Contributing Paper

Some Drainage Options - Potential for Improvement

Alfred Heuperman
Independent Expert, Australia

Prepared for Thematic Review IV.2:
Assessment of Irrigation Options

For further information see http://www.dams.org/

4.2 Technological – Potential for Improvement

- **Irrigated Agriculture**

Irrigation development has contributed to increased food security. By the end of the 18th century when the world population was less than 1 billion, the total irrigated area was about 8 Mha. By the end of the 19th century the world population had grown to 1.5 billion but the irrigated area had increased 5-fold to 40 Mha. This trend continued in the 20th century; between 1970 and 1987 the world's irrigated area increased from 168 Mha to 227 Mha.

Rapid irrigation development has resulted in a range of environmental problems. Many of these relate to salinity in soil and/or water resources, often associated with a lack of drainage facilities. Salinity problems can result from salt imported in poor quality irrigation water or from salt, deposited and stored deeper in the profile and mobilised by a rising watertable. In irrigation areas often a combination of these 2 processes takes place; in dryland areas the latter 'rising water table' scenario can result from clearing of deep rooting vegetation. Whatever the cause of irrigation salinity problems, their solution is always found in the provision of drainage to reverse the salt accumulation process in the rootzone. For dryland salinity problems, restoration of the pre-clearing hydrological balance by vegetation management is the only long-term solution.

Historic cases of irrigation-induced salinity have been described in literature and include early settlement of Mesopotamia (3-4,000 BC) (Boyden, 1987) and the Indus River Basin (Casey, 1972).

Based on a collation of statistics from 11 major irrigation countries, representing 160 Mha of the 227 Mha irrigated at a world scale, Ghassemi et al (1995) estimate that 45 Mha of irrigated land or 20% of the total irrigated area is affected by salinity. Estimates for the annual loss of irrigated agricultural land to salinisation are quoted as being around 1.5 Mha (or nearly 3 ha per minute).

Although the provision of drainage has long been recognised as an essential component of irrigation development, in practice drainage implementation has often lagged behind the development of irrigation infrastructure. The rationalism for this delay can be issues such as the lack of funds (irrigation development is expensive and investment in drainage implementation is often delayed) or the fact that drainage was not considered necessary in the early stages of the irrigation development (watertables are often deep and out of reach of the plant roots at the early development stage).

- Provision of drainage and local drainage solutions

Drainage involves the removal of excess water, either from irrigation or rainfall in order to improve the profitability of the landuse. In addition to the removal of water, drainage also plays a role in the removal of salts and/or surplus nutrients. The timing of drainage events is often crucial, especially for agricultural landuses; eg waterlogging can be harmful at certain stages of crop growth and less so at other.

Drainage systems can be subdivided into 'main drainage systems' and 'field drainage systems'. The former receives water from the latter. Main drainage systems are traditionally based on government installed and maintained open ditches. The 'field drainage', on-farm components are based on either horizontal drainage (open ditches or horizontal pipe drains) or vertical drainage by groundwater pumping and their installation and maintenance are normally the responsibility of the landholder.

Costs of different components of drainage systems range widely. The following examples are based on the northern Victorian irrigation areas in Australia:

- Regional 'main drainage systems'; about US$ 200/ha;
- On-farm 'field drainage systems'; about US$ 500/ha (for border-check flood-irrigated pastures, excluding costs for field grading);
- Tile drainage; US$ 1500-3000/ha (used for horticultural tree crops, depending on spacing);

- Groundwater pumping; US$ 200-400/ha (used for watertable control in either pasture or orchard areas).

A major issue associated with drainage is the quality of the effluent. Plant wateruse inevitably results in increasing salinity levels in drainage water escaping below the rootzone; the more efficient the plant is in using applied water, the more saline the drainage effluent will be but the smaller the volume of the effluent.

Plants differ in their ability to use poor quality water. Most plants exclude salts during uptake in their root zone; these have to be removed by leaching down the profile out of reach of the roots. Some plants such as *Atriplex spp.* are able to take up salts through their root system but exude these salts through their leaves and thus recycle it to the soil surface where some of it washes off to streams and the rest infiltrates back into the rootzone. The sustainability of a plant system depends on a long-term salt balance in its root zone.

Where effluent is of an acceptable quality, it can be reused for irrigation purposes. Where its quality is unacceptable, alternative disposal options will have to be considered. In the following, a range of drainage options will be discussed.

- Disposal to rivers, lakes or seas

River disposal is a widely used mechanism to manage drainage effluent. However, with increasing concerns about river water quality, this disposal system is likely to become increasingly less acceptable around the world.

In the Murray Darling Basin Catchment in Australia, disposal of saline effluent is now regulated by providing regions with disposal loads or 'salt credits'. These credits can only be used during times of high flow when disposal has the least impact on river water quality. The salt credit concept aims at minimising the inevitable negative impact of irrigation development on river salinity.

Salinity is not the only consideration when disposing of drainage effluent. For example, in California naturally occurring Selenium poses a problem and drainage disposal to natural lakes and reservoirs has been stopped to avoid negative impacts on the wildlife habitat. A plan proposing drain effluent disposal to the ocean was also shelved for this reason.

Other minerals such as Boron and Arsenic can also be mobilised by drainage implementation and can cause problems for downstream users.

The transfer of soil biota like nematodes has been identified as a problem in drainage reuse in some horticultural areas in Australia.

Irrigation development has a direct impact on river water quality and habitat. An environmental impact assessment should be an integral part of any new irrigation development and this is nowadays often the case. However, public opinion continuously changes and issues like environmental flows for habitat and/or recreational purposes are becoming increasingly important considerations in water resource management.

- Low-service drainage

In (semi)-arid areas, regional drainage systems are often designed to manage high rainfall events, rather than manage the much smaller drainage return flows from irrigation. For example, in the northern Victorian irrigation regions in Australia, until recently the main arterial drain system in pasture areas was designed to remove a 1 in 10 years rainfall event of 75 mm/day in 5 days. In this area design criteria applied to new drainage implementation are now based on removal of 1 in 2 years rainfall events of 50 mm/day which results in considerable cost savings . The comparatively smaller dimensions however require a higher standard of maintenance to ensure that drain capacity is not affected by weed growth.

- Shallow drains to minimise saline seepage

In irrigation areas with shallow saline watertables, deep drains intercept this saline groundwater and thus mobilise salts which subsequently have an adverse impact on river systems. The construction of shallow, wide drains is preferable in these situations.

- Watertable control

Watertable rises of 0.1- 0.2 m/yr are common after the introduction of irrigation. When watertables reach the bottom of the rootzone of vegetation, leaching of salts becomes difficult and some form of watertable control will have to be considered. Open ditch field drainage systems can serve the dual purpose of both surface and sub-surface drainage. However, to provide sub-surface drainage they have to be deep and/or closely spaced; in addition they also occupy valuable irrigation land and as a result, are expensive to construct.

Two commonly used methods to control watertables are groundwater pumping and horizontal pipe drainage. Pumping relies on the presence of shallow aquifers of high enough transmissivity to extract the required drainage volumes; relatively large areas can be protected by one pump. Horizontal pipe drainage can be installed to control watertables where no aquifers are present; generally installation costs are higher than for vertical well drainage. Pipe drainage systems however allow for a more accurate protection of the required area and thus minimise drainage effluent volumes.

Drainage effluent volumes are minimised by increasing irrigation efficiencies and thus reducing leaching fractions. More efficient irrigation will result in smaller volumes for disposal; however, the salinity of the effluent will be higher with higher efficiencies.

- Disposal to salt tolerant vegetation

Irrigation of salt tolerant crops with saline drainage effluent is an accepted ‘disposal’ mechanism. As the salts are not removed from the disposal area, this management system is not long-term sustainable without the provision of some form of salt balance mechanism. Which will eventually include the use of evaporation basins to contain the salts. The commonly used term ‘disposal’ is not correct; as the salts as stored in the rootzone of the ‘disposal’ area, the term ‘containment’ would be more appropriate.

Tree plantations (both for wood and oil production) are being used for saline drainage disposal. *Eucalyptus* and *Melaleuca* species have shown to produce good oil yields under saline conditions. Salt Bush (*Atriplex spp.)* can be used for low-intensity grazing. In addition to production values, disposal blocks can have high habitat values.

- Containment in evaporation basins

Evaporation basin schemes can range from small on-farm local protection systems to large regional systems, providing protection to thousands of hectares. Where suitable salt qualities are found in high evaporation climates, salts can be harvested and sold..

> *The Wakool-Tullakool evaporation basin scheme in New South Wales, Australia is an example of a regional scheme to control shallow saline watertables by groundwater pumping. The scheme consists of 53 pumps, delivering groundwater to 2000 ha of basin through a network of 100 km of pipe line. The scheme directly protects about 200,000 ha of agricultural land, most of which is irrigated and which without the scheme would have been taken out of production.*

- Bio-drainage

While physical drainage relies on engineering features such as ditches or wells, bio-drainage relies on vegetation to remove excess soil water. Physical drainage works are expensive, both capital investment wise and with regards to operation and maintenance. Bio-drainage is attractive because it requires only an initial investment in site development (planting of “bio-drainage crop”) and returns a benefit when the bio-crop is harvested.

Where watertables are deep, plants rely on surface water inputs (rainfall and/or irrigation) and vegetation can be used to minimise accessions to the watertable; this process is often referred to as ‘recharge control’. The hydrological balance in natural habitats relies on this concept; water flows passing below the bottom of the rootzone of vegetation communities are laterally discharged through the regional sub-surface drainage aquifers. Where these systems are changed by agricultural ‘development’ (clearing) and crops with lower annual water use are planted, recharge often increases and the conveyance capacity of the underground aquifer system is often not high enough to accommodate the increased recharge volumes

Where watertables are shallow, they often become saline. The long-term sustainability of bio-drainage in this environment is a topic of intense debate. Smedema (1997) highlights this in a short topic paper. He suggests that bio-drainage could be considered for waterlogged landscape depressions and canal seepage interception, and could be applied in ‘parallel field drainage’ arrangements as an alternative to conventional field drainage systems. In Australia it is now widely accepted that in some situations bio-drainage sites will eventually succumb to salinity, unless some form of engineering drainage is installed to provide salt balance to the vegetation’s rootzone by removal of saline drainage effluent.

A 3 ha tree plantation was established in 1976 in a shallow watertable area in northern Victoria, Australia, to investigate the ability of trees to lower the watertable. A range of Eucalypt species was planted and the plantation was irrigated for 7 years after planting whereafter irrigation ceased. A network of observation bores and piezometers was installed in 1982.

During the 1982-1993 monitoring period, watertables underneath the plantation were between 2 and 4 m lower than in the adjacent irrigated paddocks. In 1984, the drawdown impact on the surrounding paddocks was restricted to about 20 m from the edge of the plantation. In 1991, the drawdown impact was measured at one location at least 40 m out from the plantation boundary.

The flow of groundwater from the surrounding area towards the tree plantation rootzone, essentially convered the plantation site into a "discharge area". This resulted in a build-up of soil salinity under the trees over the 1984-1994 period and a slow but steady rise in the watertable.

- ‘Sacrificial land’ or ‘land retirement’

In natural arid landscapes low-lying depressions often act as discharge areas, concentrating salt. These areas have a very low agricultural potential. When irrigation is introduced in these landscapes, these discharge areas expand and threaten productivity in the adjoining irrigation areas. As water, rather than land, is often the limiting production factor, concentrating the irrigation supplies in higher areas with better soils and sacrificing the lower parts of the landscape can be a viable proposition. However, often the process of land retirement will have a negative impact on regional economies.

- **Alternative sources of supply**

Competing use for water resources by recreation, the ‘environment’ and increasing populations has made water a scarce commodity. For example in the Murray-Darling River system in Australia ‘caps’ have now been applied on water diversion to avoid ‘over development’ and protect the river habitat.

Many rivers in the world have been depleted of much of their source water through irrigation development. For example, the Snowy River in Victoria, Australia, which for many years had more than 95% of its head waters diverted out of its catchment, has recently become the centre of environmental concern and moves are under way to re-direct 25% of its natural upper-catchment flow back to the original catchment.

Around the world the competition for water resources has led to an increasing call for more efficient use of these resources. Supply alternatives to the traditional river supplies such as groundwater and in some cases drainage reuse and waste water, are also coming under increased pressure.

- Reuse of drainage and waste water

The following scenarios apply to this issue:

- Reuse of surface drainage

Surface drainage from rainfall or irrigation can be reused either on-farm or off-farm further downstream in the landscape. Drainage water often contains ‘contaminants’ (nutrients, suspended soil particles or salts), some of which can be beneficial for agricultural production. Interception and reuse of these loads protects river habitats at the outflow of drainage systems and result in an overall improvement in water use efficiency (WUE), either on-farm (for on-farm reuse) or in the drainage catchments (for off-farm reuse). If the savings resulting from this increased WUE are not translated into increased water availability for environmental flows to improve river habitat, they will result in higher agricultural productivity but smaller river flows.

- Reuse of groundwater

In most irrigation areas, groundwater resources are more saline than surface waters. Depending on salt tolerance levels of the irrigated crops, groundwater can be used straight or will have to be shandied with low-salinity surface water (‘conjunctive use’).

Reuse of saline groundwater for irrigation requires the selection of salt tolerant crops (such as barley, alfalfa, sugar beets) or trees (such as certain Eucalypt spp.). With saline irrigation the provision of drainage to avoid accumulation of salts in the root zone is important. The reuse area should be located in the area of influence of the groundwater pump.

- Conjunctive use

In undisturbed natural landscapes water inputs (rainfall and sometimes flooding) are in balance with water outflows (evapo-transpiration and drainage). This hydrological balance results in long-term stable watertables which fluctuate according to seasonal conditions. Changing vegetation by removing deep-rooted trees and introducing irrigation upsets this balance. Increased accessions to the watertable will have to be removed by sub-surface drainage. Conjunctive use of surface and sub-surface water resources is a management system that optimises wateruse efficiency by simultaneously providing watertable control and minimising off-catchment disposal of salts in drainage effluent. However, in the long term conjunctive use is not sustainable without salt balance and controlled export of salt and/or containment of salt in evaporation basins should be a component of long-term management strategies.

Groundwater pumping with reuse of the saline effluent for irrigation (conjunctive water use or CWU) is the most economic and environmentally sustainable means of salinity control over most of the Shepparton Irrigation Region in northern Victoria, Australia. A pilot project, covering 600 ha with 15 groundwater pumps has been in operation since the early 1980s. The salinity of the shandied groundwater is kept below threshold level for the crops (.8 dS/m for the clover-based pastures in the area). The management system prevents salinisation of the rootzone. However, slow but steady rises in groundwater salinity are being observed and long term sustainability will depend on the ability to obtain salt balance in the area protected by the pumps. This is likely to involve some form of either salt export through the drainage system (presently limited access is available during winter periods of high rainfall) or salt containment in the rootzone of salt tolerant crops such as tree plantations.

- Reuse of waste water

Many waste water systems have in the past (and many still are at present) relied on river disposal for the discharge of their (treated) effluent. River habitat and public health (blue-green algae)concerns have resulted in stricter guidelines and in many river catchments disposal to land has now become the norm rather than the exception. This development has raised problems related to the sustainability of this system such as sodicity (waste waters are often sodic and have a negative impact on soil properties). Management of the sodicity problem could be expensive but, considering the relatively small areas involved, this should not pose unsurmountable problems.

- Serial Biological Concentration of salts

Serial Biological Concentration (SBC) involves the irrigation of crops or pastures in 'series' arranged in order of increasing salt tolerance; the drainage water intercepted from underneath each crop in the sequence is used to irrigate the next, more salt tolerant stage. Trials are presently under way in Australia and California. The system is known under different names such as ‘cascading’ (Pakistan), ‘Integrated On-Farm Drainage Management’ (USA) and ‘Indikken’ (the Netherlands).

The SBC process offers potential to maximise the productive use of high salinity drainage effluent and thus reduce the final volume to be disposed of into evaporation ponds. Experiments with fish species in inland saline basins (mariculture) have shown that high yields are possible. The harvesting of salts as a final stage of the process would make the system long-term sustainable but this requires appropriate salt composition and high management inputs to produce marketable, high-value products.

In the future, specialist ‘saline drainage effluent farmers’ that receive water from surrounding farms and make an income from growing salt tolerant (tree)crops, fish farming and salt production could well become important players in the management of salinity problems in irrigation areas.