balances must be calculated for project areas, for regions and for the country as a whole. Separate calculations are necessary for the root-zone and for greater depths in the soil. To be regarded as successful, a SCARP should show decreased salinity/sodicity in the root-zone and improved sustainability of the agricultural system.

4 For currency exchange rates, see page 4.

5 The planned projects are: the Left Bank Outfall Drain, the Right Bank Outfall Drain, the Khushab SCARP, the Fordwah Sadiqia SCARP and the Swabi SCARP.

6 Studies in SCARP-I showed that large areas of salt-free soils were damaged by sodicity through the use of tubewell water of low salinity but moderate to high sodium hazard (Jalal-ul-Din and Rafiq 1973; Hussain and Muhammad 1976). Such sodicity seriously affects germination due to surface crusting (Byerlee and Siddiq 1990).

7 The Left Bank Outfall Drain has been promoted as a way of disposing of hazardous groundwater. However, its influence on the total salt balance of the Indus Basin will be small. Each year, Pakistan adds salt to the land as canal water (35–40 million tonnes), 'fresh' groundwater (20 million tonnes) and 'saline' groundwater (60–65 million tonnes). The Left Bank Outfall Drain is expected to convey only about one-fifth of this salt to the sea (International Commission on Irrigation and Drainage 1991, Figure 3).

**Table 2.1.**
**Costs of the engineering approach.[a]**

| Item | Cost (billion PKR[b]) |
|---|---|
| SCARP and drainage projects | |
| – interest on capital invested[c] | 0.31 |
| – operation and maintenance[d] | 1.91 |
| Private tubewells | |
| – interest on capital invested[e] | 0.13 |
| – operation and maintenance[f] | 8.86 |
| Total | 11.21 |

a Information on the financing of SCARPs and drainage schemes is not readily available. The scale of the financial commitment has been estimated making a few 'bold' assumptions (see below).

b For currency exchange rates, see page 4

c The value given is the estimated interest payable in 1990 on the 47 completed SCARPs and drainage projects which had been completed at that time (International Commission on Irrigation and Drainage 1991). These projects were implemented with an initial investment of 11.2 billion PKR. The interest was calculated assuming that: (a) costs were spread evenly over the implementation period of each project, (b) costs could be amortised by equal payments over 20 years, and (c) the interest rate for public expenditure is 5% per year. Our calculation is an underestimate as it does not include projects completed after 1990, or those only partially implemented by 1990.

d Calculated for 1995–96 assuming: (a) there are 19 088 tubewells (Water and Power Development Authority 1997), and (b) operating and maintenance costs are about 100 000 PKR per tubewell (Ahmad and Chaudhry 1988, Table 6.59).

e Calculated assuming: (a) 4000 tubewells are established per year (see Section 2.1.2), (b) half of these are diesel powered (cost 50 000 PKR each) and half are electrically powered (cost 70 000 PKR each), and (c) funds are borrowed over a term of 8 years at 14% per year.

f Calculated for 1997 assuming: (a) there are 243 000 tubewells (see Section 2.1.2 above), (b) about half of these are electrified and the balance are diesel powered, (c) the annual operating and maintenance costs for electrically powered tubewells in 1983 was 10 600 PKR (Ahmad and Chaudhry 1988, p. 6.107), (d) the annual operating and maintenance costs for diesel powered tubewells in 1983 was 23 600 PKR —1500 hours at 19 PKR/hour (Ahmad and Chaudhry 1988, pp. 6.105, 6.108), and (e) costs increase by 6% per year.

## 2.2 The Reclamation Approach

In contrast to the engineering approach, the *reclamation approach* can be conducted on a small scale. The main purpose of this approach is to use simple interventions to leach salt out of the surface soil. This approach includes the following strategies.

- *Leaching with higher levels of irrigation.* Salt can accumulate at the soil surface due to the drying of the soil. Salt accumulation is more substantial where watertables are close to the soil surface. The process can be reversed by leaching the soil using extra irrigation water (perhaps that pumped from tubewells used to lower watertables). This approach has promise for well-drained saline soils and gypsiferous saline–sodic soils which have good structure and high rates of water infiltration. Leaching with brackish water has been successful for the initial reclamation of sodic soils of low permeability (Muhammed et al. 1969; Bhatti et al. 1977; Hussain et al. 1986; Ghafoor et al. 1991). However in these instances, use of better quality water is necessary in the final leaching stages, which can cause a deterioration of soil structure unless it coincides with the application of gypsum.
- *Use of gypsum.* Sodic soils have low rates of water infiltration because they contain little soluble calcium, a condition which leads to soil dispersion (see Section 3.3.2). Gypsum is the cheapest source of soluble calcium available in Pakistan.[8] The use of gypsum on saline–sodic and sodic soils improves rates of water infiltration and the leaching of salt into the subsoil.[9] One reason for the popularity of gypsum with farmers is that its price is currently subsidised by the government.[10]
- *Use of acids.* A number of sodic soils contain calcium in insoluble forms (like limestone nodules). In theory this can be made soluble by treating the

8 Gypsum is the common name of the chemical calcium sulfate ($CaSO_4.2H_2O$).

9 There are now large amounts of experimental data on various aspects of the use of gypsum for reclaiming saline–sodic and sodic soils. The reader is referred to papers by Hussain et al. (1981), Chaudhry et al. (1984, 1985), Ghafoor et al. (1988), Khan et al. (1990), Ghafoor and Muhammed (1990), and Chaudhry and Hameed (1992). Qureshi et al. (1992) successfully used gypsum with lateral flushing of salt for the reclamation of dense saline–sodic soils at Sadhoke.

10 The subsidised price is about 15 PKR per 50-kilogram bag. The unsubsidised price was about 30 PKR per bag.

soil with sulfuric or hydrochloric acid (Ghafoor and Muhammed 1981; Mujtaba 1984; Ghafoor et al. 1986). In practice, these amendments are not popular because of their high cost and the need for great care in their handling, transport and application.

- *Use of wastes.* Agricultural and industrial wastes (such as farmyard manure and pressmud) have been used to improve soils affected by high sodicity.
  - Farmyard manure is especially beneficial as it improves soil physical structure as well as providing nutrients for plants (Ghafoor et al. 1990).
  - Pressmud from sugar mills is another excellent source of organic matter for improving the physical condition of soil. Following changes in the sugar extraction process, pressmud now also contains sulfur, which helps to acidify the soil. In sodic and saline–sodic soils this acidification makes soluble calcium available from limestone nodules, which improves soil structure and increases the leaching of salt.[11]
- *Physical methods*. Some farmers have practiced scraping salt from the land surface, and chiselling or deep ploughing land with a hardpan or low permeability.
  - Surface scraping may be of short-term benefit. However, it renders a small part of the land completely unproductive and it removes many of the plant nutrients found close to the soil surface. Furthermore, the salt can easily leach out of the scraped heaps to make the adjoining land salt affected (Photo 2.2).
  - Deep ploughing and chiselling are not always helpful, especially with saline–sodic soils with unstable structure. In these cases, the soil 'slumps' again when wetted and sets hard when dry.
- *Biological methods.* A number of workers have reclaimed soils through the use of salt and waterlogging-tolerant plants. These treatments improve soil structure in two ways: they add organic matter to the soil, and they have an acidifying action which makes soluble calcium available. One means of biological reclamation involves the use over a number of years of a succession of kallar grass (*Leptochloa fusca*)[12] followed by dhancha (*Sesbania bispinosa*) as a green manure,[13] and then normal crops.

**Photo 2.1.** *People gathered around a tile drainage access point. The land in this area has poor permeability to water and remained saline after tile drains were installed. [PHOTOGRAPH: E. BARRETT-LENNARD]*

**Photo 2.2.** *Surface scraping – the surface of the land in the foreground has been scraped into a heap in the background. However, salinity has returned because the cause of the degradation (shallow watertables) has persisted. [PHOTOGRAPH: E. BARRETT-LENNARD]*

11 A note to farmers and extension workers. It would be wise to check whether the sugar mills in your area use the sulfonated extraction system. There are sugar extraction processes that add considerable amounts of calcium carbonate to the pressmud. This can be a problem, causing phosphorus and micronutrient deficiencies for plants.

12 Kallar grass is highly salt and waterlogging-tolerant and is an excellent primary coloniser of soils where low-quality irrigation water is available (Section 5.4.3). One well-documented example in which this occurred was on a saline–sodic soil near Lahore. This soil was highly impermeable, but had a large number of limestone nodules at a depth of about 30 centimetres. Kallar grass at the site formed a dense root mat which produced carbon dioxide (a weak acid) through respiration. After about 3 years, the limestone nodules in the soil had been broken down, producing soluble calcium. With soluble calcium present, there was an increase in rates of water infiltration, and the salt was leached into the subsoil by irrigation (Malik et al. 1986, pp. 62–68).

13 Dhancha is an excellent green manuring plant (Section 6.2.10). Its roots are profusely nodulated, fix large amounts of atmospheric nitrogen and grow deeper than kallar grass. The ploughing in of this crop, and its subsequent decomposition, can further improve the soil, making it fit for the growth of crops like wheat and rice (Sandhu and Malik 1975; Sandhu and Haq 1981).

A number of studies have compared the efficiency and cost-effectiveness of biological and chemical methods of reclamation (Qadir et al. 1990; Kausar and Muhammed 1972; Ahmad et al. 1990). The key conclusions that emerged from these studies are:

- biological methods are particularly suited to the reclamation of more permeable soils;
- biological methods are not more economic than the use of gypsum, but they do improve the efficiency of reclamation with gypsum;
- biological methods take longer to achieve reclamation than does the use of gypsum; but
- biological methods have other advantages (like improving the nutrient status of the soil).

We conclude this section with five observations on the effectiveness of the reclamation approach.

- The use of simple leaching for the reclamation of saline–sodic soils is least cost-effective, very inefficient, takes a long time, and may cause deterioration of the soil by converting saline–sodic soils into sodic soils.
- The use of chemical amendments (especially gypsum) is cost-effective, efficient and fast acting (within 1 year), although the initial cost is high. These costs are offset to some extent by the government subsidy on the cost of gypsum.
- Biological methods do not require much initial investment but take longer (several years) to achieve results than chemical amendments. However, they have the advantage of enhancing the biological activity of the soil, adding much-needed organic matter and improving the supply of nutrients.
- The use of physical methods may be of value in special circumstances only.
- The use of combinations of methods may be the best strategy. The optimal combination will depend on the properties of the soil and on the farmer's circumstances (financial position, access to irrigation water). Farmers should seek advice from reclamation experts.

## 2.3 The Saline Agricultural Approach

The *saline agricultural approach* aims to obtain better use of saline land and saline irrigation water on a sustained basis through the profitable and integrated use of genetic resources (plants, animals, fish and insects), and improved agricultural practices.

The major outcomes of saline agriculture are:

- increased economic returns to farmers by improving the productivity of their salt-affected land;
- increased cover of the soil, which reduces evaporation, decreases rates of salinisation, and enhances biological activity;
- increased reclamation of salt-affected soils;
- increased use of saline irrigation water for sustainable agriculture (under special circumstances).

This approach has a number of advantages.

- Production will be achieved from 2–3 million hectares presently declared as wasteland due to high salinity and sodicity.
- Production will be achieved without reclamation. The approach is therefore more cost-effective in terms of initial investment.
- The approach will be small scale. Implementation may start with a single acre. Heavy machinery will not be required; there will be no requirement for large loans.
- The approach will not increase pressure on Pakistan's scarce energy resources for managing water. On the contrary, energy will be 'fixed' for reuse in the form of wood and other vegetation products.
- The approach will complement and substantially improve the efficiency of the engineering approach.
- The approach will improve the beauty of the environment and will help in the conservation of wildlife.
- The condition of salt-affected land will improve with time rather than deteriorate as at present. Benefits to soil condition will occur through the shading of the soil surface, the addition of organic matter and the lowering of watertables.
- The socioeconomic circumstances of poor farmers will greatly improve.